International Congress

on

"Cotton and Other Fibre Crops"

at

ICAR Research Complex for NEH Region,
Umiam (Barapani) - 793 103, Meghalaya

20-23 February, 2018

Compendium of Lead and Invited Papers

Organised by

Cotton Research and Development Association (CRDA)
CCS Haryana Agricultural University, Hisar - 125 004

ICAR Research Complex for NEH Region,
Umiam (Barapani) - 793 103. Meghalaya

In collaboration with :
Indian Council of Agricultural Research (ICAR), New Delhi
and
Indian Association of Hill Farming (IAHF), Umiam

Complied and Edited by :
Dr. M. S. Chauhan
Dr. R. S. Sangwan

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COMPENDIUM OF LEAD AND INVITED PAPERS

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PREFACE

Cotton is one of the most ancient and very important commercial crop of global importance with a significant role in Indian agriculture, industrial development, employment generation and improving the national economy. It is cultivated for domestic consumption and also exported in about 111 countries worldwide and hence called **"King of Fibres"** or **"White Gold"**. Millions of people depend on cotton cultivation, trade, transportation, ginning and processing for their livelihood. India is the only country in the world growing all the four cultivated species of cotton alongwith their hybrid combinations in the vast diverted agro-climatic situations. Cotton is basically cultivated for its fibre which is used as textile raw material. It is cultivated from Punjab in the north to Kanyakumari in the south and Assam in the east to Kutch (Gujarat) in the west.

India, the second largest producer, consumer as well as exporters of cotton next to China with 34 per cent of world area and 21 per cent of world production and continue to maintain the largest area under cotton. Within a span of fifteen years, the cotton production in the country has gone more than double with the increase of the productivity. The productivity of cotton has not made headway because of more than 70 per cent area is under rainfed cultivation and appearance of new diseases and insect pests in transgenic cotton. However, new emerging threats in terms of biotic and abiotic factors are to be understood properly and effective strategies need to be evolved for their proper redressal. The problems and prospects of *Bt* cottons in the country need to be put in a proper perspective. Therefore, there is an urgent need to properly understand the IPR issues in the best interest of farmers and scientists.

In order to maintain pace with the increased demand for the commodity, both in national and international market, it is imperative to give impetus for development of new cotton and fibre crops varieties and hybrids with appropriate cultivation technologies. Introduction of large number of private sector *Bt* cotton hybrids have brought a welcome change in recent times as far as production gains are concerned. However, to meet the ever increasing demand both in the domestic and international markets, an effective strategy needs to be developed.

The Jute, flax, cotton, ramie, Mesta, agave, banana, pineapple etc. are the important fibre crops of north eastern region of India. However, the productivity and area coverage is very low. Technological backstopping and adequate policy support would pave the way for improving fibre crop scenario in the region. The Congress would give the scientists, experts and officials working in the region a platform to share their ideas with experts from other parts of the country and abroad which would be helpful in developing a strategy for the fibre crop development in the region.

The research papers included in the **"Compendium of Lead and Invited Papers"** are related to **"Crop Improvement, Biotechnology, Post Harvest Technology, Crop Production, Mechanization, Economic Development, Crop Protection and Biosafety"** which were the theme areas of the congress. Present compilation on **"Cotton and Other Fibre Crops"** is a compendium of holistic advancements and other relevant information related to cotton and other fibre crops covering different disciplines. We hope that the information contained in this **"Compendium of Lead and Invited Papers"** will be useful to all the stakeholders *viz.,* researchers, students, developmental officers, planners and farmers. All these manuscripts have been pre reviewed by eminent scientists of the respective disciplines/fields before publishing in this **"Compendium of Lead and Invited Papers"**. We are thankful to the authors of individual chapters/papers for their contribution, time and diligence without which this volume would not have been possible.

We deem it a rare privilege to place on record our sincere gratitude to Dr. D. P. Biradar, Vice Chancellor, UAS, Dharwad and President, CRDA for his valuable guidance and directions in the general functioning of CRDA. We take this opportunity to thank all concerned and hope this **"Compendium of Lead and Invited Papers"** will serves the purpose of cotton research workers for furthering the cause of cotton and fibre crops farmers.

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Editors
Dr. M. S. Chauhan
Dr. R. S. Sangwan

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Genetic improvement for fibre quality in *desi* cotton

D.B.DEOSARKAR* AND V.N.CHINCHANE
Department of Agricultural Botany,V. N. Marathwada Krishi Vidyapeeth,Parbhani 431 402
**E-mail : dbdeosarkar@gmail.com*

All the domesticated species of cotton suitable for commercial cultivation have been classified into two categories, new world cotton and old world cotton. The new world cotton has further been divided in two groups based on fibre properties. Group I consists of Egyptian, American Egyptian or Pima and Sea Island extra long staple *Gossypium barbadense* cotton whereas the Group II comprises of American and African upland medium staple *G.hirsutum* cotton. The old world cotton contains two diploid species of Asiatic short staple cotton, *G.arboreum* and *G.herbaceum*. The fibre, in general, is shorter and coarser with staple less than 25.0 mm, micronaire value of 6.0 and usually considered uneconomical for processing. The old world diploid species are more drought tolerant and insect resistant as compared to the new world. Of the two old world diploid species, *G.arboreum* is most widely grown and cultivated commercially in India, Pakistan and other parts of south east Asia.

Fibre quality parameters of cotton, fibre length and fineness have a vital influence the yarn strength. Fibre length is the most important cotton fibre character which determines the amount by which fibres can overlap with one another. The greater overlapping, the easier it is for the fibres to be bound together and result in better yarn strength (Ahmad *et al.,* 2003). Fibre fineness is another important fibre character affecting yarn strength. It contributes to the number of fibres in the cross-section of yarn. The better the fineness of cotton, the more fibres there are per cross-section resulting in higher yarn strength. Broughton *et al.,* (1992) acknowledged that increasing fibre length results in improved yarn strength because a long fibre generates a greater frictional resistance to an external force. Broughton *et al.,* (1992) stated that at high fibre length, the tensile strength of the fibres becomes the controlling factor of yarn strength.

Fibre length and fibre strength properties have influenced textile processing. With this thrust, breeders must always develop new elite cultivars with both high yield and improved quality. One third of foreign exchange is earned by export of cotton. In total, cotton production contributes to 30 per cent of the Indian agricultural gross domestic product and accounts for 30 per cent of all export earnings. Current modernized spinning mills fibre standards sets mainly based on greater fibre quality, especially strength (Arioli, 2005). Strong fibres survive the rigours of ginning, cleaning, opening, carding, combing and drafting. Ahuja (2003) also suggested that developing high fibre length and strength cultivars or hybrids is required for current modernized spinning mills.

Among the fibre properties which contribute most to spinning value are staple length, fibre fineness and strength. The staple length constitutes the basic norm for evaluating

Table 1. Catagories of fibre length and fibre strength in cotton in India (Singh *et al,*2004)

Category	Fibre length		Fibre strength		
	Mean stable length	2.5 per cent Span length (mm)	Category	3.2 mm gauge (g/t)	Tenacity (g/tex)
Short	19.0 and below	Below 20	Very low	Below 17	Below 34.5
Medium	20 - 21.5	20 - 24.5	Low	17-19.5	34.5- 37.4
Superior medium	22 - 24	25 - 27.5	Average	19.6 - 25	37.5 - 43.0
Long	24.5 - 26	28 - 31.5	Good	25.1 - 29.9	43-.1- 47.4
Superior long	27 and above	32 and above	Very good	29.1 and above	47.5 and above

quality of cotton in the trade and by the consuming textile industry. Five stable length categories were used for the classification of cotton in India proposed by Singh (2004) (Table 1).

Genetic resourses in wild species for improvement of fibre quality : In India, all the four cultivated diploid (*G.arboreum* and *G.herbaceum*) and tetraploid (*G.hirsutum* and *G.barbadense*) species have been cultivated. Both the diploid species bears short and coarse fibre, where as the tetraploid possesses long and fine fibre. Apart from cultivated species, some of the wild species, which may be utilized as good sources for fibre properties, have been presented in Table 2.

I) Past attempts for fibre quality improvement in *desi* cotton : The traditional old varieties of diploids evolved by selection in local land races were low yielder mainly because of their small boll size (1.5 to 2.0 gm) that were shy bearers. In addition, they possess coarse and inferior fibre length (21 to 22 mm) and were spinnable upto 10^s-20^s count. These varieties mainly include G 12, G 22, G 46 (Maharashtra),Karangani 2 and Karangani 5 (Tamil Nadu).Qureshi and Rao (1973) developed long staple *G.arboreum* genotypes with reduced plant height and increased boll number. However, their ginning percentage was very low in addition to poor yielding ability.

Efforts were made to improve the yield potential and to some extent fibre properties and ginning outturn of desi cotton by adopting conventional breeding methods. This has resulted into upgrading yield potential from 300 to 700 kg/ha, ginning outturn from 32 to 40 per cent, fibre length from 19.0 to 23 mm and spinning potential from 16^s to 20^s count. This material includes the varieties like PA 32,AKH 4,Y 1 (Maharashtra), CJ 73 (Gujrat), Karangani 1 (Tamil Nadu) and Veena (Andhra Pradesh).The north zone *arboreums* are still inferior in fibre quality having fibre length ranging from 15 to

Table 2. Wild species of *Gossypium*, sources for good fibre properties

Species	Character
Gossypium sturtianum	Fibre strength,fibre yield
Gossypium australe	High spinning
Gossypium thurberi	Fibre strength,fibre length
Gossypium harknessi	Lustrous fibre
Gossypium aridum	Fibre strength
Gossypium raimondii	Fibre fineness,length and strength
Gossypium stockii	Fibre strength and elasticity
Gossypium areysianum	Fibre strength and elasticity
Gossypium longicalyx	Fibre fineness and strength

Table 3. Qualitative and quantitative status of *G.arboreum* strains grown in the country (1935-1995)

Variety	Year of release	Zone	Yield (q/ha)	Ginning (%)	Mean length (mm)	Mike (mv)	Tenacity at 0 guage (g/tex)	Spinning potential
Bengal *deshi*	Traditional	North	5	38	17	7.0	44.0	• 10s
Comila	Traditional	North east	5	44	15	6.0	48.0	20s
G 6	1936	Central	4	32	24	5.0	48.9	• 30s
G 1	1948	South	5	28	24	5.2	44.0	• 20s
H 420	1949	Central	6	33	20	4.5	36.0	• 24s
G 12	1950	Central	4	31	24	4.8	45.0	• 26s
Virnar	1950	Central	5	38	22	5.0	48.0	• 20s
Cacanada 2	1952	South	5	30	22	5.2	45.6	• 30s
Rayalseema 1	1952	South	5	33	22	5.4	42.5	• 20s
Maljari	1954	Central	7	35	22	5.0	46.1	• 20s
K 5	1954	South	4	30	23	5.1	45.2	• 24s
Daulat	1955	Central	5	37	22	4.7	36.0	• 26s
K 6	1957	South	4	33	25	4.2	47.7	• 30s
G 46	1958	Central	7	37	22	4.0	49.0	• 36s
G 22	1958	Central	8	37	22	4.5	50.0	• 30s
Sanjay	1959	Central	6	34	22	5.0	47.5	• 30s
AK 235	1960	Central	6	41	23	4.4	47.0	• 30s
Adonicum	1961	South	7	33	23	4.8	51.0	• 30s
Y 1	1962	Central	4	39	23	4.7	50.0	• 20s
Nandicum	1962	South	6	27	24	4.6	51.0	• 30s
K 7	1964	South	6	35	26	5.1	49.3	• 30s
Shyamali	1964	North	11	39	20	6.5	46.0	• 16s
G 27	1969	North	10	37	16	7.6	48.0	• 10s
Lohit	1969	North	8	38	18	7.0	46.0	• 10s
K 8	1971	South	6	36	26	4.6	51.5	• 30s
Jyoti	1973	Central	7	39	24	4.5	45.0	• 32s
AKH 4	1975	Central	7	40	23	4.5	45.5	• 30s
Srisailam	1976	South	7	36	22	4.6	46.0	• 26s
LD 133	1978	North	20 (I)	39	16	6.8	48.0	• 10s
HD 11	1978	North	17 (I)	40	16	7.3	38.6	• 10s
Maha Nandi	1978	South	8	31	22	4.5	45.0	• 26s
Saraswati	1978	South	8	35	25	4.3	45.8	• 36s
PA 32	1981	Central	8	39	22	5.2	46.6	• 20s
AKA 5	1982	Central	8	39	22	4.2	46.0	• 30s
Rohini	1984	Central	8	38	24	4.8	46.0	• 30s
RG 8	1985	North	18 (I)	40	16	7.5	40.0	• 10s
LD 327	1987	North	28 (I)	42	18	7.1	42.6	• 10s
K 11	1992	South	12	35	24	4.4	48.0	• 30s
PA 141	1993	Central	10	39	25	4.8	44.8	• 30s

19 mm and spinnable upto 10^s count only. The fibre quality parameters of promising arboretum have been presented in Table 3.

Concentrated efforts were continued to improve the yield and fibre properties of desi cotton by adopting conventional breeding methods to bring this species to a level of *G.hirsutum* particularly at Parbhani (Maharashtra) and Dharwad (Karnataka).These efforts resulted into development of productive long linted varieties like PA 255 (Parbhani Turab),AKA 8401 (Maharashtra) and MDL 2463 (Andhra Pradesh). The fibre quality parameters of promising quality *arboreum* have been presented in Table 2.The yield potential of these varieties is upto 1500 kg/ha, fibre length ranged from 26-28 mm, ginning outturn from 37 to 38 per cent and spinning potential upto 30^s count.

The conventional breeding approaches helped in improving spinning potential of diploid cotton from 10 to 30s count. For further elevating the spinning potential above 40s count, improvement in fibre length along with fibre strength and micronaire suitable for high speed spinning is prime requirement to fulfill present demand of modern textile industries.

Breeding for fibre quality improvement : Conventional breeding methods *viz.,* introduction, selection, hybridization followed by pedigree method , back cross method and multiple crossing have largely been used for developing varieties.

I.Utilization of primary gene pool for fibre quality improvement in *desi* cotton : *G.arboreum* (A_2A_2), *G.herbaceum* (A_1A_1), *G.anomalum* (B_1B_1), *G.tryphyllum* (B_2B_2), *G.captis viridis* (B_3B_3) comprises of primary gene pool.In this gene pool there are two approaches where one aims at introgression and selection and another to exploit heterosis.

a.Introgression and selection : *G.arboreum* × *G.herbaceum*, *G.arboreum* × *G.anomalum, G.herbaceum* × *G.anomalum* are

Table 4. Fibre quality parameters of *G.arboreum* strains released for commercial cultivation (1995-2005)

Varieties	Year of release	2.5 per cent span length (mm)	Uniformity ratio (UR)	Mike (mv)	Maturity (%)	Tenacity at 1/8 guage (g/tex)	Elongation (%)
LD 491	1996	18.7	50	6.7	89	16.8	3.3
PA 183	1996	26.1	50	4.9	92	19.9	3.9
HD 106	1996	17.6	52	6.9	91	17.3	3.7
J.Tapti	1997	25.4	51	4.7	88	21.0	3.9
G.Cot.19	1997	22.3	50	6.2	89	18.9	3.5
AAH 1	1999	18.1	51	6.6	90	16.9	3.2
DH 18	2001	17.8	52	7.2	94	16.8	3.4
PA 255	2002	28.9	48	4.4	94	22.9	4.9
MDL 2463	2002	26.4	49	4.6	89	21.4	3.7
PA 402	2005	26.5	47	4.5	93	21.7	4.1
DLSA 17	2005	26.9	51	4.7	91	21.9	3.7

mostly exploited crosses for fibre quality improvement.The *G.arboreum* variety AKA 8401 released from Akola was improved through introgression of *G.anomalum*.

b. Exploitation of heterosis : Looking to the tremendous success and popularity of hybrids in tetraploid cotton, the hybrid development was also attempted in *desi* cotton.Pha 46 from Maharashtra, G.cot DH 7 and 9 from Gujrat and DDH 2 from Karnataka were released for cultivation which were cross between *G.herbaceum* × *G.arboreum*.

II.Utilization of tetraploid species for fibre quality improvement in *desi* cotton : Introgression of favorable traits like big boll size and fibre length of cultivated tetraploid *G.hirsutum* into cultivated diploid *G.arboreum* were attempted at Parbhani (Deshpande *et al.*,1992) Owing to the limitation of interspecific transfer of favourable traits of *G.hirsutum* into *G.arboreum* at ploidy level.Polyploidy was introduced in diploid *G.arboreum* and the autotetraploid so obtained was crossed with *G.hirsutum*. The resultant F_1 was vigorous and had intermediate traits and there was no boll set. The pollen fertility was present to the extent of 27.6 per cent. This pollen fertility was utilized for further introgression of favourable traits. The resultant interspecific F_1 was further backcrossed with the original autotetraploid in C_4 generation.From the segregating population of these backcross progenies, introgressed lines having big boll size (3.0 to 3.5 g),superior fibre length (25 to 29 mm) and high fibre strength (21 to 25 g/tex) have been identified.The varieties like PA 402 (Vinayaka) from Parbhani and DLSA

Table 5. Fibre quality parameters of promising *G.arboreum* genotypes at various stages of development (ICC mode) at CRS,MB Farm,VNMKV,Parbhani

Sr. No.	Genotype	2.5 per cent Span length (mm)	Uniformity ratio (%)	Micronaire (mv)	Fibre strength (g/tex)	Elongation
I.Genotypes developed from conventional breeding method						
1	PA 741	32.2	49	4.9	23.1	5.1
2	PA 760	30.4	50	4.8	25.2	5.8
3	PA 781	31.4	48	4.8	22.2	5.0
4	PA 788	30.1	52	4.9	23.9	4.9
5	PA 789	32.9	50	4.3	24.5	5.3
6	PA 791	31.7	48	4.7	22.8	4.9
7	PA 794	32.7	49	4.1	23.8	5.5
8	PA 793	30.9	46	5.5	23.4	6.4
9	PA 796	30.4	51	4.7	22.4	5.4
II.Genotypes developed from introgression						
10	PAIG 366	31.1	48	4.7	22.1	5.6
11	PAIG 368	31.7	48	5.2	22.1	5.3
12	PAIG 325	30.8	48	4.9	22.0	5.4
13	PAIG 77	30.1	43	5.4	21.3	5.8
14	PAIG 373	29.8	45	4.9	23.2	5.7
15	PAIG 371	31.3	45	4.4	25.5	5.9
16	PAIG 372	28.2	48	4.8	23.8	5.6

17 from Dharwad were evolved from the same introgressed population developed at Parbhani and released for general cultivation in Maharashtra and Karnataka respectively. Both these varieties possesses yield potential, boll size and fibre traits at par or even superior than varieties/hybrids of tetraploid cotton under rainfed condition.

GENETIC STUDIES FOR FIBRE QUALITY IMPROVEMENT

Gene action : The inheritance of fibre quality characters of fibre properties in cotton may be governed by oligogenes with distinct effect of individual gene, and polygenes with small additive effect of each gene. The inheritance of fibre characters, *viz.,* fibre length and strength is governed by polygenes. In polygenic inheritance, the variation for character is continuous from one extreme to another. The fibre length, fibre strength, fibre fineness and uniformity ratio were mainly governed by additive gene action with some of the degree of dominance.

Association studies : In path coefficient analysis, indirect effect of seed cotton yield was influenced positively by ginning outturn, lint index, seed index, 2.5 per cent span length, bundle strength and seed protein. The direct effects of seed cotton yield were influenced in negative direction by uniformity ratio, fibre fineness, and elongation percentage (Ashokkumar and Ravikesavan, 2008). Fibre length and strength were negatively associated with seed cotton yield as reported by Amudha *et al.,* (1996), Gururajan and Sunder (2004) and Ahuja *et al.,* (2006).

On going efforts for fibre quality improvement in desi cotton : At present, the

Table 6. Fibre quality parameters of promising *G.arboreum* genotypes at various stages of development (HVI mode) at CRS,MB Farm,VNMKV,Parbhani

Sr. No.	Genotype	Upper half mean length (mm)	Uniformity ratio (%)	Micronaire (mv)	Fibre strength (g/tex)	Elongation
I.Genotypes developed from conventional breeding method						
1	PA 801	30.7	85	5.0	29.6	5.9
2	PA 809	33.7	88	4.1	29.6	5.6
3	PA 825	30.0	84	4.8	31.2	6.0
4	PA 808	30.1	47	5.1	29.7	5.7
5	PA 827	29.5	49	5.1	28.5	5.6
6	PA 837	30.7	85	4.8	29.3	5.8
7	PA 828	29.8	83	5.1	31.1	6.4
8	PA 841	30.2	83	4.6	27.6	6.3
9	PA 847	31.3	84	4.6	28.8	5.8
II.Genotypes developed from introgression						
10	PAIG 375	30.7	83	5.0	27.3	5.8
11	PAIG 377	32.1	87	4.3	28.2	5.4
12	PAIG 380	33.1	87	4.3	31.6	6.0

work on genetic enhancement for fibre quality of *G.arboreum* cotton is in progress at Cotton Research Station,Parbhani mostly by adopting conventional/introgression breeding method to bring these species to an level of *G.hirsutum*. The strenuous effort carried out these research stations resulted into development of novel material of *G.arboreum* cotton. The fibre quality parameters of these genotypes have been presented in Table 5 and 6.All these newly developed genotypes are under testing in Central and south zone and available in coming years for commertial cultivation on farmers field. Thus conventional and introgression through interspecific hybridization helped in creating tremendous unexpected potential variability which is exploited for improving fibre quality of *G.arboreum* cotton.

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Interspecific hybridization in cotton

PANKAJ RATHORE, DHARMINDER PATHAK AND HARISH KUMAR
Punjab Agricultural University, Regional Station, Faridkot - 151 203
**E-mail : pankaj@pau.edu*

Cotton belongs to genus *Gossypium* of Malvaceae family. Genus *Gossypium* includes about 50 species which are distributed in arid to semi-arid regions of the tropics and subtropics (Wendel and Cronn, 2003). Recently, two more tetraploid cotton species namely *G. ekmanianum* (Grover *et al.*, 2015) and *G. stephensii* (Gallagher *et al.,* 2017) have been recognized. Forty five cotton species are diploid (2n=2x=26) and seven are allotetraploid (2n=4x=52). *G. arboreum* and *G. herbaceum* are the two diploid cultivated cotton species popularly known as Old World, Asiatic or *desi* cottons. Among the tetraploid cottons, *G. hirsutum* and *G. barbadense* are cultivated. *G. hirsutum* contributes about 95 per cent of the current world production of 118 million bales (Lee and Fang, 2015). India is the only country to grow all the four species of cultivated cotton and the interspecific hybrids.

Single letter genome symbols have been designated to related clusters of *Gossypium* species based on observations of pairing behavior, chromosome sizes, and relative fertility in the interspecific hybrids (Beasley 1941). Presently, eight diploid genome groups (A through G and K) are recognized (Endrizzi et al 1985, Stewart 1995). *Gossypium* species can be further grouped into three gene pools based on ability to generate fertile hybrids between donor and recipient species and frequency of homeologous recombination (Harlan and de Wet 1971). By following these criteria, Stewart (1995) assigned the *Gossypium* species into primary, secondary and tertiary gene pools. The wild, commensal and feral forms of *G. hirsutum* and *G. barbadense*, including other tetraploid species constitute the primary gene pool. The secondary gene pool comprises of A and D genome progenitors of allotetraploid subgenomes and B and F genomes whose chromosomes are structurally similar to A and D genomes (Phillips 1966, Phillips and Strickland 1966). Secondary gene pool species are diploid, so initial interspecific hybrid with tetraploid cotton is a sterile triploid with only few rare exceptions. Tertiary gene pool comprises of C, E, G and K genomes which are difficult to hybridize with tetraploid cotton and level of genetic recombination is low.

Diploid cottons were the predominantly cultivated cotton species in India. However, due to several reasons including the commercialization of bollworm resistant transgenic *Bt G. hirsutum* hybrids, area under *desi* cottons has largely been displaced. Nevertheless, breeding programmes of *G. arboreum* are active at many centres in the country. Several reports suggesting narrow genetic base of dominating cotton species *G. hirsutum* are available. Cultivated diploid cottons are important reservoir of genes of economic importance. For example, Asiatic cottons have contributed high fibre strength and resistance to *Pectinophera gossypiella*, *Puccinia cacabata*, *Xanthomonas campestris* pv. *malvacerum* (Fryxell, 1984; Meredith, 1991). *G. arboreum* is also known to be resistant to cotton leaf curl disease (Singh *et al.*, 1997; Narula *et al.*, 1999; Rashida *et al.*, 2005; Gupta *et al.*, 2006), a serious threat to American cotton cultivation in north zone cotton growing states of India and Pakistan. Asiatic cottons are sources of resistance to the sucking pest complex (hoppers, thrips, mites and whiteflies) (Mehetre *et al.,* 2004).Thus, it has been suggested that assessment of genetic diversity of *G. arboreum* is important for all the cotton breeding programmes including those of American cotton (Stanton *et al.*, 1994).

Beasley (1942) transferred gene for superior lint strength in *G. hirsutum* through amphidiploid of *G. thurberi* x *G. arboreum*. Knight successfully transferred bacterial blight resistance genes from *G. arboreum* into tetraploid cotton by creating a synthetic tetraploid followed by successive back crossing to the tetraploid parent (Knight 1948, 1953). Resistance to rust caused by *Puccinia cacabeta* in *G. anomalum* and *G. arboreum* was reported by Blanks and Leathers (1963). Wheeler *et al.,* (1999) reported that *G. arboreum* was resistant to fungus *Thielaviopsis basicola* causing black root rot. *G. arboreum* lines immune to grey mildew caused by *Ramularia areoala* are available (Mohan *et al* 2000, Mukewar and Mayee, 2001). Sacks and Robinson (2009) introgressed resistance against *Rotylenchulus reniformis* nematode into tetraploid cultivated cotton through crossing a resistant *G. arboreum* accession with a hexaploid bridging line.

Incompatibility caused by several pre or post zygotic barriers is known to limit the production of hybrids between distantly related species. Weaver (1957, 1958) and Pundir (1972) conducted extensive fertilization and embryological studies of *G. hirsutum* x *G. arboreum* and reciprocal crosses and observed that endosperm and embryo abortion occurred in both. In *G. hirsutum* x *G. arboreum* cross, endosperm degeneration leads to embryo abortion, while in reciprocal cross, differentiation of both embryo and endosperm was abnormal. Consequently, obtaining hybrids with diploids as maternal parents are extremely difficult. Other workers also suggested that crosses were more successful when lowest ploidy parents were used as pollen parents (Beasley 1940, Brubaker *et al.,* 1999).

Several techniques have been devised to overcome barriers between two incompatible species for successful production of viable hybrids like bridging species technique, use of exogenous growth substances, ovule culture, embryo rescue, mixed pollen technique, use of irradiations, grafting etc. Of these techniques, embryo rescue was found to be very successful for obtaining difficult hybrids in *Gossypium* (Mehetre *et al.,* 2002). Embryo culture involves isolating and growing an immature or mature zygotic embryo under sterile conditions on an aseptic nutrient medium with the goal of obtaining a viable plant. The basic hypothesis for this technique is that the integrity of the hybrid genome is retained in a developmentally arrested or an abortive embryo and that its potential to resume normal growth may be realized if supplied with the proper growth substances. The technique depends on isolating the embryo without injury, formulating a suitable nutrient medium, and inducing continued embryogenic growth and seedling formation

(Bridgen 1994). This process is difficult due to the tedious dissection necessary and the complex nutrient medium requirements. Alternatively, *in ovulo* embryo culture has been employed which eliminates dissection of minute embryos. This shifted the focus of researchers to *in ovulo* embryo culture as it proved to be more simpler and successful method for rescuing embryos.

Different media formulations for *in ovulo* embryo culture have been suggested (Stewart and Hsu 1977, Gill and Bajaj 1984, Sacks 2008, Fuller *et al.,* 2011), but frequency of obtaining hybrids remained low and few studies have reported comparison of different media with respect to their relative efficiency for hybrid embryo rescue (Sacks 2008). Genotypes of the parents involved in the hybridization programme influence success of the cross (Gill and Bajaj 1984, Dhumale *et al.,* 1996, Brubaker *et al.,* 1999,Virk and Pathak, 2016).

Many reports can be found wherein researchers have been trying to produce the new polyploid species and/or introgresssing the genes from the wild to the cultivated *Gossypium* species for increasing the diversity in the modern cultivars (Ahmad *et al.,* 2011, Nazeer *at al.,* 2014, Zhang *et al.,* 2014, Liu *et al.,* 2015 and Mehetre *et al.,* 2009). The characterization of interspecific hybrids is another aspect of the biological research. Morphological and molecular characterization of the genotypes reveal the various genetical and epigenetical phenomena and helps in understanding inheritance of various traits as well.

Plant breeders have used unadapted germplasm, almost exclusively, as a source of major genes for insect and disease resistances and have mostly relied on repeated intercrossing of adapted elite genotypes for improvement of yield (Fulton *et al.,* 2002). India has been a leader in the development and commercialization of cotton hybrids. The first interspecific (*G. hirsutum* x *G. barbadense*) hybrid Varalaxmi was released during 1971 (Katarki 1971). Later on, a series of hybrids viz. DCH 32, HB 224, DHB 105 etc have been developed. Interspecific crosses involving *G. arboreum* x *G. herbaceum* have also been developed and released. Examples include G Cot DH 7 and DDH 2.

Interspecific hybridization of *G. hirsutum* x *G. barbadense* followed by selection in the segregating generations has led to the development of many improved cultures including MCU 2 and MCU 5. Similarly, *G. arboreum x G herbaceum, G arboreun x G anomalum, G herbaceum x G anomalum* are most exploited cases for fibre quality improvement. For example in AK 8401 (*G. arboreum*) fibre length was improved through introgression with *G. anomalum* (Kulkarni *et al.*, 2001).

Many breeding stocks as well as varieties have been evolved so far through interspecific hybridization involving wild species. Genes for lint strength from a lintless wild species *G. thurberi* have been transferred into cotton. A triple hybrid [(*G. thurberi* Tod. × *G. arboreum* L.) × *G. hirsutum* L.] was first utilized as a genetic source for higher fibre strength (Beasley, 1940). In India, American cotton variety Arogya was developed through *hirsutum* × *anomalum* hybridization programme at CICR, Nagpur and was released for rainfed conditions in the Central Zone of India. Immunity to bacterial blight and tolerance to sucking pests were introgressed into this variety from the wild species *G. anomalum*.

Successful introgressions between *G. arboreum* and *G. hirsutum* have been reported (Deshpande *et al*, 1992; Kulkarni and Khadi, 1998; Deshpande and Baig, 2001). DLSA 17, an *arboreum* variety with better fibre quality has been released. Deshpande and Baig (2001) have reported the identification of segregants with increased boll weight, staple length and ginning outturn derived from interspecific crosses of *G. arboreum* and *G. hirsutum*.

Patel and Desai (1963), with an objective of improving local *G. herbaceum* types for quality characters used the Persian 211(*G. barbadense*) for crossing with improved *G. herbaceum* strains at Surat and synthetic cultures *viz.*, 1802, 1773, 1777, 1789 and 1799 were derived from the cross (1027 ALF x Per 211) FI X 1627 A.L.F. which possessed ginning out turn ranging from 26.1 to 40.1 per cent, fibre length ranging from 0.98" to 1.14" but, were low in yield in comparison with the local improved strains. They were, therefore, further crossed with the promising Surat and Buroach types to improve their yield and as a result some of the promising ones possessing good combination of yield, ginning outturn and fibre qualities were obtained. Ramachandran *et al.,* (1964) developed hybrids involving *G. anomalum* with *G. arboreum* cultures like, 5001, 6874 and B 32-48. The results were assessed in the first and second back crosses and also in the straight crosses of the above hybrids in the advanced generations. The composite samples of lint of selected families showed the fibre weight to be 0.213 millionth of an ounce per inch compared to 0.200 for *G. arboreum*, a pressely strength index of 8.94 lb/mgm compared to 7.8 lb/mgm for *G. arboreum*. In the progeny of the hybrid BC_2F_2 of 6874 x *G. anomalum,* a pressley strength index of as high as 9.82 lb/mgm and fineness of 0.093 millionth of an ounce/inch were recorded.

Meyer (1974) transferred characters such as nectariless from *G. tomentosum*, fibrous root character from *G. sturti*, increased fibre strength from *G. thurberi*, boll worm resistance from *G. anomalum* and cytoplasm of *G. tomentosum*, for development of male sterile hybrids into cultivated tetraploid, *G. hirsutum*. Nectarilessness is a necessary character to prevent outcrossing and impart pest tolerance. Meyer and Meredith (1978) were able to transfer nectarilessness character from *G. tomentosum* to upland cotton and cultures were popularised as DESTOM16. *G. herknessii, G. aridum* and *G. trilobum* have been used as donors for cytoplasmic genetic male sterility system. However, due to yield penalty, these systems could not be used commercially.

Katageri *et al.,* (2004) reported the results of interspecific hybridization using *G. barbadense* as donor and *G. herbaceum* and *G. arboreum* as recipient parents. Selected recipient plants of Jayadhar possessed fibre lengh of 24 – 26 mm, fibre strength of 20 – 23 g/tex as against 22 mm and 16 g/tex of Jayadhar. Similarly, selected A 82-1 *arboreum* plants had fibre length 24 mm and 25 g/t against 16 mm and 13g/t of the recipient. Plants with 24 g/tex fibre strength and 28 mm fibre length were isolated in F_3 from cross between *G. hirsutum* var. Abadhita x (G.cot 11 x *G. tomentosum*) by Soregaon (2004).

Ahton *et al.,* (2003) investigated mating schemes to achieve *G. sturtianum* and *G. australe* diploid cottons into tetraploid *G. hirsutum.* They were able to obtain seven different single chromosomes of *australe* in *hirsutum* background. These lines constitute valuable materials for carrying out fundamental and applied genetic investigations.

Pima cottons possess superior fibre properties than the Upland cottons. Saha *et al.,* (2004) reported the development of substitution lines in the *hirsutum* background where a chromosome/chromosome arm of *hirsutum* genome was substituted by a corresponding chromosome/chromosome arm of *barbadense* genome. The lines with substitutions for chromosomes 15, 18, 14sh and 22sh had reduced seed cotton yield and lint yield. Lines with alien chromosomes 2, 6, 16, 18, 5sh, 22Lo, and 22sh had improved lint percentage. Lines with substitution of chromosome 25 had reduced micronaire and increased fibre length. All the substituted chromosomes except 2,4 and 6 had reduced boll weight. Lines with substituted 14sh, 15sh and 25 had increased fibre length. The results provided information on the association of specific chromosomes with genes agronomic and fibre traits. These new genomic resources will, provide additional approaches for improvement of upland cotton and will enable the development of chromosome specific recombinant inbred lines for higher resolution mapping.

Besides lint, cottonseed is also an important source of edible oil. Gossypol has to be removed from the oil that increases the processing cost. Gossypol is considered to impart resistance/tolerance to some insect pests. Therefore, it would be desirable to have plants with gossypol present in the shoot but absent in the seeds. Vroh *et al.,* (1999) synthesized two trispecies hybrids *G. thurberi -G.sturtianum - G.hirsutum and G. hirsutum – G. raimndii – G. sturtianum.* Backcrosses with the *hirsutum* parent were made. The gland levels in the backcrossed seeds ranged from glandless seeds to normally glanded seeds. All vegetative parts of those hybrids were glanded, but a wide range of variability for gland density was observed on leaf stem, bract and calyx. Plants derived from seeds having a reduced level of gossypol constitute very interesting germplasm to develop cultivated glanded cotton with low gossypol seeds.

Mehetre (2010) introgressed successfully the desired traits like fineness and strength, non-convoluted and fully thickened with secondary cellulose deposition and thinnest fibre from wild *G. anomalum* into cultivated varieties blending both conventional and nonconventional techniques.

Another study attempted to explore the possibility of successfully transferring the jassid resistant genes from two wild cotton species *G. armourianum* and *G. raimondii* into the cultivated *G. hirsutum* genotypes through backcrossing and colchiploidy (Pushpam and Raveendran 2006). The percentage of boll set was maximum in the cross *G. hirsutum* x *G. raimondii* (14.3%) and minimum in the cross *G. hirsutum* x *G. armourianum* (7.5 %). Viable seeds were obtained in all combinations indicating the compatibility between all the *hirsutum* lines with the wild species *G. armourianum* and *G. raimondii*. The hybrids between *G. hirsutum* x *G. armourianum* and *G. hirsutum* x *G. raimondii* involving wild species as seed parents were highly sterile. Also there was no boll set on self pollination as well as backcrossing with the cultivated parent. Although about 3400 crosses were effected, no boll setting was observed. Nevertheless, in reciprocal backcrosses when the F_1 was used as pollen parent on *G. hirsutum* female parents, a few bolls were obtained.

Nazeer *et al.,* (2014a) explored the possibility of transferring virus resistant genes from the wild species *G. stocksii* into *G. hirsutum*. Interspecific F_1 hybrid between the two species was produced after attempting 438 pollinations. 3.4 per cent boll setting and 42.9 per cent germination was obtained during this hybridization programme.The F_1 population did not show any symptom of cotton leaf curl disease (CLCuD) in the field, tested by grafting with CLCuD susceptible rootstock. It was concluded that it is possible to transfer CLCuD resistance and high fiber strength from *G. stocksii* to *G. hirsutum*.

A new synthetic allotetraploid ($A_1A_1G_2G_2$) between *G. herbaceum* and *G. australe* was produced by Liu *et al.,* (2015) with the objective to transfer “Glandless-seed and Glanded plant” trait to the upland cotton. The putative interspecific F_1 hybrid plant appeared to be highly male and female sterile The sole putative hybrid plant was propagated by grafting and treated with 0.10 per cent colchicine for 24 h during squaring stage. In the sixth year, one branch of the hybrid plant had produced three bolls and a total of 19 S_1 seeds were obtained from these bolls by self pollination in 2012. This interspecific tetraploid hybrid had partial fertility. In 2013, one S_1 plant was rescued which set five bolls to give 22 seeds. S_2 seeds were planted. The interspecific incompatibility, to some extent, had been alleviated in the S_2 generation. Both S_1 and S_2 were new synthetic allotetraploid plants.

Fertilization barriers in interspecific crosses and subsequent generations : A major objective in most of breeding programs is to generate the genetic variability for improving economic traits of crop. Hybridization among species and between species generates considerable amount of genetic variation, which could be used for further selection of desirable traits. But, several pre and post zygotic barriers prevent the successful gene transfer from wild to cultivated species reviewed by Mehetre *et al.,* (2002a).

Failure of pollen germination is an important incompatibility barrier in obtaining wide crosses. Peng and Qian (1989) observed that the triploid F_1 pollen grains from the cross between *G. hirsutum* x *G. raimondii* were not germinated on the stigma or showed partial germination and abnormal growth. Slow pollen tube growth is one of the major crossability barriers restricting fertilization in wide crosses of cotton. Govilla (1970) found that pollen tube of *G. arboreum* pollen fails to reach ovules of *G. raimondii*, which has longer style than *G. arboreum.* Baloch *et al.,* (2000) observed that difference in style length of tetraploid and diploid species was significant, with tetraploid species having two times longer style than that of diploid species. So, they predicted that differential reproductive structures could at least be partially responsible for crossing failure and reciprocal crosses may be tried for successful fertilization. Study by Saravanan *et al.,* (2010) also supports the work of Baloch *et al.,* (2000) as they reported severe reduction in number of pollen tubes as they grew in style depending on initial pollen load. Apart from arrest of the pollen tube at different levels, several abnormalities like twisting and bulging of the pollen tube, knot formation in pollen tube, lateral enlargement of pollen tube and growth of pollen tube in opposite direction were noticed. Sometimes contents of the pollen tube are not released in the ovule. Shakhmedova (1981) reported that pollen tube did not enter the ovules in the cross of *G. hirsutum* x *G. anomalum.*

Post fertilization barriers hinder or retard the development of the zygote after fertilization and normal development of the seed. They include reproductive abnormalities in F_1 hybrids and their later generation progenies. Hybrid inviabilty or weakness may be due to several mechanisms affecting the development of the zygote from the first cell division after fertilization and up to the final differentiation of reproductive organs and formation of gametes. Weaver (1957, 1958) carried out embryological studies in *G. hirsutum* x *G. arboreum* direct as well as reciprocal crosses. Weaver attributed incompatibility in direct cross to physiological imbalance between hybrid embryo and hybrid endosperm. This imbalance caused cessation of embryo development 6 days after pollination (DAP) leading to embryo starvation. In reciprocal crosses, many of nuclei start abnormal divisions giving rise to structural abnormalities like dumb-bell shaped nuclei, large vacuoles and clumping of nuclei.

As a result of wide hybridization, there are two different types of genomes present in a nucleus, due to this, hybrid sterility may arise because of differences in structure and number of chromosomes, lack of chromosome homology resulting in variable number of univalents and production of unbalanced gametes. When we cross tetraploid species with diploid species of *Gossypium* triploid F_1 so form is expected to be sterile because of production of unbalanced gametes. This is common in case of crosses between new and old world cottons *G. hirsutum* x *G. arboreum.* (Gill and Bajaj 1987; Mehetre *et al.,* 2007; Nazeer *et al.,* 2014b), *G. arboreum* x *G. anomalum* (Mehetre *et al.,* 2004b), *G. hirsutum* x *G. raimondii* (Saravanan *et al.,* 2007) etc. Hybrid breakdown is a type of reproductive failure defined as inviability or sterility observed only in the F_2 or later generations of interspecific crosses, while F_1 hybrids are viable and fully fertile. Even if hybrid have been produced successfully and are found to fertile, hybrid breakdown is the next problem it may encounter.

Overcoming cross compatibility : Incompatability observed in wide hybridization of crop plants is a major hurdle in introgression of genes from wild to cultivated species. Boll setting in interspecific crosses of *Gossypium* is limited by physiological boll drop and boll shedding due to injury to pistil during emasculation and pollination. There are reports of increase in boll retention after application of growth regulators. Gill and Bajaj (1987) used mixture of 50 ppm GA_3 + 100 ppm NAA for increasing boll retention in *G. hirsutum* x *G. arboreum* and reciprocal crosses. They applied mixture of growth regulators at base of pedicle for three consecutive days starting from one day after pollination. They reported that boll retention varied between 52.9 - 79 per cent in *G. hirsutum* x *G. arboreum* and 43.7- 60.7 per cent in *G. arboreum* x *G. hirsutum* after application of growth regulator as compared to 6.4- 17.6 per cent retention in the control, where no growth regulator has been applied.

Altmann (1988) observed that cotyledons

appeared more fully developed when NOA/GA and NAA/GA treatment were used. Further, reduction in boll absicission with 50 ppm GA_3 + 100 ppm NAA was recorded along with increase in mean boll weight. Also, hormonal treatment resulted in more embryos/boll and improvement of embryo quality. He concluded that application of optimum levels of growth regulators was superior to embryo/ovule culture in obtaining interspecific hybrids in most of the crosses performed during this investigation.

In an another investigation, efforts were made by Mehetre *et al.,* (2002b) to induce boll setting in interspecific hybrids in which boll and seed setting was a problem, so as to use the ovules from these bolls to supplement *in ovulo* embryo culture. Hence to exploit these hybrids for the introgression of desirable genes from wild to cultivated cotton 16 different treatments, *i.e.* combination of (i) without sugar and agar, (ii) sugar 30 per cent, (iii) sugar 30 per cent and agar 0.04 per cent with (a) GA_3 50 ppm + NAA 40 ppm, (b) GA_3 50 ppm + NAA 100 ppm, (c) NAA 100 ppm and (d) IAA 100 ppm were used. Out of all tried treatment containing mixed pollen in 30 per cent sugar + GA_3 50 ppm + NAA 100 ppm was found to be effective in inducing boll setting on interspecific hybrids. Also it was observed that different treatments gave different results on different genetic background.

Rauf *et al.,* (2006) crossed *G. hirsutum* and colchicoid *G. arboreum* in both direct and reciprocal manner. Direct crosses proved successful but reciprocal crosses were complete failure so they tested different treatments of hormonal application for inducing boll setting in reciprocal crosses. They observed highest number of interspecific bolls or seeds/boll when 0.5 mg/l GA_3 and 0.5 mg/l IAA was used in *G. arboreum* genotype FDH 228 and HK 113 respectively. They also reported genotypic specificity to different hormonal treatments.

The first use of embryo culture in cotton was reported by Skovsted (1935). A weak embryo of *G. davidsonii* x *G. sturtianum* was rescued and cultured on sterile glucose agar media. Beasley (1940) cultured interspecific *Gossypium* species hybrids on White’s media. Some of them germinated and formed roots and hypocotyls but did not develop further. He also performed embryological studies to determine the cause of incompatibility and observed that degeneration of endosperm lead to embryo starvation in both *G. hirsutum* x *G. arboreum* and reciprocal cross. Lofland (1950), Dure and Jensen (1957) were successful in obtaining seedlings when embryo was excised 20-25 days post anthesis. However, younger embryos failed to mature *in vitro*.

In vitro culturing of *G. hirsutum* embryos from heart stage to maturity by adjusting osmotic potential of media and using high salt media was reported by Mauney (1961). In a later study, Mauney *et al.,* (1967) performed chromatographic analysis of liquid endosperm from 12-14 day old cotton ovules and found that malic acid (7 mg/ml) was major organic acid and further reported that addition of calcium or ammonium malate (upto 4 mg/ml) to media improved growth and viability of cotton embryos cultured at heart stage. Malate was also observed to effect osmotic pressure of medium. So, embryo could be cultured for longer period of time on low osmotic pressure medium. This eliminated the need for addition of NaCl to maintain osmotic pressure at 10 atm as suggested by Mauney (1961).

After this, the focus of researchers

shifted to *in ovulo* embryo culture as it proved to be more simpler and successful method for rescuing embryos. Culturing of ovules is advantageous because these can be easily excised at zygote stage and also provides a "maternal environment" to growing embryo. Joshi (1960) first reported ovule culture in *Gossypium*. Six DAP ovules were excised and cultured on low salt medium containing casein hydrolysate, vitamins, indoleacetic acid (IAA) and gibberellic acid (GA). Growth of ovules was abnormal and fibres did not grow. This culture method was later modified and ovule growth response was documented by Joshi and Johri (1972). They studied the effect of IAA, KN, GA_3, CH and YE on *in vitro* growth of selfed cotton ovules excised 6 DAP. They observed embryo growth upto early dicotyledonous stage on White's medium containing higher concentration (1000-2000 ppm) of CH, while on lower concentration (upto 250 ppm), embryo grew only upto globular stage. Also, higher concentration of IAA (1-2.5 ppm) did not favour embryo development. Fully differentiated embryos were obtained 96 days after fetilization from 12 celled pro embryo.

The first successful method of ovule culture for fiber development was given by Beasley *et al.,* (1971). The essential features for success were the use of high salt BT media and use of liquid culture instead of agar solidified medium. However, this report was only concerned with development of ovules and fibres for two weeks and no embryos developed to maturity. Beasley and Ting (1973) studied effect of phyto hormones (BTP medium) on fiber development in fertilized and unfertilized ovules. They reported that fertilized ovules (2DAP) did not require hormones and exogeneous IAA did not promote additional fibre growth. Addition of exogeneous GA_3, however, had stimulatory effect, while, kinetin and abscisic acid (ABA) were observed to be inhibitory. In case of unfertilized ovules IAA and GA_3 had additive affect for fibre growth. Exogeneous kinetin promoted increase in ovule size but did not support fibre development. They further stated that disposition of parent plant greatly affected the capacity of ovules to grow *in vitro* and also their response to applied growth substances. At the same time, a Belgium group (DeLange and Eid 1971, Eid *et al.,* 1973) published report concerning fibre growth on cultured ovules and found that MS was superior to media with lower salt formulations. They concluded that relatively high nitrogen content of MS was advantageous. They examined the effect of auxin and GA_3 and reached same conclusion as Beasley and Ting (1973).

Stewart and Hsu (1977) found that BTP medium (BT medium with phytohormones) was basically correct for *in ovulo* embryo growth except for poor development of cotyledons. They noted that supplementation of BTP medium with 10-15 mM ammonium ions supported ovule growth and germination of embryos. Further, they observed that after germination, radical tip became necrotic and no lateral roots were formed. Subsequent observations indicated that seedlings were unable to tolerate high salt or high sugar media and inositol was inhibitory to root development. Low salt media without inositol allowed balanced root and shoot growth with two to three leaves. They also reported differences in germination response with respect to cultivars. In subsequent study, Stewart and Hsu (1978) reported culturing of 2-4 DAP ovules to obtain interspecific hybrids between Asiatic diploid and American tetraploid cottons in all possible combinations. In most cases, the presence of GA and kinetin was deleterious to recovery of hybrid plants. Consequently, they recommended that only auxin be used when culturing ovules of species other than *G. hirsutum*.

In a similar study, Umbeck and Stewart (1985) recovered interspecific hybrids from eight of twelve crosses made using three wild species as maternal parent and four cultivated species of cotton as paternal parent. They applied GA_3 (3.5 mmol/l) to the flower at anthesis and immature embryos were rescued 15 – 25 DAP and cultured on medium of Stewart and Hsu (1977). They observed that success of fertilization and embryo development was strongly influenced by paternal parent used and degree of hybrid embryo development might be a more important factor than age or size at the time of embryo rescue.

Interspecific hybrids between cultivated diploid species and wild diploid species were obtained by Gill and Bajaj (1984) using MS media supplemented with IAA (1.5 mg/l), kinetin (0.5mg/l) and casein hydrolysate (250mg/l). They applied mixture of growth regulators (NAA @ 100mg/l + GA_3@ 50mg/l) at base of pedicel for 5-8 DAP to prevent early boll shedding. Later on, Gill and Bajaj (1987) used same method to obtain hybrids between *G. arboreum* x *G. hirsutum* by culturing 3 days old ovules. Similar work was done by Kalamani (1996). However, Thengane *et al.,* (1986) observed that no single medium was adequate to ensure complete development of fertilized ovules, hence, they performed sequential five step transfer to different media to obtain interspecific hybrid between *G. hirsutum* cv. Laxmi and *G. arboreum* cv. Jyoti. Dhumale *et al.,* (1996) used BT and MS media for obtaining hybrids in three varieties of *G. arboreum* and four varieties of *G. hirsutum* in different combinations and found that response of hybrid embryos to media was genotype oriented. *In ovulo* embryo culture was used to rescue hybrid between amphidiploid (*G. arboreum* x *G. anomalum*) and *G. hirsutum* by Mehetre *et al* (2004b) for combining desirable traits of diploids into cultivated tetraploid.

To improve effectiveness of obtaining interspecific hybrids of *Gossypium* species, Sacks (2008) compared nine media modifications based on earlier studies. He observed highest frequency of germination for MS media fortified with Gamborg's B5 vitamins and additional 1.9g/l KNO_3. They also observed that media without phytohormones produced more seedlings than the media in which different combinations of IAA and kinetin were tested. This was contrary to results of Gill and Bajaj (1987) who observed no germination of *G. hirsutum* x *G. arboreum* without growth regulators. However, Sacks pointed out that differential genotypes used in two studies might account for differing results obtained by addition of auxin and kinetin.

Quantification of level of major and minor elements, carbohydrates, ammonium ions, free amino acid and hormones in cotton ovules, nucelli, and ovule fluid was done by Fuller *et al.,* (2009) to develop tissue culture media that normalized development of early stage globular embryos *in vitro*. To further extend this work, Liddiard and Carman (2010) quantified dissolved oxygen tensions, osmotic potentials, and pH at several locations in cotton ovules during embryony and also reported the procedures to normalize early development of embryos *in vitro* by simulating these parameters. Based on these analyses, Fuller *et al.,* (2011) devised chemically defined media and unique culture equipments for inducing rapid differentiation, growth, and germination of cotton embryos starting with globular pro-embryo as explants.

Although most of the researchers have reported the successful production of interspecific hybrids and their further generations in *Gossypium* genus using embryo rescue technique, few have reported failure as well (Altman *et al.,* 1987). So, one can use both the techniques embryo rescue and direct crosses in field, simultaneously.

Genus *Gossypium* comprises species with differing ploidy levels and represents a high degree of variability, from highly improved allotetraploid species to wild diploid species. This variability has only begun to be tapped as a source of beneficial characteristics.

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Bt cotton hybrids- Present status in Haryana

S. S. SIWACH*, S. NIMBAL, R.S. SANGWAN AND ASHISH JAIN
Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar - 125 004
**E-mail : profsssiwach@gmail.com*

ABSTRACT : A total of 80 promising *Bt* cotton hybrids approved by GEAC for cultivation in north zone were evaluated along with two non *Bt* varieties for seed cotton yield and its component characters. Higher yielding hybrids were identified and recommended to the farmer. Some of the *Bt* cotton hybrids were significantly poor in yield against the check varieties. Perusal of results of this experiment showed that only limited *Bt* hybrids had superiority in seed cotton yield over the varieties. Therefore screening and evaluation of approved *Bt* cotton hybrids is essential for identification and recommendation of superior hybrids to the farmers that certainly will lead to quantum jump in cotton production and productivity. Sufficient genetic variability exits for different traits. Characteristic of cotton plant type were described based the performance of best genotypes.

Key words : *Bt* cotton hybrids, evaluation, screening

Cotton is a miracle fiber and it has been spun, woven and dyed since ancient times. It is still the most widely used fiber for cloth today. It is soft and fluffy and grows in a boll around the seeds of the cotton plant. India is famous for cotton textile since times immemorial. The most ancient cotton fabrics known to the world, believed to be at least five thousand years old have been identified as belongings to the present *desi* cotton of northern India. After critical examination of the fiber's properties of length, weight/unit length, fiber strength, convolutions/ inch, ribbon width, and fiber rigidity, Gulati and Turner (1929) concluded that on the whole, this early cotton has been produced from cotton plants closely related to the present day *Gossypium arboreum* types. Right up to the eighteenth century, this cotton retained its supremacy in the production of cotton goods and muslins cloth manufactured. Cotton is mainly grown for fibre. Indian textile industry predominantly use cotton (57 %) as its raw material and 17 per cent of industrial production comes from textile contributing about 4 per cent GDP and providing employment to 25 per cent of industrial work force next only to agriculture. The share of Indian textile in the global market is about 17 per cent. It provides direct employment to about 35 million people. The textile sector is the second largest provider of employment after agriculture (*https:// wcrc.confex.com/wcrc/2007)*. To sustain or increase the share of textile, it is very essential to improve and quality of cotton being produced in India to compete with major cotton growing countries. Besides this, cotton has to confront the stiff competition from synthetic fibers particularly polyester. For competing internationally it is very essential to develop genotypes with better fibre quality parameters.

Cotton is grown in tropical and sub tropical regions of more than 80 countries world over. The major producers of cotton are India, China, USA, Pakistan, Uzbekistan, Argentina, Australia, Greece, Brazil, Mexico, and Turkey. These countries contribute about 85 per cent to the global cotton production. India has the largest acreage (12.655 m. ha) under cotton at global level and has the productivity of 537 kg lint /ha. In India at the time of independence, cotton production was around 23 lakh bales as against the requirement of 44 lakh bales and productivity was 132 kg lint /ha. In the year 2002-2003 just prior to *Bt* introduction the area the under cotton was 76.67 lakh ha and productivity 308 kg/ha. During the year 2016-2017 the estimated area the under cotton was 105 lakh ha and productivity 568 kg/ha (Cotton Advisory Board, 2016).

In India the cotton growing tracts have been divided into three zones *i.e.* north zone, central zone and south zone. north zone comprises of states namely Punjab, Haryana, Western U.P. and Sriganganagar and Hanumangarh distt. of Rajasthan, central zone includes states of Maharashtra, Gujarat, M.P., part of Oddisha and part of Rajasthan, whereas, Tamil Nadu, Karnataka, Andhra Pradesh and Telangana are main states of south zone. Out of 51 species of genus *Gossypium*, only four lint bearing species are cultivated viz., *Gossypium hirsutum* and *G. barbadense* (tetraploids) also known as new world cottons and *G. arboreum* and *G. herbaceum* (diploid) known as old world cottons are cultivated in our country. Among these species only *G. hirsutum* and *G. arboreum* are grown in north zone. High susceptibility of *G. barbadense* to diseases and very long duration of *G. herbaceum* restricts their cultivation in north zone.

Achievements in *Bt* cotton research : In last few decades area under *G. hirsutum* has been increased tremendously after introduction of *Bt* cotton hybrids in the year 2005 and almost 96 per cent of total area is under *Bt* cotton. *Bt* cotton has made a substantial contribution in reduction in applications of insecticidal sprays for control of key pests such as American bollworm, pink bollworm, spotted bollworm and spodoptera. Traditionally, cotton consumed more insecticides than any other crop equivalent to 46 per cent of the total insecticide market for all crops in India (Kranthi, 2012). At the global level there was reduction of 37.4 Million kg *a.i.* in 2015 alone. This resulted in increase in area under cotton cultivation from 76.67 lakh ha to 108 lakh ha in the year 2015-2016 with almost 96 per cent area under *Bt* cotton hybrids (ISAAA, 2016) leading to increase in the production and productivity of the country. Nearly 7.2 million farmers were involved in *Bt* Cotton cultivation. But this gain disappeared in few years resulting in some new problems like sudden wilting of plants, increased damage of sucking pests particularly whitefly, threat of minor pests of cotton like mealy bug, myrid bug, aphids and thrips to emerge into major pests, lower down the efficacy of *Bt* gene and appearance of pink boll worm particularly in Gujarat and other parts of the country. More over all the *Bt* cotton hybrids recommended by GEAC are not essentially good seed cotton yielder, under such situation it is essential to evaluate their performance for seed cotton yield and fibre quality parameter so that *Bt* cotton hybrids with proven yield advantage, adaptability and proven fibre quality be encouraged to make Indian cotton cost competitive, quality worthy and comparable with the international cotton. The Cotton productivity touched all time high (792 kg lint/ha) during 2011 to 500kg in 2015.During 2016 the Haryana state recorded a production of 20.41 lakh bales from an area of 5.70lakh ha with productivity of 609kg lint/ha. The prominent position of cotton in Haryana has been earned through the development of improved varieties and better crop production and protection technologies.

With this objective GEAC approved 80 *Bt* cotton hybrids for north zone were evaluated against two check varieties namely F 2226 (non *Bt* variety) and H 1098-I (non *Bt* variety).

MATERIALS AND METHODS

All the 80 *Bt* hybrids along with checks were sown in 3 replications having a plot size of 4 rows of 6.0 m length each with a spacing of 67.5 x 60.0 cm between row to row and plant to plant in randomized block design. The sowing of this experiment was done on 05.05.2016 in Cotton Research Area, Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar. The data were recorded for characters namely plant height (cm), boll/plant, boll weight (g), ginning outturn (%) and seed cotton yield (kg/ha).

RESULTS AND DISCUSSION

The incidence of sucking pests particularly white fly was very less during *kharif,* 2016 and it remained below the economic thresh hold level almost during the entire crop season. Distribution of rainfall was excellent for cotton crop almost during the whole crop season. Incidence of cotton leaf curl virus disease (CLCuD) was comparatively low and its appearance was late (almost 75 days after sowing of crop) resulted in negligible or no loss in seed cotton yield. Overall the season was favorable for cotton crop and good seed cotton yield were obtained without any serious problem of insect pest and diseases. Wide range of variability was observed for different traits and their mean values and range are presented in Table 1.

Plant height (cm) : The role of plant height in cotton cannot be specified for all conditions as it may vary with situations. In the present study, plant height ranged from 136 cm (VICH 309 BGII) to 213 cm (PRCH 333 BGII) with a mean value of 174.5 cm. Significant differences were observed for plant height among the *Bt* hybrids (Table 1).

Bolls/plant : This trait was observed to be the most important for seed cotton yield. Wide range 29.3 (YRCH 255 BGII) to 56.4 (Solar 65 BGII) was observed for this trait among the *Bt* cotton hybrids with mean value of 40.9 bolls/ plant whereas, non *Bt* varieties F 2228 and H 1098-I had boll number 36.9 and 39.4, respectively. Nine *Bt* hybrids had significantly more bolls than the best check H 1098-I for boll/ plant and only one hybrid namely, YRCH 225 BG II was significantly inferior to best check. This indicates that most of the *Bt* hybrids were *at par* in bolls/plant to the varieties (Table 1). This character besides genotypic differences is also influenced greatly by environmental factors like rainfall, humidity, drought, wind direction,

Table 1. Mean and range of different characters in approved *Bt* cotton hybrids and check varieties

S.N.	Hybrids	Plant height (cm)	Boll/ plant	Boll weight (g)	Ginning outturn (%)	Seed cotton yield (kg/ha)
1	NSPL 2223	175	38.4	4.5	34.5	3642
2	SWCH4744 (US 51 Super BG II)	185	42.9	4.4	36.0	3868
3	SWCH 4755 BGII	175	40.0	4.1	36.3	3148
4	SWCH4713 BGII	174	48.9	3.4	39.5	3765
5	SWCH4707 BGII	169	40.0	4.5	35.2	3642
6	SWCH4704BGII (SP7172BGII)	171	48.5	3.9	38.6	3786
7	Ankur 3028 BG II	168	43.3	3.7	37.5	3251
8	Ankur 3244 BG II	180	50.4	3.7	35.0	3899
9	Ankur 3224 BG II	188	43.1	3.7	32.8	3580
10	Ankur Jassi BG II	179	40.4	3.8	32.6	3230
11	Ankur 3228 BG II	172	37.8	4.1	33.8	3086
12	RCH 773 BGII	175	42.1	4.4	38.5	3683
13	RCH 602 BGII	199	41.1	3.7	35.1	3086
14	RCH 776 BGII	173	36.3	4.2	35.8	2901
15	RCH 791 BGII	198	39.5	4.1	36.3	3117
16	RCH 314 BGII	185	46.3	3.5	37.1	2942
17	RCH 650 BGII (Check)	172	37.2	3.9	34.9	2819
18	RCH 653 BGII	190	34.2	4.2	34.3	2963
19	RCH 809 BGII	198	38.1	4.3	35.6	3025
20	RCH 569 BGII	189	37.4	4.4	33.7	3354
21	Shakti 9 BGII	183	42.6	4.1	32.5	3560
22	MRC 7017 BGII	148	34.7	4.2	33.9	2819
23	MRC 7041 BGII	168	34.2	4.5	35.2	3025
24	MRC 7045 BGII	148	35.8	4.1	34.2	2984
25	MRC 7361 BGII	173	31.5	3.9	40.0	2325
26	MRC 7365 BGII	144	33.4	4.2	30.9	2634
27	VICH 309 BGII	136	47.5	3.2	35.3	2551
28	VICH 310 BGII	146	39.5	4.0	33.6	3189
29	NCS 855 BG II	171	45.9	3.8	34.8	3827
30	NCS 9002 BGII	167	47.8	3.5	34.1	3416
31	NCS 9024 BG II	192	41.0	3.9	32.1	3230
32	PCH 877 BG II	184	40.0	4.7	34.1	3930
33	PCH 9604 BGII	173	45.0	3.5	33.9	3230
34	PCH 9611BG II	185	41.9	4.5	33.9	3909
35	PRCH 7799 BGII	181	35.2	3.8	29.9	2716
36	PRCH 333 BGII	213	37.6	3.9	32.6	2984
37	ABCH 243 BGII	192	32.9	4.1	31.8	2695
38	ABCH 2099BGII	177	42.4	4.2	38.7	3868
39	ABCH 192BG II	176	34.0	4.1	31.0	2881
40	ABCH 244 BGII	174	44.5	3.7	34.1	3395
41	NAMCOT 616 BGII	167	38.2	3.5	35.1	2881

contd...

Table 1 contd...

42	NAMCOT 617 BGII	182	48.8	3.7	36.4	3889
43	JKCH 1947 BGII	176	45.4	3.4	32.4	3292
44	JKCH 1050 BGII	172	39.5	3.9	34.9	3230
45	JKCH Tarzan BGII	177	43.8	4.2	35.9	3745
46	JKCH 0109 BG II	168	43.2	3.8	38.1	3292
47	JKCH 8935 BGII	164	38.4	3.8	36.0	3148
48	JKCH8940 BGII	170	43.2	4.1	35.4	3457
49	JKCH12124 BG II	163	42.3	3.7	34.0	3251
50	NCEH 6 *Bt*	177	51.0	3.1	35.4	3436
51	KSCH 213 BGII	173	45.6	3.2	35.9	2757
52	KSCH 207BG II	188	36.9	4.0	35.7	2922
53	KSCH 211BG II	152	52.2	3.3	34.7	3663
54	MH 5302 BGII	167	46.2	3.7	36.0	3663
55	ZCH 904 Rajath BG II	153	44.7	3.5	36.6	3210
56	ZCH 1102 Zurari Milkha BG II	151	39.5	4.0	30.2	3210
57	Super 971BGII	159	36.7	4.4	34.1	3169
58	Super 931 BGII	158	34.4	3.7	36.5	2572
59	Super 965 BGII	177	41.4	3.8	33.9	3066
60	Super 544 BGII	179	39.1	4.0	34.6	3416
61	6317-2 BGII	171	35.1	3.7	36.5	2593
62	841-2 BGII(Yuva+)	177	45.0	3.2	35.5	2942
63	6488-2 BGII	172	41.3	3.8	33.7	3086
64	2113-2 BGII (Bunty)	181	40.0	3.6	35.1	2860
65	846-2 BGII (Bio 105 BGII)	167	39.0	3.7	36.2	2757
66	2510-2 BG II (6588BGII)	173	41.3	3.4	37.0	2963
67	6539-2 BG II (Super 6488 BGII)	176	45.2	3.5	35.3	3251
68	6165-2 BGII(Bio 100)	182	44.9	3.8	38.2	3477
69	Cotton H. Solar 65 BGII	182	56.4	3.3	33.2	3580
70	Cotton H. Solar 75 BGII	146	45.6	3.5	36.8	3292
71	Cotton H. Solar 77 BGII	167	38.5	3.8	34.2	3128
72	Cotton H. Gold Star BGII	175	37.3	4.5	36.0	3128
73	KDCHH 541BG II	181	38.1	3.7	31.5	2819
74	KDCHH 516 BG II	181	39.7	3.9	40.0	3292
75	KDCHH 507BG II	178	31.8	4.8	33.9	3230
76	SO7H 878 BG II	188	40.5	4.3	33.9	3621
77	DPC 3083 BGII	158	38.4	4.4	36.4	3498
78	YRCH 255 BGII	156	29.3	4.5	34.4	2613
79	Tulasi 225 BG II	184	43.6	4.1	33.8	3971
80	Solar 72	205	42.1	4.1	36.0	3745
81	F 2228 (Check)	212	36.9	4.0	33.0	3086
82	H 1098-I (LC)	175	39.4	3.7	36.5	3066
	Mean	**175**	**40.9**	**3.9**	**35.0**	**3234**
	Range	136 - 213	29.3-56.4	3.1-4.8	29.9-40	2325-3971
	CD (p=0.05)	16.3	8	0.27	1.3	502
	CV (%)	5.8	12.1	3.8	2.4	9.6

spacing, sowing time, nutrient status of soil and damage by biotic factors.

Boll weight (g) : Boll weight in cotton is second major yield contributing character boll/ plant. Larger boll size is advantageous as they are had easy to pick with less trash content. Presently cotton growing farmers can sacrifice the some seed cotton yield advantage for big boll size because of high picking charges by laborers. However in north zone, the boll size generally remains small compared to south and central zone because of short boll development period in this zone. The range for this trait was 3.1 g (NCEH 6 *Bt*) to 4.8 g (KDCHH 507 BG II) was observed the *Bt* cotton hybrids with mean value of 3.9 g and non *Bt* varieties F 2228 and H 1098-I had boll weight of 4 g and 3.7 g, respectively. Fifteen *Bt* hybrids yielded significantly superior to best check F 2228 for boll weight indicated their superiority for this trait in *Bt* hybrids (Table 1).

Ginning outturn (%) : Ginning outturn is a character of economic importance and in general it is inversely proportional to the fibre quality in cotton. Cotton is mainly grown for lint purpose so higher ginning outturn is big advantage. The range for this trait was 29.9 per cent (PRCH 7799 BGII) to 40 per cent (KDCHH 516 BG II) observed in *Bt* cotton hybrids with mean value of 35 per cent and non *Bt* varieties F 2228 and H 1098-I had boll weight of 33 and 36.5 per cent, respectively. There is need to identify higher ginning outturn genotypes with high yield and better fibre quality parameters.

Table 2. Superior *Bt* cotton hybrids for seed cotton yield and other traits

Hybrid	Plant height (cm)	Boll/ plant	Boll weight (g)	Ginning outturn (%)	Seed cotton yield (kg/ha)
Tulasi 225 BG II	183.9	43.6	4.1	33.8	3971
PCH 877 BG II	183.9	40.0	4.7	34.1	3930
PCH 9611BG II	185.0	41.9	4.5	33.9	3909
Ankur 3244 BG II	180.0	50.4	3.7	35.0	3899
NAMCOT 617 BGII	182.2	48.8	3.7	36.4	3889
SWCH4744 (US 51 Super BG II)	184.7	42.9	4.4	36.0	3868
ABCH 2099BGII	177.0	42.4	4.2	38.7	3868
NCS 855 BG II	170.6	45.9	3.8	34.8	3827
SWCH4704BGII (SP7172BGII)	170.6	48.5	3.9	38.6	3786
SWCH4713 BGII	173.9	48.9	3.4	39.5	3765
JKCH Tarzan BGII	177.2	43.8	4.2	35.9	3745
Solar-72	204.7	42.1	4.1	36.0	3745
RCH 773 BGII	175.0	42.1	4.4	38.5	3683
MH 5302 BGII	166.7	46.2	3.7	36.0	3663
KSCH-211BG II	152.2	52.2	3.3	34.7	3663
NSPL 2223	175.0	38.4	4.5	34.5	3642
SWCH4707 BGII	169.4	40.0	4.5	35.2	3642
SO7H 878 BG II	188.3	40.5	4.3	33.9	3621
Mean	**178**	**44.4**	**4.1**	**35.9**	**3784**

Seed cotton yield (kg/ha) : Seed cotton yield is a complex trait as it is the end result of product of plants/unit area, bolls/plant and boll weight. This character is highly variable because its component characters are highly influenced by environmental factors. The seed cotton yield ranged from 2325 kg/ha (MRC 7361 BGII) to 3971 kg/ha (Tulasi 225 BG II) with a mean value of 3234 kg/ha and check varieties F 2228 (3086 kg/ha) and H 1098-i (3066 kg/ha) were *at par* with mean values of *Bt* hybrids. Eighteen *Bt* hybrids yielded significantly superior to best check F 2228 for seed cotton indicated their superiority for this trait in *Bt* hybrids and three *Bt* hybrids were significantly poor to the best variety F 2228 and rest were *at par* in seed cotton yield (Table 1).These results indicated that varieties are not poor yielder than many of the *Bt* cotton hybrids. Perusal of results of this experiment showed that only limited *Bt* hybrids had superiority in seed cotton yield. Therefore screening and evaluation of approved *Bt* cotton hybrids is essential for identification and recommendation of superior hybrids to the farmers that certainly will lead to quantum jump in cotton production and productivity.

The mean value for seed cotton yield of 18 superior *Bt* cotton hybrids is 3784 kg/ha which is far above from state average indicated that if suitable *Bt* hybrids after proper screening are chosen there is wide scope to increase the cotton productivity (Table 2). From this table we can also conclude that under normal situation for cotton crop, for ideotype plant should have the plant height of about 180 cm with 45-50 bolls/ plant with a boll weight of about 4 to 4.5 g for obtaining good seed cotton yield. Although boll weight is an important seed cotton yield contributing character but its association with boll/plant is either negative (Pujer *et al.,* 2014) or no association is reported by Reddy *et al.,* 2017 and Patil *et al.,* 2017 in upland cotton. These workers also reported strong association of bolls/ plant with seed cotton yield and poor with boll weight indicated that more emphasis should be given to increase the boll number per plant.

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Optimum plant type for high density planting system in cotton for north Indian conditions

PARAMJIT SINGH*
Punjab Agricultural University, Regional Research Station, Bathinda - 151 001
**E-mail-paramjit2006@pau.edu*

Cotton (*Gossypium* spp.), a king of natural fibres is the most important component of textile industry all over the world and plays a vital role in agricultural, industrial, economic and social sectors of our country. In India *hirsutum* cotton is being grown on more than 90 per cent of the area under cotton which is being cultivated with varying inter as well as intra row spacing depending upon soil type and climatic conditions. In northern India, the *hirsutum* cotton is being grown under irrigated conditions with inter row spacing varying from 67.5 to 100 cm and intra row spacing of 30 to 90 cm or even more at farmers fields. Sohu *et al.,* (2010) concluded that short compact genotypes can be grown successfully with narrow intra row spacing of 10cm keeping wider inter row spacing of 90 cm. The short compact genotypes always gave higher yield at higher plant densities due to narrow intra row spacing (Mert *et al.,* 2006; Tomar *et al.,* 2002; Sharma *et al.,* 2001). This wider intra row spacing often creates problem of wider gaps when the plant stand is affected either by rainfall at the time of sowing or immediately after sowing resulting into poor germination due to crust formation or seedling mortality due to high temperature with prolonged dry spell during seedling development. Therefore the poor plant stand results in suboptimal seed cotton yield. To maintain optimum plant populations at this inter row spacing, the intra-row spacing has to be reduced and short compact genotypes with sympodial plants can be grown which produce higher yield at closer intra row spacing as reported by Basavanneppa *et al.,* (2000) and Mert *et al.,* 2006). Due to scarcity and costly hand picking labour, the farmers have to adopt the mechanical picker which picks the short compact genotypes very efficiently.

Though, India ranks second in the world cotton production, yet its production levels are very low. Despite the availability of *Bt* technology, it is a matter of concern that productivity started declining from 750 kg lint/ha in 2006-2007 to 197 kg lint/ha in 2015. Though during 2016-2017, the state was able to get the average yield 756 kg lint/ha but it is very less as compared to developed countries. Several leading cotton producing countries like United States of America (USA), Australia, Brazil, China and Uzbekistan having very high productivity by developing suitable plant types to accumulate plant densities from 100,000 to 250,000 per hectare whereas the plant population with hybrid cotton varieties in India ranges from 6,000 to 15,000/ha. Moreover, the cost of hybrid seed is much higher and plant growth is luxuriant and therefore does not permit high density planting. The compact and short statured determinate plant of cotton under such a relatively high plant density produce few bolls/plant which ultimately result in large number of bolls/unit area in a short period of time leading to early termination of crop as well as synchronized crop maturity making it highly suitable for machine picking (Chahal, 2017). Though majority of cotton growing countries cultivate cotton under HDPS but an outstanding success of fivefold increase in productivity through HDPS under rainfed conditions in Brazil has become a natural choice of attraction for rainfed cotton areas of India. Brazil operationalised HDPS with a plant population of 1,50,000 to 2,50,000 plants/ha by developing compact and sympodial fruit bearing varieties which are highly suitable for machine picking. So the HDPS has become potential technology for successful cultivation of cotton under rainfed conditions in India especially to minimize the risk of yield losses under uncertain availability of moisture during crop development and maturity in such areas. The Central Institute for Cotton Research (CICR) adopted this approach in India to improve productivity of rainfed cotton in Vidarbha (Maharashtra) under Technology Mission on Cotton (TMC). Since the availability of an ideal variety suitable for HDPS is an essential prerequisite for its success so after screening 5 varieties in 2010; 10 in 2011 and 13 in 2012. Only three varieties were indentified, which along with additional technology for regulation of plant growth have shown noticeable potential for increasing productivity of rainfed cotton in India. It is pertinent to note that HDPS in cotton has historically evolved primarily for adoption of machine picking, but in India on the other hand it is being adopted mainly for increasing sustainable production of rainfed cotton. In view of such an impressive experience of HDPS with rainfed cotton, the scope of this technology is being demonstrated at farmers' fields with hybrids under irrigated conditions in Punjab, since this adventure has escaped the requisite research through experimentation. So the real potential of such a system under assured irrigated cotton growing areas like that of Punjab needs to be viewed in light of well recognized scientific facts about growth and development characteristics of the cotton plant.

Optimum plant type for HDPS in cotton: For the success of HDPS in north India, the first step is the development of an ideal *Bt* cotton variety suitable for HDPS and mechanical picking. World over, during the last 50 years, breeding efforts concentrated on developing sympodial varieties with fewer bolls/branch and more bolls closer to the main stem. The bolls that were closer to the main stem received better nutrition, were more uniform and were expected to produce lint of good quality. So most of varieties developed during the last three decades in many cotton growing countries except India could be fitted to narrow row spacing. But HDPS did not take off in India because no serious efforts were made to develop early maturing varieties with fruiting bodies close to the main stem and breeders continued to select for robust plants bearing more bolls/plant. The HDPS requires a short statured determinate type of plant primarily having short fruiting braches (sympods) without any vegetative branch (monopod) on the main stem (Venugopalan *et al.*, 2013). The flowers born on sympods near to the main stem must be completed in a short span of time without any overlap of vegetative and fruiting phase. Such a plant type is akin to be determinate growth habit in crop plants where main stem terminates into reproductive meristem curtailing all vegetative growth (Chahal, 2017). But the cotton plant does not follow such a system and thus is indeterminate with overlapping of vegetative growth. The terminology of "determinate cotton" however, is used to describe a variety that terminates the reproductive development comparatively abruptly *i.e.* comes to "cut out" phase of flowering and does not readily start a second fruiting cycle such that all bolls can be harvested mechanically in a single operation without any loss of yield and quality of cotton. Such a disciplined growth habit is essential due to the fact that cotton is basically a perennial plant which has been forced under cultivation to attain annual behavior by extremely low temperature at the end of crop season. Irrespective of its inherent potential to produce large number of bolls, the cotton plant thus can be forced, like that under HDPS, to produce few bolls in the short span. But the availability of adequate moisture and nutrition, on the other hand can trigger the plant for additional growth followed by flowering and uncontrolled plant structure rendering it unsuitable for machine picking for cotton especially under agro climatic conditions of north India. A variety with strictly short statured compact plant type is relatively less prone to such unpredicted growth especially as compared to robust plant type of hybrids of cotton which has potential risk of reducing relevance and efficiency of machine picking.

Prospectus of HDPS cotton in north India : The main reasons of India to be the only country for commercial cultivation of hybrid cotton lie in its relatively less cost of manually produced hybrid seed and frost free long crop season as cotton attains a robust plant structure to produce large number of good sized bolls from relatively less number of plants/unit area. The cost of manual production of crossed seed by artificial crossing makes hybrid cotton to be incompatible with higher plant population required for machine picking in other parts of cotton growing countries. The adoption of hybrid cotton for HDPS under irrigated conditions of North India would thus be scientifically contradictory to the benefits of the basic concept of heterosis in cotton which endows hybrids to produce very large number of bolls (80-100)/plant as compared to few (4-8 bolls)/plant envisaged under HDPS system. It appears to be scientifically inappropriate and illogical, to force hybrids in cotton under HDPS conditions to produce just few bolls against an inherent potential of very higher bolls/plant. It amounts to gross underutilization of actual potential of otherwise very high cost of hybird seed required under HDPS. The desired plant structure for HDPS under irrigated conditions, on the other hand, may already be available and can also be developed in the form of straight varieties without any loss of their inherent yield potential, which should be an ideal choice for adoption of HDPS system in Punjab.

The HDPS in cotton has been a technology of choice for twin purposes of high productivity and adoption of mechanization in harvesting. It is making inroads in low productivity dry and rain dependent areas of Maharashtra and Telangana. The main attraction of Punjab with relatively high yield levels of cotton, on the other hand, is primarily for possible introduction of machine picking through HDPS system. The anticipated increase in production under HDPS is generally perceived only to off set the additional cost of seed, growth regulators, machine picking and mechanically pre cleaning of harvested cotton before marketing. It needs to be recognized that a major part of area under cotton in Punjab is covered under hybrids which obviously are not the right type of material for commercial cultivation for HDPS system as it grossly underutilizes their inherent yield potential. The HDPS for Punjab thus requires targeted research for identification of short statured compact plant type variety suitable for machine picking. The Punjab Agriculture University had released a non *Bt* cotton variety F 2383 for cultivation under HDPS in 2015, but it could not become popular due to small boll size and susceptibility to boll worms. So regarding the possibility of HDPS cotton in north India by adopting non *Bt* cotton cultivation, the crop should be monitored regularly for the attack of bollworms and its timely management. The best alternate for HDPS and mechanical picking is the development of short compact *Bt* cotton variety and work in this direction is going on in PAU Regional Research Station, Bathinda. PAU has already developed a *Bt* cotton variety PAU *Bt* 1 and suitability of this variety and other varieties will be worked out for mechanical picking. The breeding for the development of varieties with more bolls closer to the main stem and its conversion into *Bt* varieties is going on in the University.

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Integrated water management for Indian cotton soils and crops

M. L. GAUR*

B A College of Agriculture, Anand Agricultural University, Anand - 388 301

**E-mail - mlgaur@yahoo.com , mlgaur@aau.in*

ABSTRACT : Cotton remains as one of the most important, cash, commercial and fibre yielding crop cultivated under rainfed as well as irrigated conditions. Historical facts about cotton and its connectivity with water, its production and productivity trends, water applicability, actual and virtual water footprints (WF) are major constituents of this paper. It is often criticized as being a "thirsty" crop or for consuming water that would otherwise go to "better" uses. Using average values of kilograms of output per cubic meter of water, cotton is judged to be inefficient. It is often considered that more kilograms of wheat, rice, maize and soybeans can be produced per cubic meter of water than kilograms of cotton lint. Present paper throws some logical arguments and background updated information in this regard by encompassing critical reviews on relevant aspects as well as available technological potential. It is believed here that if cotton is inefficient in the use of a scarce resource like water, why do farmers grow it? Certainly there exists some lucidity leading to deliver net benefits to them. Various though provoking issues and discussion are presented to offer directions for futuristic water managerial guidelines for cotton growing in India. Some of the latest interventions towards smart irrigation methods, irrigation schedules, relevant software and their strengths are well offered herein. Certain important indices to establish water based effectiveness are termed herein including indicators like water use efficiency, water crop productivity, irrigation water use index, gross production water use index etc. Salient information in regards to cotton WFs and probable resolutions to reduce these are presented with supportive statistics. Cotton-water relationship and climate change influences on it are emerging as most sensitive issues, which are appropriately expounded in this paper. An in depth description with updated reviewing, thought provoking portrayal and historical facts about cotton are offered, to facilitate researchers, R and D industries and policy planners to set aside their priorities for harnessing potential benefits of cotton crops in a sustainable manner by simultaneous meeting of demands from growers, industrialist, consumers, and environment. Considering water as a pivotal resource, some of the cotton water stories from India, Australia and some other leading cotton producing nations are also touched to present a wide picture of cotton water relationships offering water based opportunities for enhanced cotton yield at field levels. Potential key areas that cotton growers should focus are elaborated by including aspects like maximizing storage and distribution efficiency of on farm dams/channels, efficiency and uniform water application, water use and scheming and alternative irrigation systems *e.g.* overhead sprinklers, bank less channels and drip irrigation.

Indian economy is agro based and agriculture is its mainstay because it constitutes the backbone of rural livelihood security system. Cotton, being a major agri crop (about 15 per cent of total agri crops in India) has major impacts in this regard. Area under cotton cultivation constitutes almost 9 per cent of total area under Indian agriculture, being about 26 per cent of total world cotton area offering 4.59 million tonnes (27 million bales of 170 kg each) of cotton which remains about 18 per cent of world cotton production. More than 60 million people including 4.5 million farmers in India depend on cotton for their livelihood, as it is not only an imperative crop from food point of view, but more notably the spine of Indian textile industry, that consumes 59 per cent of the country's total fibre production, being about 34 per cent of country's export fetching about [1] 50000 crores annually to the exchequer. India annually cultivates cotton on more than 10 million ha (Mha), largest in world. In fact, one out of every 4 ha of land under cotton in world is in India. Around 6 to 6.5 million farmers predominantly grow this crop in about 10 States (Punjab, Haryana, Rajasthan, Gujarat, Madhya Pradesh, Maharashtra, Andhra Pradesh, Telangana, Karnataka and Tamil Nadu). Most recently country has secured global position of largest cotton producing and 2nd largest cotton exporting country. It produces roughly a fourth of global cotton production being 22.7 million metric tonnes (MMT). With a projected production of 6 MMT in 2016-2017, country is way ahead of China by a magnitude to the tune of 3.7 MMT. As per different estimates country is having maximum (~10 Mha) area under cotton but average yield (405 kg lint/ha) remains low when compared at global level. During last 3 decades cotton is enormously cultivated across 90 districts of India encompassing 25 agro ecological sub regions, having wide variability in regards to rainfall, temperature, soil depth, texture, hydraulic properties, soils, evapotranspiration, cotton growing periods and yield variations (72-855 kg lint/ha).

From field to end product, cotton passes through a number of distinct production stages with different impacts on water resources. Cotton's average irrigation requirement remains around 7-8 megalitres (ML)/ha, which actually depends upon conditions of region and season. From Indian perspectives, total climatic water requirement of cotton remains about 700-1000 mm, which depends on time of sowing and varies from genotype to genotype, soil to soil and scientific management to farmer's management. Key issues under prevailing cotton cultivation remains effective and optimum water management, smarter irrigation methods and schedules and providing space for reduced cotton WFs at micro and macro scales (Aggarwal *et al.,* 2008, Warade *et al.,* 2010). Though the area under irrigated cotton is marginal, but it too differs widely from district to district, showing gamut of factors yielding wide variations in water productivity of cotton (Jeya and Thyagarajan 2011).

Historical glimpses of cotton crop : The word 'cotton' is derived from 'qutun' or 'kutun', an Arabic word used to describe any fine textile. This crop dates from at least 7000 years ago making it one of the world's oldest known fibres, which at present is produced in more than 100 countries, but 6 of them (China, India, Pakistan, USA, Brazil, Uzbekistan) contribute about 80per cent of global production. Archaeologists found 5000 year old cotton fabric at *Mohenjo Daro*, an ancient town in the Indus River Valley. Other than food products, the cotton and its by-products are used to deliver huge range of produces like bank notes, margarine, rubber and medical supplies. Even the 1st light bulb manufactured by Thomas Edison in late 1800s used a cotton thread filament. The age old global cotton history encompasses a long time span starting from 5000 BC when cotton fibre and cloth fragments were obtainable in Mexico followed by its presence in Indus river valley (3000 BC) and later cotton spinning industries through East India Company UK (1600s onward) sprouting over china, Egypt, USA, Australia, Europe, Asian and African continents and by now worldwide. India has been the producer of cotton and finest cotton fabrics since the Indus valley civilization which all together flourished Indian sub-continent ever since 5000 years ago. Practically, till the end of 18th Century, no source of supply of cotton other than India was known to the world. Later the “Cotton Extension Scheme” and “Grow More Cotton” campaigns, sponsored by Govt of India, were launched being earliest development efforts on cotton in Independent India. Afterward there had been tremendous developments with intensive R and D efforts on this great crop.

Prevalent cotton scenario : Right now cotton is considered as an international crop and India is on top with 1st rank having about 33 per cent of total cotton grown area at world level, followed by China, USA, Pakistan, Uzbekistan and Brazil offering respective cotton grown areas to the tune of 16, 11, 9, 4, and 3 per cent of global cotton acreage. Cotton is primarily produced for its fibre, which is used as a textile raw material. Globally on an average about 1483 lakh bales are often received annually, where highest contribution remains from China (28.3%), followed by India (22.7per cent), USA (13.6%), Pakistan (8.1%), Brazil (6.0%) and Uzbekistan (3.9%). About 80 per cent of global cotton production is offered by above mentioned 6 countries, among which China remains world’s leading producer owing to its higher productivity. In 2014, China and India accounted for slightly more than half of world cotton production, while the United States, Pakistan, Brazil and Uzbekistan offered an additional 29 per cent. Though global area devoted to cotton production has remained relatively stable over past 3 decades, regional changes have amply occurred. Advent of new production technologies and better water management practices has given rise to an almost 100 per cent increase in average global yields over past 30 years being 411 kg/ha in 1981 to 790 kg/ha of cotton lint in 2014 (GOI, 2014). Accumulated gap between world cotton production and consumption between 2011 and 2014 amounted to 11.6 MMTs. Though India is global leader in cotton production, still there remains an ever widening gap between demand and supply owing to highly variable cotton production, productivity across top 10 cotton producing states (Table 1).

Why cotton is preferred crop even under scarce water resources : The properties of cotton crop and its products have its own distinctions that is why in spite of high water use, farmers prefer this crop to capture reliable bigger volume of net benefits. Cotton is both a food and fibre

Table 1. Variability of area, production, and productivity in India

Period	Scenario during past 25 years			Top 10 cotton producing Indian states
	Area (Lakhs ha)	Production (Lakhs bales)	Yield (kg lint/ha)	(*Area-Lakh ha/ Production-Lakh bales / Productivity-kg/ha*)
1990-1991	75.50	97.80	221 (+15.93)	· Maharashtra (38.7/78.3/360.7)
1992-1996	81.80	122.20	254 (+24.95)	· Gujarat (26.9/116.8/758.1)
1997-2001	89.20	108.40	207 (-11.29)	· Andhra Pradesh (22.7/69.5/569.4)
2002-2006	83.76	159.82	324 (+47.44)	· Karnataka (5.9/20.9/629.6)
2007-2011	104.74	280.76	456 (+ 75.77)	· Haryana (5.7/20.0/690.8)
2012-2016	118.26	334.39	481 (+ 19.10)	· Madhya Pradesh (6.2/18.3/520.1)
				· Punjab (5.1/18.5/706.9)
				· Rajasthan (3.0/12.9/785.5)
				· Tamil Nadu (1.4/2.8/611.6)
				· Odisha (1.3/4.0/507.5)

Note : Figures in parenthesis indicates per cent change in production during indicated periods *Source: GOI (2014)*

crop which upon maturity offers fibre (or lint) from the seed and later oil and other products from seed. Cotton lint makes up about 40-45 per cent of the picked cotton by weight, and contributes about 85 per cent of the total income from a cotton crop. The other 15 per cent income comes from cotton seed. Almost all parts of cotton plant are used in some way including lint, cottonseed, linters, stalks and seed hulls. Cotton fibre has its own distinguishes, as it is a soft, absorbent and breathable natural fibre, making it the perfect fibre for clothing and undergarments worn close to the skin. It keeps the body cool in summer and warm in winter because it is a good conductor of heat and also the non allergenic unlike synthetic fibres. Cotton is one of the easiest fabrics to dye due to its natural whiteness and high rate of absorbency, as it can hold up to 27 times of its own weight in water and becomes stronger when wet. The cotton lint from one 227 kg bale can produce 215 pairs of denim jeans, 250 single bed sheets, 750 shirts, 1200 t-shirts, 3000 nappies, 4300 pairs of socks, 680000 cotton balls, or 2100 pairs of boxer shorts. About 60per cent of world's total cotton harvest is used to make clothing, and rest is used in home furnishings and industrial products. More unusual uses of cotton fibre include tents, car tire cord, fishnets and book binding. Products made from cotton seed have their own importance and income benefits for growers. Around half the weight of the picked cotton, is mostly used to make cotton seed oil, as one tonne of cotton seed yields approximately 200 kg of oil, 500 kg of cotton seed meal and 300 kg of hulls. These by products remained valuable feed sources for not only humans but also the livestock. Global cotton seed production has potential to offer protein requirements for half a billion people and many billions of other animals. In India, cotton is grown under diverse agro-climatic conditions and its water requirements vary widely depending on region, length of growing season, climate, cultivar, and irrigation method and production goal.

Water sustainability issues in cotton

and scope of present paper : India supports 15 per cent of world's population, but has only 4 per cent of the world's water resources. World Bank data shows that only 35 per cent of India's agricultural land is irrigated. This means that a huge 65 per cent of farming depends totally on rain. Even after constructing 4525 large and small dams, the country has managed to create per capita storage of only 213 m^3 compared to 6103 in Russia, 4733 in Australia, 1964 in United States, and 1111 in China. India uses almost twice the amount of water to grow crops as compared to China and United States. In current time the agricultural sector accounts for over 90 per cent of total water drawn, but contributes only 15 per cent to the country's GDP. While looking into another matrix, 89 per cent of India's extracted groundwater is used in irrigation sector followed by household use @ 9 per cent, and industrial use @ 2 per cent. India's thirsty crops like cotton are always being criticised as a mode of draining country dry. But it is not the exact fact. Looking into prominent business and income values, major bottlenecks remains low water productivity of this boon crop. Various issues in respect of cotton growing remains active across 3 main sustainability dimensions (economic, environmental and social) and include pest and pesticide management, water management, soil management, biodiversity and land use, climate change, economic viability, poverty reduction and food security, economic risk management, labour rights and standards, occupational health and safety, equity and gender, and farmer organization. Among these water remains as most dominating element, which inevitably needs variety of considerations and adaptations from its integrated managerial point of views. Availability and applicability of required water magnitudes at proper times, happens to be extremely treasurable concern as it is profitably important to increase yields and to improve cotton quality, and cotton production which is often limited by improper water supply in most countries (both irrigated and rain fed situations). Present paper incorporates a thorough discussion towards prevailing WFs in relation to Indian cotton crops along with plethora of technological options/potential for reduction of consumptive WFs.

COTTON WATER CONNECTIONS : Cotton is one of most important natural fiber used in textile sector worldwide. Global consumption of cotton is expected to be 105.5 million bales in 2016/17 (Johnson *et al.,* 2016). Over the last 3 decades there has been an increased cotton production in China and India to meet the demands of cotton consumption (Oerklion, 2010). Cotton consumption is liable for as much as 2.6per cent of global water use (Hoekstra and Chapagain, 2008). From field to end product, cotton passes through a number of distinct production stages in different locations and with different impacts on water resources in the countries where it is grown and processed. Main stages remains (i) agricultural stage i.e. growing the cotton, and (ii) the industrial stage *i.e.* processing of seed cotton into final cotton products. Contrary to popular belief, cotton happens to be a right drought tolerant plant. The plant is drought adapted and responds favorably to periods of water stress sufficient to slow excessive vegetative growth. In fact, in many regions of the world, cotton gets all of its water from rainfall. In the U.S., about 60 per cent of the cotton crop is produced without irrigation, and most irrigation used in the remaining 40 per cent of U.S. cotton crop to supplement crop needs. Only 4 per cent of the U.S. cotton harvested acres in 2008 required irrigation to grow (Tolk and Howell, 2010). It is not only the quantity of water, but even the quality too is also preserved in modern cotton production systems. In this regard, the increase in conservation tillage practices might well results into reduced runoff from agricultural lands, decreased non-point source pollution of fertilizer/pesticides. Also the benefits of no till cotton in protecting both ground and surface water resources are well established facts. In most countries, whether crops are irrigated or rainfed, cotton production is limited by water supplies at critical times. Cotton yield and fiber quality gets amply influenced by water availability at critical crop growth stages.

Cotton water requirements : Like other crops, a cotton plant's water requirements too vary by atmosphere it grows in, being 600-1200 mm widely depending on region, length of growing season, climate, cultivar, irrigation method and production goal. The relationship between yield and water use for cotton could remain linear as well as curvilinear. It has been reported that almost 3000 to 7000 l of water are needed to produce 1 kg of cotton lint plus 1.4 kg of cottonseed. There exists evidences where about 0.14-0.33 kg of cotton lint and 0.41-0.95 kg of cotton seed can be produced/m^3 of water with a mean value of 0.23 kg of lint (Zwart and Bastiaanssen, 2004). A little wilting early in season isn't the worst thing for cotton, rather it will probably make for a more robust plant later on. Based on global/national experiences it is well established that water stressed cotton early in the season often have more extensive root system and less above ground vegetative growth, and thus a more robust vascular system as well. Correct decisions are to be made about types of irrigations systems to be installed or type of systems that is already existing therein. One unusual but logically important reason towards irrigation timing is that when there is inadequate water going to cotton, plant is going to invest more energy into producing fruit because that's where the plant will find water.

Cotton crop characteristics and usual ecological conditions, are critical in defining cotton water use, which increases gradually from initial stage (dominated evaporation losses) to developmental stage, and finally peaking at the mid season stage. This peak water-use stage coincides with a stage of full canopy and maximum boll load of cotton plant. Cotton uses water throughout its lifecycle through combined processes of evapotranspiration which remains a function of weather variables (solar radiation, wind, air temperature, humidity), as well as soil characteristics, crop characteristics, and cultural practices. Shooting in cotton plant is often considered extremely imperative as shoots and leaves will decrease or increase their growth depending upon drought stress, by having increased or decreased water retentions in specific nodes on cotton plant. If we have adequate water, we have much better balance between roots and top of plant, and our fruit production tends to be limited only by next limiting factor, whether it's fertility or something else. Leaf water content too, affect several functions/attributes of cotton leaves (primarily orientation, expansion, and structure within leaf) affecting the opening of stomata's transpiration and thus irrigation water needs/ schedules. Decreased transpiration is great from a water-saving standpoint for plant, but considered bad from standpoint of plant temperature and incoming carbon dioxide.

Several global irrigation strategies have been evolved from cotton water research, which advocates that early wilt early in the season prior to 1st square be often occurs in wet soils. Mild to moderate wilt usually do not decrease yield when it shows up in early part of growing season. Peak water use is going to be plus or minus 2 weeks from peak bloom. Nonetheless in a good irrigated cotton field too, there remains several ways of grander water losses. Even with pivot irrigation, one can have a lot of sources of water loss (evaporation, drift, runoff, percolation). With drip irrigation, there are a different set of challenges, but nice thing is that one can put water right into rooting zone to have less water lost by evaporation. Precision irrigation technique is emerging as another good substitute having advantage of capabilities in regards to variable rate technology so that water can be cut off in some areas and increased in others as per true demands in field. If one is visualizing shooting for three bales of cotton, assuming that for every 180 kg of dry plant matter, equal weight *i.e.* 0.18 ML of water, it runs at about 470 mm irrigation water depth, which is a pretty good estimate. This all together convey facts that even with a 500 mm of rains one can plan a cotton growing. Under Indian conditions, for high yields, the seasonal crop water requirements for cotton is usually estimated to be 350 to 900 mm/ha under range of climatic conditions and varying length of growing season (150-210 days) with an average daily evapotranspiration rate of 4 to 8 mm/day. Peak demand arises during 100-125th day after its sowing and remained sustained even up to 150th day. Fig. 1 depicts a generalized temporal distribution in this regard.

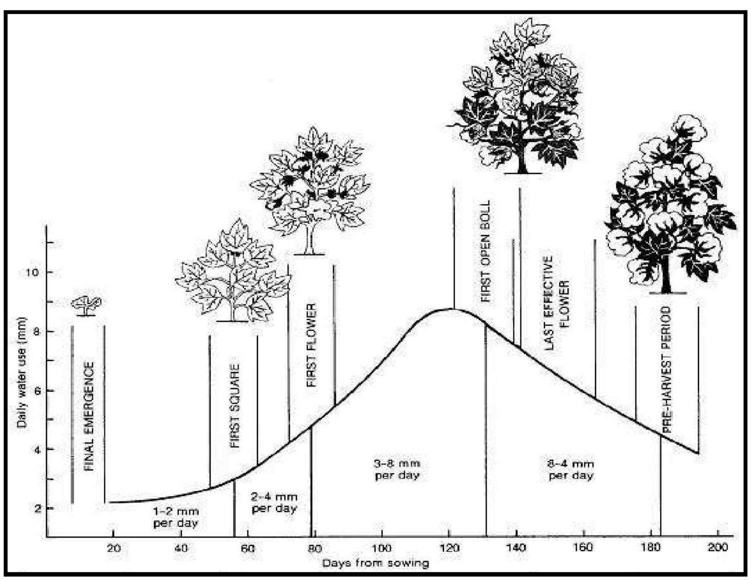


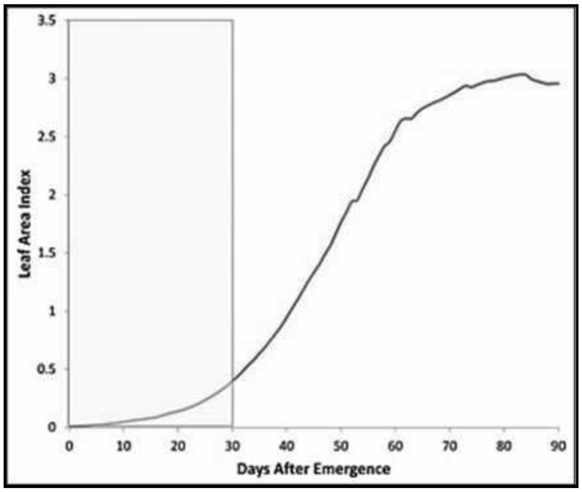
Fig. 1. Nominal seasonal daily water use (mm/day) for cotton production (Source : WATERpak, 2013)

Water sensitivity towards cotton growth stages : The sensitivity of cotton to water stress varies by its growth stage. Usually from 1st square to 1st bloom is a critical time, advocating a properly scheduled irrigation to alleviate detrimental impact of soil water deficit stress on diverse plant physiological processes and effects under water scarce stage (cell growth, root tips expansions, seed coat elongation, reproductive growth regulation, hormonal changes, shedding of fruiting structures like squares and bolls). A good irrigation management must always be aimed at reducing stress at such critical times so plants are provided greatest ability to initiate and retain mature bolls. In a broader perspective cotton growing period has 6 precise delicate stages where water plays an important role to govern quality and quantity of cotton yields (planting, emergence, 1st square, 1st flower, peak bloom, and open bolls). From practical considerations, the leaf area index is often considered as an effective indicator to judge and quantify the variability pattern of water strain in cotton growing period (Fig. 2), to reflect variety of water stress influences across growth periods.

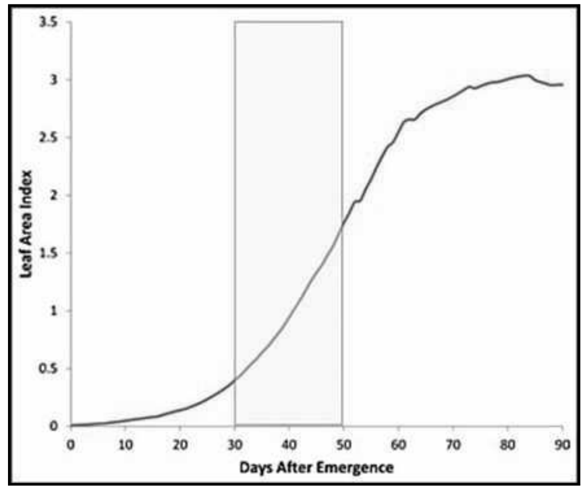
IRRIGATION SCHEDULES AND SYSTEMS

Irrigation scheduling for cotton : Irrigation scheduling actually refers to timing and volume of water application in a manner that ensures meeting plants' water demand preventing over or under irrigation sand ensuring balanced cotton growth. A location specific water budget is usually adopted to determine how best to utilize the available water resource by determining and matching crop area at beginning of season. Ineffective use of irrigation, poor conveyance, and storage can lead to huge wastage of water, which advocates efficient irrigation schedules and applications. It altogether requires to consider plethora of technological aspects like, on farm water planning, water budgeting, proper understanding of drainage and conveyance losses, managing of channels and water bodies on land surface, water metering and pumping, irrigation management/ methods/practices, judicious scheduling with caring decision supports, utilities of available weather data/climatic-expertise, technological tools/interventions, and regionalised water application plans (in space and time domain) to suit plant physiological needs on one side and available water supplies.

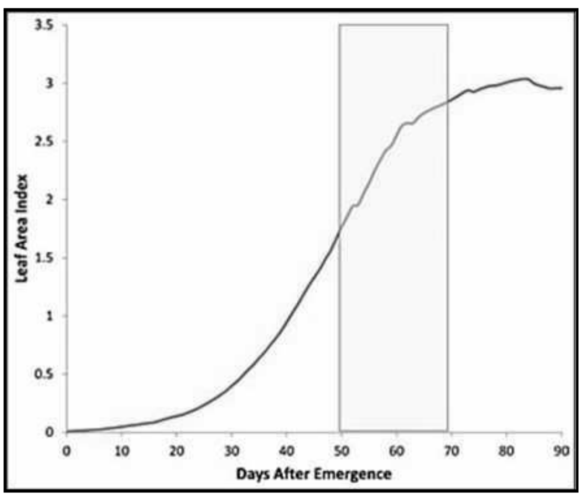
Scheduling irrigation for taking care of critical stages : Sensitivity to water stress is high during distinct phenophases of cotton crop cycle, resulting into leaf expansion stopping, slowing down photosynthesis, stopping squaring/flowering/boll-development. Irrigation at 10 to 12 days interval during these stages is often considered optimum. In situations of shortage in water supply, irrigation could be easily curtailed in early stages to prevent excess vegetative growth and thus regulate stunted growth and delays in formation of fruiting parts. Depending on climatic condition and soil type irrigation at 10-15 days interval for light soils and 15-25 days for medium and heavy soils is normally suggested, where 2 irrigations before flowering and 4 irrigations during post flowering may offer good yields. Cotton crop water requirements is predicted as a product of daily reference crop evapotranspiration (ETo) by



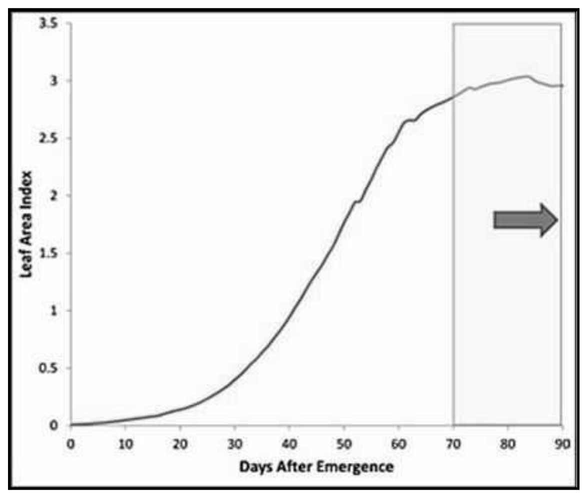
(a).Prior to first square, water stress typically has little impact on cotton yield or fibre quality



(b).Water stress during 1st square to 1st bloom can reduce total no of potential fruiting sites



(d).Water stress has less impact than squaring & early bloom after peak bloom has occurred.



(c).Water stress impacts growth, boll retention, and fibre properties during this time period

Fig 2. Water stress impacts on cotton crop via Leaf area index versus days after emergence

Penman-Monteith method and crop coefficient on specified day/plant-developmental-stage. Begin with 0.4 Kc of daily ETo in initial period, it is often raised to 0.7-0.8 at vegetative and square formation, 1.2 at flowering, boll formation and boll development stages, and later decreased to about 0.7 at crop maturity stage. On an average such crop water requirement remains about 4 to 8 mm/day with seasonal needs of 350-900 mm. Irrigation scheduling by using daily growing rate and leaf water potential measurement by pressure chamber at 1.4 to 1.8 MPa may suitably enables efficient use of water, fertilizer and energy inputs. While scheduling irrigation in cotton there could be different approaches like,

ü Soil moisture depletion and

climatological based approach, where irrigation schedules are based on per cent depletion in available soil moisture (50-75% depletion) or soil water potential (0.5 bars) in a soil profile of 30 cm depth. Trials in southern India revealed that when cotton is irrigated at 75per cent depletion of available soil moisture it offers good yield

- Opting climatological approach for scheduling irrigation at 0.40 and 0.60 IW/CPE ratio during vegetative and reproductive phases respectively may remain a good alternative
- Approach of protective irrigation too is found of greater significance to positively influence seed cotton yield. Although scheduling of irrigation at 0.8 IW/CPE ratio produced highest seed cotton yield, yet it could be *on par* with ample irrigation at boll development period offering highest water productivity
- Surge irrigation approach, wherein water is applied into furrows erratically to increase evenness of surface irrigation by swelling advance rate and abating infiltration opportunity time variances across field by reducing infiltration rate at upstream ends of borders.

Widespread irrigation methods in cotton : Making decisions about different types of irrigations systems to be installed or the type of systems that already have installed, is emerging as another important factor because it governs the energy used by plant during its physiological processes. When there is inadequate water going to the cotton plant, the plant is going to invest more energy in creating fruit because that's where plant will find water. There are many ways to deliver irrigation water to cotton fields, moreover best system is always a field/location specific. Major options are, (i) Surface irrigation by applying water down the furrow from siphon tubes or poly-pipe as well as flooding an irrigation basin (ii) Drip irrigation which may be either surface or subsurface, and (iii) Sprinkler irrigation systems, where centre pivots are recent sorts used for cotton production. A brief categorical allusion of a few popular irrigation methods is as follows,

Surface irrigation : Check basin method remains most popular option for irrigating cotton, where convenient square shaped check basins (2x2 to 4x4m) or other rectangular sizes are used for irrigation. Accurate levelling generally not remains as a necessary task, since bunds are provided on all the 4 sides of basin, keeping water well within basin and preventing run off. The size of ridges or bunds depends upon water-depth to be impounded in basin. The water is turned on to the upper side and is turned off following application of required quantity. Method is considered more efficient in fine textured soil, having added advantages of salt leaching and thus offering more opportunity time for infiltration. Yet, drawback remains relative levels/levelling among check basins to ensure uniform water supplies.

Furrow irrigation : It remains another broader and common category of irrigation method capable to effectively handle and regulate wastage of water with good level of adaptations for cotton crops and soils that have uniform and moderate slopes. Usually furrow length up to of 100 m (slope < 0.3% and stream size of 2- 3 l/sec) is considered as a good choice for cotton fields. This method is not suitable for very sandy soil. There remains variety of modifications/development in furrow irrigation approach for cotton with options like,

1) Skip furrow irrigation where skip row planting is adopted for very scarce water available areas in appropriate manner (say one out of 3 furrows is skipped *i.e.*, not planted and space available in skip furrow could be intercropped with pulses if two cotton rows are spaced at 60 cm or so). Plant population in unit area could be upheld by reducing plant to plant spacing in planted rows by one third (say 22.5 instead of 30 cm). Often sprout irrigation is given for planted rows and other irrigations are given only in the furrows between the planted rows. In this manner usually 50 to 60 per cent saving of irrigation water can be easily achieved without sacrificing copious cotton yield. Skip furrow irrigation has advantages like (i) its suitability to heavy soils , (ii) conversion to ridges having a wide bed formation, (iii) potential to save at least 50per cent water when compared to simple flood irrigation.

2) Alternate furrow irrigation where cotton is planted just like in the conventional method as there is no variation in spacing but variation in water application (areas). Water is applied in alternate rather than in all furrows (Irrigating odd and even furrows alternatively). 1st irrigation is applied in furrows which do not receive the 2nd irrigation and so on. Such scheduling of irrigation in Gujarat has well revealed that alternate furrow method have potential to offer highest seed cotton yield and being superior to flood irrigation.

3) Irrigation under paired cotton row planting is another method where instead of making ridges and furrows at 75 cm apart, furrows are made 150 cm apart and seeds are sown (60 cm apart) on the both sides of furrows and then irrigated. This system provides the same number of rows and the same plant population/unit area as conventional planting. Yet it allows each row to receive more light on one side than the other. Cotton is strongly responsive to light and could produce 70 to 80 per cent of bolls on the open side. Moreover, less water would be lost by evaporation in 2 inner sides because of more rapid and complete shading by the plant (being less weedy). Control of weed is also easier in the outer side because of availability of space. Soil aeration is maintained at a higher level because of the dry inter-space between the paired rows, resulting in high seed cotton yields.

4) The siphon tube system for majority of cases where the cotton is planted on beds, and water is applied to the furrows that are adjacent to each bed. There are a number of ways that water is directed into these furrows. The siphon tube system consists of an aluminium or plastic pipe that is laid over the bank of an open ditch as described above. One end of this tube is submerged in the ditch with the other directed into the furrow that is to be irrigated. Water flows into the submerged end of the tube and is siphoned over the bank and into the furrow. Flow rate is controlled by the diameter of the tube and the elevation difference between the water surface in the ditch and the end of the outlet tube. Flow rate tends to be very uniform using siphon tubes; however, trash screening devices must be utilized to prevent trash within the irrigation ditch from clogging siphon tubes. Other pipe system can also be utilized.

Micro irrigation : In this category drip

Irrigation remains a major kind where irrigation water and fertilizer is saved by allowing water to drip slowly to plant roots, either onto soil surface or directly onto root zone, through a network of valves, pipes, tubing, and drippers. It remains one of the largest technological intervention having high adaptability in diverse soil types, but being more suitable for porous soils, water scarce areas and undulated lands. Since water is applied daily/alternate days at low rate at low pressure (1 kg/cm^2 or so) over a long period of time in close vicinity of plant roots, it maintains soil moisture level around root zone close to field capacity. It offers considerable flexibility through the frequency of irrigation right from daily interval to once in eight days in cotton. Other advantage includes the use of saline water (even up to 8-10 dS/m) without affecting yield, simultaneous and precise fertigation etc. Prevailing drip irrigation systems in India comprise many drip versions (average narrow drip line spacing of 2 m with 1 or 2 lateral/crop row), having emitters of varied configurations (spacing @ 0.4 to 0.75 m, flow rates @ 0.6 to 2.0 LPH) depending upon soil properties. Two broader drip options for cotton irrigation could be,

1) Surface drip irrigation to irrigate high-value cotton crops, as it can precisely deliver water and nutrients to crop root zone and saves water by only wetting a small area of overall soil surface, thus reducing evaporation. Additional advantages include low application rates, precise water placement, and low operating pressures. Disadvantages include initial system cost, specialized equipment to install/remove tubing, and maintenance. It basically consist of a pumping plant, pressure regulation, a filtration system, and a distribution system divided into zones delivering water to drip tubing. A major consideration in design is drip tubing lateral spacing, with varied configurations (Fig. 3) for cotton row crop production.

2) Subsurface drip irrigation offers additional advantages like, less annual labour, increased life expectancy, reduced occurrences of soil-borne diseases/weed infections, higher trafficability, reduced compaction, more efficient use of water and nutrients, improved yield and quality, moreover the filtration remains one of the greatest challenge in this system.

Sprinkler irrigation : It applies water in a way which is similar to rainfall, and uses system of pipes for water distribution by pumping and spraying into air to irrigated entire soil surface through spray heads ensuring breaks up into small water drops which fall to ground. It is appropriately suitable even on conditions like shallow sandy soils of uneven topography, un-levelled land scape, scarce labour and local water sources availability to offer advantages like delivering water at a desired and controlled rate, ensuring uniform distribution of water, high water use efficiency and many others. The drawback remains only the high initial investment cost and evaporation losses. A properly designed sprinkler “package” for important crops like cotton, frequently considers factors like water supply, soil, crop, topography, atmospheric conditions. Both the high pressure impact type sprinklers as well as low-pressure spray type sprinklers, are used, but regardless of type of sprinkler, the system always needs to be designed closer to ground realities to meet cotton water requirements. For a sprinkler package design, the irrigator always required a location specific "timer chart" that will indicate the application depth for various timer percent settings. For example, a chart might indicate that the irrigator select 22 per cent speed to achieve 10 mm application depth. With the advent of IT and ICT based smart tools and techniques, sprinklers are intensively utilized. Centre pivot sprinkler irrigation systems are among most popular mechanical move systems for applying irrigation water to cotton field crops. Basic design concept is consistently improved and refined, but still remains very similar to the original system invented and patented by Frank Zybach in 1952. Centre pivot systems have many inherent advantages like, low labour requirements, effective water applications, unattended operating for longer durations, sensor based automation, simplified water delivery, abilities to improve irrigation management and apply agri chemicals, least maintenance costs. It feature a water supply main-line or lateral that rotates about a fixed point (pivot point), and lateral is supported by a series of towers which propel lateral around in a circular fashion by rubber-tired wheels driven by electric or hydraulic motors mounted on each tower. Towers support the lateral at a height such that clearance between ground and lateral support trussing remains ample (~10 feet). It has certain disadvantages too like, high initial cost, high application rates at outer end of lateral causing runoff, high pipe friction losses, miss-matching of circular pattern with square cotton fields leaving dry corners, variations in potential operating pressure etc.

Contemporary cotton irrigation practices : Water management research continues to develop more accurate and easier ways to determine cotton water needs and, in fact, new techniques greatly facilitating present day growers by better predictions adopting variety of smart approaches to decide when to irrigate and how much to irrigate. These includes (i) Computer models that predict water use based on the growth stage of the plant and weather

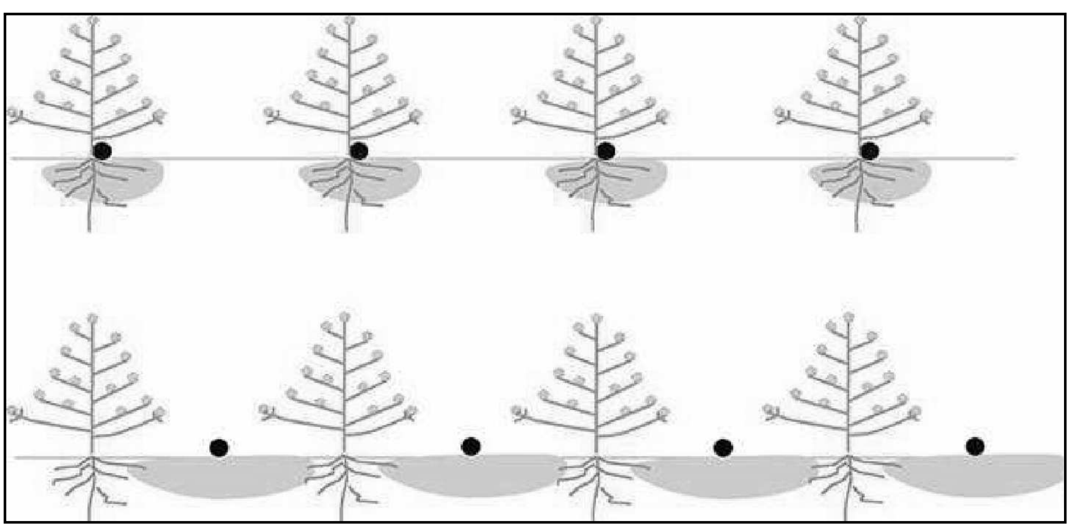


Fig. 3. Various possible drip irrigation configurations for cotton crop

data, (ii) Soil moisture probes that determine if there is sufficient water present to meet crop needs, and (iii) Thermal infrared thermometers (IRTs) that measure temperature of the cotton leaves as and when plant begins to run out of water, its leaf temperature gets increased. Some creative/innovative irrigation technologies for cotton production systems are as follows,

1) Low Energy Precision Application (LEPA) using drop tubes to decrease water losses
2) Subsurface Drip Irrigation (SDI) with effective and desirable delivery options to eliminate soil evaporation/daily crop evapo-transpiration (even 75% higher WUE for lint production).
3) Attempting reusable water for new age irrigation systems to offer sustainability
4) Biologically Identified Optimal Temperature Interactive Console (BIOTIC) to provide irrigation scheduling based upon measurements of canopy temperatures and threshold values to schedule an irrigation event. Researcher in USA have well revealed that cotton lint yields may get declined 343 kg/ha for each 1 h that the temperature exceeded 28 degrees celsius.

Irrigation system design : Design layout of fields, storages and channels are a significant task while planning and implementing any cotton irrigation plan as it greatly influence the ultimate water use. Among above described irrigation methods (Rajak *et al.,* 2006) furrow irrigation is most popular from cotton irrigation point of views, with salient technical design considerations on aspects like,

- To visualize suitability of over the bank siphon/furrow irrigation in cracking clay cotton soils, with fully optimised siphon systems, as small changes in water management may increase water productivity by regulating irrigation flow rates and cut off times offering high application efficiency and distribution uniformity and thus reduced runoff and deep drainage.
- Adopting Centre Pivot Lateral Move (CPLM) systems to apply small amounts of water at each application, allowing more frequent irrigations to meet cotton crop water demands.
- Opting subsurface drip irrigation systems with a configurations where they correctly operate at lower pressure reducing energy costs.
- Adopting bank-less channels to serve as an effective irrigation systems for avoiding need for siphons, reduced labour requirements, better machine efficiency.

Indian R and D organizations (ICAR, CICR, SAUs) have put ample efforts via coordinated research to evolve below given cotton irrigation strategies for cotton growing states,

- Punjab : 4 to 6 irrigations as per prevailing rainfall, 1st irrigation 4-6 week after sowing, subsequent irrigations at interval of 2-3 weeks, sowing cotton on ridge, furrow irrigation avoiding water scarcity at flowering/fruiting stages, last irrigation by September end.
- Rajasthan : 4-5 irrigations, 1st at 35-40 days after sowing then @ of 25-30days, rest same
- Haryana : Total cotton water

requirement as 800-1000 mm, about 4 irrigation of 240 mm each in April, May, August and September, last irrigation after opening of about 1/3rd bolls, adopting furrows in place of flooding to get about 25 per cent saving in irrigation water

- Gujarat : Irrigation after 3-4 weeks of last rainfall, @ 20-25 day interval in black soils, @15days interval in Sandy loam soils(GORADU), Irrigating alternate furrow
- Maharashtra : Ploughing once after 3 years in rain fed cotton, ploughing every year in irrigated cotton, drip irrigation, furrow irrigation (protective mode alternate furrows), sowing cotton on ridges, irrigation @ 10-12 days interval till the on-set of monsoon, protective irrigation if dry spell exceeds 3 weeks, 1.25 IWR:CPE ratio
- Andhra Pradesh: 2-3 irrigations as per soil types, considering drainage as important aspect, irrigation @ 20-25 days interval considering available moisture, 2-3 irrigations if cotton is in kharif, 6 irrigations if it is in Rabi season. , care for water logging, 3 irrigations for vertisol, 5 irrigations for alfisol.
- Karnataka : for black soils irrigations @ 20 days interval having irrigation depths 5–7 mm, for light red/sandy loam soils irrigation @15 days interval, irrigation depth 8–10 cm, furrow lengths @ 100-150 m, furrow grades @ 0.1-0.3 per cent, stream sizes @ 2–4 lps.

Cotton water planning – other apprehensions : Detecting and managing ensured irrigation supplies during peak water use which is going to be plus or minus two weeks from peak bloom in cotton. If a cotton grower takes a scenario for shooting having three bales of cotton, and assuming that for every 181 kg of dry plant matter, he is going to have equal *i.e.* 181 kg of water, it runs at about 470 mm, which could be a pretty good irrigation estimate, giving a clue that 450-500 mm is going to be the minimum amount of rain/irrigation cotton farmers must work with.

- Preventing irrigation water losses is another important solution to increase cotton water use productivity. Water lost several ways in each and every kind of irrigation system. Even with pivot irrigation it gets lost through evaporation, drift, runoff and percolation. Provision of adequate rain guns has great influences to this aspect. If we take the example of a drip irrigation, again there exists a different set of challenges, moreover nice thing remains that cotton grower can put water right into the rooting zone to have less water lost through evaporation. Coming to another technology using precision irrigation with variable rate, the losses needs to be rewarded, where water can be cut off in some areas and increased in others.
- Quality of irrigation water also plays an important role, hence appropriate techniques are required for proper management of poor quality water. Use of inferior water with high sodium or total salt or both may cause deterioration to the physical properties of soil which ultimately influences the yield of cotton. Lighter the texture, greater is the tolerance to saline water, hence sprinkler irrigation may holds best in light textured soils but not in heavy soils. High organic

matter content of the soil enhances the tolerance of crops to saline water used for irrigation. Furrow irrigation certainly can help in solving problems, while flooding too some time helps to control soil salinity by leaching out salts away from root zone by flooding

- Drainage is another critical factor during cotton irrigation as it greatly influence the response of cotton to fertilizers, leading to uneconomic yield. The major and immediate effect of water logging is blocking transfer of oxygen between the roots and the soil atmosphere.
- Problems owing to excess moisture also needs to be appropriately considered as the excess moisture at later stages delayed opening of bolls which are susceptible to boll rot pathogens and lodging of plants. It has generally adverse effect on fibre quality, mainly because of increase in proportion of fibres that fall to mature properly.

WATER FOOT PRINTS OF COTTON : Globally, freshwater resources are becoming scarcer due to an increase in population and subsequent increase in water appropriation and deterioration of water quality. The impact of consumption of people on the global water resources is now a days easily mapped with the concept of the 'water footprint' (Hoekstra and Hung, 2005). Cotton is the most important natural fibre used in the textile industries worldwide. From field to end product, cotton passes through a number of distinct production stages with different impacts on water resources. These stages of production are often carried out at different locations and consumption can take place at yet another place. For instance, Malaysia does not grow cotton, but imports raw cotton from China, India and Pakistan for processing in the textile industry and exports cotton clothes to the European market. For that reason the impacts of consumption of a final cotton product can only be found by tracing the origins of the product. The major interest in the said WF is rooted in the recognition that human impacts on freshwater systems can ultimately be linked to human consumption, and that issues like water shortages and pollution can be better understood and addressed by considering production and supply chains as a whole. In general there remains 3 basic WFs (Green, blue and grey).

In order to assess these WF of cotton consumption in a country or region we need to know the use of domestic water resources for domestic cotton growth or processing and we need to know the water use associated with the import and export of raw cotton or cotton products. Thus total WF includes two components, (i) the part of the footprint that falls inside country (internal WF) and (ii) the part of footprint that presses on other countries in the world (external WF). The virtual water content of seed cotton (m^3/ton) is often estimated as the ratio of volume of water (m^3/ha) used during the entire period of crop growth to the corresponding crop yield (ton/ha). The volume of water used to grow crops in the field has 2 constituents (i) effective rainfall *i.e.* green water, and (ii) irrigation water *i.e.* blue water. The 'green' virtual water content of cotton can be estimated as the ratio of the effective rainfall to the crop yield, while the 'blue' virtual water content of the crop is often taken equal to the ratio of the volume of irrigation water used to the crop yield. The average virtual water content of seed cotton in various countries projects a first rough indication of relative impacts of various production systems on water. Cotton from India, Argentina, Turkmenistan, Mali, Pakistan, Uzbekistan, and Egypt is most water-intensive. Cotton from China and the USA on other hand is very water-extensive. Since blue water generally has a much larger opportunity cost than green water, it makes sense to particularly look at the blue virtual water content of cotton in various countries. China and the USA then still show a positive picture in this comparative analysis. Also Brazil comes in a positive light now, due to acceptable yields under largely rain-fed conditions. The blue virtual water content and thus impact per unit of cotton production are highest in Turkmenistan, Uzbekistan, Egypt, and Pakistan, followed by Syria, Turkey, Argentina and India. In auxiliary words the blue WF used to be the amount of fresh surface or groundwater used to grow a crop or produce goods or services. It gets evaporated, incorporated into the product, returned to a different location or in a different time period from where it was withdrawn. The green WF is indeed remains the total rainfall or soil moisture used to grow plants. Similarly, the grey WF is a measure of pollution, and usually expressed as the volume of water required to assimilate the pollutant load to meet ambient water quality standards. The pollutant that requires the largest assimilation volume is referred to as the critical pollutant and is used to calculate the grey WF; if there are both surface and groundwater discharges and also it needs to be separately estimated for each kind of discharge.

The global WF related to the consumption of cotton products is estimated at 256 Gm^3/yr, which is 43 m^3/yr per capita in average. About 42 per cent of this footprint is due to the use of blue water, another 39 per cent to the use of green water and about 19 per cent to the dilution water requirements. About 44 per cent of global water use for cotton growth and processing is not for serving domestic market but for export. If we do not consider water requirements for cotton products only, but take into account water needs for full scope of consumer goods and services, the global WF comes around to 7450×109 m^3/yr, which includes the use of green and blue water for full spectrum of global consumption *i.e.* goods and services, but excluding the water requirement for dilution of waste flows (Chapagain and Hoekstra, 2004). These 3 specific constituents of cotton WF (green water use, blue water use and grey water use) affects water systems in different ways. Use of blue water generally affects the environment more than green water use. Blue water is lost to the atmosphere where otherwise it would have stayed in the ground or river system where it was taken from. Green water on the other hand would have been evaporated through another crop or through natural vegetation if it would not have been used for cotton growth.

Reducing green and blue WF of cotton : Cotton water consumption is responsible for 2.6 per cent of the global water use, because as a global average, 44 per cent of water use for cotton growth and processing is not for serving the domestic market but for export. It means that if coarsely spoken, nearly half of the water problems in world related to cotton growth and processing can be attributed to overseas demand for cotton products; and about one fifth of global

WF due to cotton consumption could be considered as related to the pollution. Such WF exactly measures the consumptive water use and volume of water polluted. Water use in itself is not the problem, but not returning the water or not returning it clean is the problem. There are always substantial opportunities to reduce the green, blue and grey WFs of cotton production in India due to the large production volume, the low productivity in terms of kg/ha, high pesticide use and sub-optimal utilization of broad range of agronomic measures available today. Effects of individual and combined measures aiming at yield improvement, evapotranspiration reduction and pollution reduction has ample potential which needs to be attempted at grass root levels. In India about 70 - 80 per cent cotton remains rain dependent. In some innovative evaluations researchers have well reported that in India the conventional cotton farms of Gujarat have generated an average grey WF about 20 times higher than the state's organic farms. Similarly for states like Maharashtra such conventional farm's grey WF was reported even 100 times higher than state's organic farms, advocating organic cotton cultivation.

Looking into rising competition for fresh water, the consumptive WF reduction in irrigated cotton production too have a great scope/ importance. Chukalla *et al.,* (2015) have explored and well demonstrated the positive effect of various management practices on the soil water balance, plant growth, evapotranspiration, yield and thus consumptive WF of certain crops. Specific management practices *viz.,* 4 Irrigation techniques (furrow, sprinkler, drip, subsurface drip), 4 irrigation strategies (full, deficit, supplementary, no irrigation), 3 mulching practices (no mulching, organic mulching, synthetic mulching) , 4 global climatic environments (arid, semi arid, sub humid, humid), 3 regional rainfall distributions (wet, normal and dry years), and 3 soil types (sand, sandy loam, silty clay loam) were intensively monitored for associated green, blue and total consumptive WFs to investigate end results under specific sceneries of furrow irrigation, full irrigation, no mulching. The average reduction in the consumptive WF was reported as 8–10 per cent if we just change from the reference to drip or sub surface drip, 13 per cent when changing to organic mulching, 17–18 per cent when moving to drip or sub surface drip in combination with organic mulching. These interpretations and inferences seems to be extremely relevant and vital for regulating futuristic cotton WFs by seeking and applying smarter combinations while growing cotton crop. Magnitudes of such WF for Indian scenarios could be least under deficit irrigation, and furrow/drip irrigation too might offer substantially reduced consumptive WF.

COTTON AND CLIMATE : Cotton production is both a contributor to and a 'victim' of climate change. Overall any agricultural production, processing, trade and consumption contribute a high level of world's GHG emissions. As per general belief cotton production too contributes in it (may be around 1% of global emissions). Cotton production (particularly in tropical regions) looks to set /suffer under enormous kind of climatic factors, which includes, rising temperatures, decreased soil moisture, more extreme weather events , flooding, droughts etc. Certain concerns on connectivity among cotton growing *v/s* climate change remains as follows,

- Cotton growers greatly depend on natural environment and weather to produce their crop
- Being a perennial plant grown commercially in regions that experience climate variability driven by El Nino/La Nina cycles
- Cotton growing has a better than neutral carbon footprint. Net on farm emissions of greenhouse gases on cotton farms are often negative because cotton plants store more carbon than is released from production inputs used during growth
- The main sources of emissions on an irrigated cotton farm are synthetic fertilisers and electricity and fossil fuels used to power irrigation pumps
- On farm case studies have indicated that the adoption of minimum tillage has reduced energy costs and greenhouse gas emissions by 12 per cent since 2000
- Maximising efficiency of major inputs used in cotton growing such as energy and nitrogen by optimising irrigation pump performance, using fuel efficient farm machinery
- Using alternative sources of nitrogen, e.g. using legume rotation crops to fix soil nitrogen
- Implementing other practices to improve soil health including using controlled traffic and minimum tillage systems
- Using renewable and alternative energy sources and fuels such as solar panels to power irrigation pumps, and biofuels
- Conserving and managing native vegetation/riparian on farm as valuable carbon stores
- Adopting available smart tools like 'carbon footprint calculators' for cotton farms which demonstrates how farmers can be carbon neutral, or even better, being carbon positive
- Learning and adopting tailored information and decision support tools to understand and better manage weather and climate during cotton growing periods.

TARGETING HIGHER WATER PRODUCTIVITY IN COTTON : Water is critical to the cotton industry to maximise both the crop yields and fibre quality. In most cotton-growing regions, crop water demand exceeds the rainfall/ irrigation supply. Uncertainty about availability of irrigation water is widely accepted as most limiting factor in cotton production systems. Increasingly, water is becoming scarce due to the rising demand of alternatives uses (other crops, urban communities, environmental flows etc.). Decisive focus must remain towards promoting effective water use, optimising performance of irrigation systems, evaluating evolving alternative systems to conventional irrigation systems, understanding soil water dynamics and deep drainage, reducing water losses from on farm storages, and developing a better understanding of soil water plant relationships. Many studies have investigated cotton plant water relations, agronomic variables, and water use, yield and fibre quality relationships. Comprehensive discussions on the physiology of cotton plant–water relations is provided by Hearn (1979), Jordon (1981), and Turner *et al.,*(1986). Management of limited water scenarios during drought was reviewed by Hearn (1995). In this review 5–6 ML/ha was considered the optimum use, depending on location and irrigation water allocation prior to planting. Irrigation scheduling strategies and optimisation for cotton growth and development have been summarised by Brodrick *et al.,*(2013) and Gibb *et al.,*(2013). There exists a comprehensive body of knowledge (Hearn and Constable, 1994) where water use performance remains highly variable across cotton farmers, farming fields and regions. Using conventional furrow surface-irrigation systems in cotton one may expect >250 kg/ML (1.1 bales/ML total water use as irrigation, rainfall and reserved soil moisture) while 295 kg/ML (1.3 bales/ML) with centre-pivot and lateral-move machine systems. It establishes vast potential for further advance in water use productivity on cotton farms.

Water use efficiency (WUE) : WUE effectively measures existing capacity of any given cotton cropping system and it is primarily relied upon, (i) soil's ability to capture and store water (ii) crop's ability to access water stored in soil and rainfall during season (iii) crop's ability to convert water into biomass and (iv) crop's ability to convert biomass into grain (harvest index). In this context it becomes inevitable to have clear understanding of basic constituents of this important indicator. Some of them are (i) Fallow efficiency being efficiency with which rainfall during a fallow period is stored for use by following crop, (ii) Crop WUE being efficiency with which cotton crop converts transpired water to grain, (iii) System WUE being efficiency with which rainfall is converted to overall end products having higher water productivity. Water productivity and WUE are often considered alike, but there exists a big phenomenon difference in this regards. WUE concept is commonly used to evaluate performance of any irrigation system, and defined as ratio of amount of water used for an intended purpose to the total amount of water input within a spatial domain of interest. Depending on intended purpose and domain of interest, there are many efficiency concepts, such as crop water use efficiency and water-application efficiency. In any of the context including the cotton crop and product, the WUE concept is not directly related to the amount of food/end product that can be produced with an amount of available water. The optimum level of applied water for a particular situation is that which produces the maximum profit or crop yield /unit of land or/unit of water, depending on the underlying objective function and the limiting factor.

However, the 'water productivity' is often defined as the amount of food/end product produced/unit volume of water used, which is more relevant. Because the water used may have various components like evaporation, transpiration, gross inflow, net inflow, and others; it becomes essential to specify which components are included when calculating water productivity. It is the reason why the concept of water productivity or WUE inevitably requires clear understanding/specification of the domain of interest. Moreover, in general the terms WUE and water productivity are complementarily to assess overall impact of cotton water management strategies/practices used to produce more crops with less water. Perfect grasp among these 2 indicators may prevent certain flawed inferences from adopted practices.

Optimum and judicious use of water remains the true success of any cotton production system, where working out mega-litres (ML) of water used for producing unit quantity of cotton crop or its lint remains a common adaptations to reflect WUE values. Further in view of cotton water, the WUE encompasses a number of performance indicators including, (i) water use indices (WUI) that relate production (yield, return, gross margin) to water use (irrigation water, total water, evapotranspiration), (ii) irrigation system efficiencies that relate water inputs to water outputs at different locations reflecting quantum of water lost, and (iii) distribution uniformity that measures evenness of applied irrigation water. Some of the advanced cotton growing nations/ regions like Australia, predominantly adopts values of gross production water use index at farm level ($GPWUI_{farm}$), crop water use index (CWUI), and farm level Irrigation water use index

$$IWUI_{farm} = \frac{Total\ production\ for\ farm\ (bales)}{Irrigation\ water\ supplied\ to\ farm\ (ML)} \quad (1)$$

$$IWUI_{field} = \frac{Total\ production\ for\ field\ (bales)}{Irrigation\ water\ supplied\ to\ field\ (ML)} \quad (2)$$

$$GPWUI_{farm} = \frac{Total\ production\ for\ farm\ (bales)}{Total\ water\ used\ on\ farm\ (ML)} \quad (3)$$

$$GPWUI_{field} = \frac{Total\ production\ for\ field\ (bales)}{Total\ water\ applied\ to\ field\ (ML)} \quad (4)$$

($IWUI_{farm}$) to superior comparisons among cotton yield, total water use (available water), crop ET and on-farm water losses. These performance indicators can be derived, by using below given simplistic equations,

These values are recently getting promoted to better reflect WUE in cotton based production systems, having sizeable numerical deviations as evident from an Australian cotton water scenarios (Table 2). It requires various authentic data from farm/field level for quantifying bales/ML. Data includes farm records with each grower, yields from ginning reports, data on water inputs etc. Vital location specific information includes water diverted (using data from pumps, water meters, bores etc.), volume of land surface diversions (storm water runoff from fields, water harvested during storms/floods/rainfall on storages using metered data/ estimations from pumping/ storage volume records), storage volumes (using surveys with calibrated gauge board/electronic/ storage meter), starting and ending soil moisture deficit (using soil moisture monitoring equipment), and on-farm rainfall (using rain gauge records).

WUE for cotton : Researchers have amply reviewed cases from many studies with cotton field experimental results and offered several yield-water use relations by comparing WUEs. There remains significant effects of water management practices, soil and water conservation and other climate based variables, with certain interesting findings/facts as follows,

- Cotton is an efficient plant, where about 70 per cent of all water is used by the crop.
- Cotton is only planted when sufficient water is made available from rivers and groundwater sources, else when there’s no water, there’s no cotton planting.
- Cotton’s average irrigation requirement is 7.8ML/ha, when compared to rice

Table 2. Variations in advanced WUE indicators on an Australian cotton production system

Sr. No.	Performance indicators	2006-2007	2008-2009	2012-2013
1.	Yield (Bales/ha)	10.69	10.63	11.14
2.	Total available water (ML/ha)	9.31	9.66	10.16
3.	Crop evapotranspiration (ML/ha)	7.36	7.59	8.48
4.	On-farm water losses (ML/ha)	1.95	2.07	1.64
5.	CWUI (bales/ML)	1.46	1.41	1.31
6.	$IWUI_{farm}$ (bales/ML)	1.40	1.99	1.41
7.	$GPWU_{farm}$, (effective bales/ML)	1.17	1.14	1.12

Source : Waterpak 2013

(12.6 ML/ha), fruit and nut trees (5.6 ML/ha) and cut flowers/turf (4.9 ML/ha).

- Irrigation water for cotton delivers best return/unit of water.
- Cotton crop water use is different under different irrigation systems, suggesting about 14 per cent decrease in crop water use when micro irrigation is adopted giving about 25 per cent higher yields if it is a shifting from furrow to micro irrigation system.
- Broadly WUE is reported 0.39 to 1.08 kg/m^3 for cotton with a mean value of 0.6 kg/m^3.
- Comparing WUE and ET trends, about 5.5per cent of water use can be saved if cotton production goal is set to achieve maximum WUE rather than maximum yields.
- Australian irrigated lint yields are now a days the highest of any major cotton producing country in the world, being about 3 times the world average, achieving about 40 per cent increase in water productivity over last decade.
- Australian cotton growers have well demonstrated that their irrigation water use index for cotton gets easily doubled from 1.1 bales/ML in 2000-2001 to 1.9 bales/ML in 2009-2010

RECENT KNOW HOW AND TOOLS

Projected techniques for cotton growers to enhance WUE

- Use of soil moisture probes
- Improving existing irrigation systems like furrows by making changes in regards to flow or size of their siphons followed by relevant optimizations and evaluations.
- Evolving and shifting to alternate irrigation systems (centre pivots and lateral move systems).
- Redesigning fields by adopting GPS and laser levelling to ensure uniform, drained fields with their positioning near existing storage dams/surface water bodies to cut evaporation
- Seeking and adapting deficit irrigation practices, drip or overhead sprinkler systems, better accounting of soil variations, changed bed shapes, using irrigation scheduling probes, pump optimisation and reductions in

distribution losses

- Using sophisticated weather forecasting software for better predictions
- Using zero and minimum till farming to better retain soil moisture
- Adopting IT and ICT tools (soil moisture probes, satellites and drones) to decide watering only when it is critically needed and in optimize quantity and rates.
- Lining irrigation channels that pump water to the fields to reduce loss through seepage
- Obeying existing ecological managing program which includes water management module covering water quality, efficiency of storage/distribution for dry land and irrigated cotton
- Seeking easy and rapid assessment of soils for their suitability for irrigation by harnessing utilities like mobile electromagnetic meters
- Understanding/implementing 'tail water recycling systems' so that water could be reused
- Reducing evaporation by shortening row lengths, and covering water storages
- Avoiding needless water storage on farm and not putting water directly into dry storages
- Lining surface water storages/channels with clay/non-porous materials to avoid seepage.
- Using thermal imaging/electromagnetic surveys to identify "leaky" dams/pipes/channels
- Considering mulching/stubble retention to retain soil moisture, reducing irrigation needs
- Creating eternal wheel beds in crop fields to reduce soil compaction and increase infiltration
- Screening, understanding and active enactment of software packages for on-farm water management and irrigation scheduling.

Futuristic innovative issues for R and D

- Cotton growers can act as a long term investor in cotton-water research where they could nominally pay a compulsory research levy/bale of cotton they produce which could be further matched by Government by setting an appropriate limit (say 0.5% gross value of production). It could underpins cotton industry easing innovation, evolvement and adoption of technology, environmental management and making high quality/high yielding cotton.
- Identifying regional links between improved productivity, natural resource management and addressing climate change by R and D to seek ways towards further improvements in water, fertiliser and energy use efficiency for reducing greenhouse emissions.
- Better concentrations towards increased crop yields, improved fibre quality, improved irrigation and water use efficiency, promoted productivity and innovation, research information on salinity, river health, groundwater and enhanced biodiversity.
- More recent are efforts to better understand the requirements of our

international markets and to attract and retain a skilled workforce

- Launching effective cotton information programs to connect cotton growers with research by bringing together them with consultants, irrigation and crop experts, latest news, information, events and technological tools to achieve best practice in cotton industry
- Thinking of cotton catchment communities, cotton cooperative research centre, and cotton operational RandD projects could be newer sights by involving smart decision support systems, policy planners and other policy based ingredients.
- Promoting organic cotton production is another growing aspect. Usually cotton grown without using synthetic chemicals is considered 'organic cotton'. In 2013, the largest organic cotton producers by volume were India, China and Turkey, Tanzania and USA. Going for organic cotton by adopting comprehensive and inclusive production methods is need of hour where cotton farming needs to be managed in accordance to true organic standards by incorporating ingredients like water and irrigation, soil, air, seeds, machinery, and pest/weed control and growing cotton using seeds that are not genetically modified.
- Propagating and adopting soil and water conservation practices and also the conservation agriculture concept is another potential area. Soil erosion-control methods could be proved fundamentally important to cotton growers to protect the soil surface and manage adverse influence of water and wind being focussed on minimizing erosion and health of top soil. Cotton growing areas often remains flat/mild sloppy lands where simplistic conservation measures/practices like wind breaks (planting trees in lines along crop fields) to reduce wind induced erosion, contour farming (orienting cotton crop rows perpendicular to land slope to reduce water erosion), conservation tillage (for preserving crop residue on land surface) and reducing number of tillage operations (to control weeds/soil disturbances).
- Region specific integrated crop modelling together with hydro meteorological models
- Working towards generating deeper and broader field data base on cotton irrigation water use and various indices to quantify cotton water productivity at various levels.
- Incorporating smart technologies and tools (IT, ICT, IoT, DSS) and knowledge sharing.

SUMMARY AND CONCLUSION

Cotton being a vibrant cash crop of high industrial importance, is indeed a natural fibre that grows on a plant, which is a leafy, green shrub related to the hibiscus Squares (flower buds) develops several weeks after plant starts to grow followed by appearance of flowers a few weeks later. It remains the largely produced natural fibre in the world representing about

31per cent of world textile market. Indian has established herself into a leading giant cotton producer to govern global business of cotton and cotton products. Land and water scarcity are major constraints to the production of cotton crops required to meet the recent quantitative and qualitative shifts of the world's cotton demand. There is always a need to close the common and often large gap between actual and attainable yield per unit water consumption. The scarcity of these resources is further worsened by climate change. Water is most valuable resource a cotton farmer has. Every drop of it counts and growers and researchers are continually required to look upon newer ways to improve water use efficiency and at last the water productivity from various perspectives. Integrated water management issues in case of cotton crops requires a broader understanding of water budget as well as water supply-demand scenarios, not only from cotton growers point of view, rather keeping an assimilated focus by visualizing the foresighted industrial utilities of cotton yields. Being a prime cash crop of global industrial prominence, it is not only the quantity but quality of crop too remains equally vital to decide upon the net profits for growers and producer of cotton products. Based upon prevailing R and D releases from variety of cotton industries and cotton growers, five most important key areas for cotton growers may be enlisted as, (i) maximising storage and distribution efficiency on-farm dams and channels, (ii) maximising application efficiency putting water near to crop root zones, (iii) achieving uniform water applications, (iv) monitoring water use and calculating efficiencies while the crop is growing, (v) evolving and employing innovative alternative irrigation systems such as overhead sprinklers, bank less channels, sub surface drip, economic versions of pivots, sensor based irrigation regulators, precision irrigation etc.

Cotton is a drought and heat-tolerant crop, and thus generally well suited to climates with low rainfall too, and thus can be well grown in many regions where precipitation is low. Only important aspect is a judicious and smart irrigation scheduling. Under the current agrarian situation, the cotton is considered to be highly affected by climate changing and environmental related constraints. Impact of cotton production on climate change and impact of climate change on cotton production, both are emerging as very sensitive issues for growers, researchers, industrialists, market persons, and policy planners. Cotton water foot prints too are adding fuel to the fire, when we consider the effective management of our confined natural resources, specifically the water. WF reduction in irrigated cotton could be another vital way forward for efficient and sustainable water resource use. This paper provides a comprehensive though provoking stuff regarding its potential by just regulating irrigation management practices and other strategies. Irrigation methods, techniques and operational strategies towards agricultural water management in cotton are reviewed and described in depth. Research efforts at global and regional scales have been well documented showing enormous potential for improvements in cotton water relationships towards irrigation methods, schedules, WFs and water productivity point of views. These efforts have offered variety of food for thought, which is well pinpointed in preceding segment of this write-up hence not being continual here. Contents provided herein might be useful as an updated reference for future studies on potential effect of integrated water management practices towards getting better cotton water productivity and reducing the alarming consumptive WF of cotton to make it a lucrative crop for growers as well as industrialist. Water management practices to improve cotton water production- irrigation scheduling, caring critical stages of plants, soil moisture depletions, and protective irrigation methods (check basin, furrow-skip/alternate, and pivot) always invites an appropriate judging of water availability, due demands of water by cotton crops at specified critical growth stages, on-farm and off-farm water management strategies and technological options are required to be realized, understood, assessed and managed at grass root levels.

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High density planting system and mechanical harvesting in India

E. NARAYANA* AND N.V.V. DURGA PRASAD
Acharya N.G. Ranga Agricultural University, Guntur - 522 034
**E-mail : dirpmangrau@gmail.com*

Cotton (*Gossypium hirsutum* L.) is not only the principal cash crop of the world that is primarily grown as fiber and oilseed crop (Dong *et al.,* 2010), but it is also the most important cash crop of India having prime share in national economy, export earnings with production ranging from 338 to 398 lakh bales in recent years. In India, cotton is grown predominantly in 9 states and in last five years area has been fluctuating between 105 to 128 lakh ha, having the largest area in the world and recently from 2016-2017 became largest producer as well Globally due to reduction of area in China. Currently though first in both area and production in the world, the productivity levels are low between 511 to 568 kg lint/ha way behind the brazil (1345 to 1522 kg/ha),China (1570 to 1719 kg/ha), US (859 to 974 kg/ha) and world average of 763 kg/ha. The major reason for low productivity in India is rainfed cotton occupies 7 M ha (70%) with an average productivity of 230 kg/ha. The bottle neck in rainfed cotton is erratic crop growth and development due to intermittent dry spells and excessive moisture stress, leading to poor yields. The monsoon period should be effectively utilised in the rainfed cotton for which manipulation in Agrotechniques are required with desired genotypes. The possible way for redefining the cotton productivity in India can be through manipulation of row spacing in order to increase plant density and the spatial arrangements of cotton plants with an appropriate plant geometry, which is termed as high density planting system (HDPS) in cotton, that naturally demands for mechanical harvesting to maintain an economic viability. Therefore, using cotton planters and pickers can certainly lead to total mechanization in cotton, that helps to reduce the cost of cultivation considerably besides improving in productivity under rainfed as well as irrigated conditions.

Usually farmers adopt plant spacing and plant density according to their traditional methods of planting rather than variety requirement that results in yield penalty in cotton. In India during the last 30 years, cotton hybrids were grown extensively under spacings which are considered as wider ranging from 90 to 150 cm between the rows and plant spacing of 45 to 90 cm accomdating 15000 to 30000 plants/ ha according to soil type, rainfall pattern and moisture holding capacity of the soil. Cotton growth and development are greatly influenced by environmental circumstances, as well as seasonal management practices (O'Berry *et al.,* 2008). One of the options to maximize yield/unit area is to maintain optimum plant population per unit area that also varies from variety to variety in cotton (Ali *et al.,* 2009). Plant spacing has a key role in managing optimum plant density according to the requirement of variety under consideration to boost cotton productivity especially under irrigated conditions (Nadeem *et al.,* 2010).

High density planting system in the world : The HDPS system is popular in several countries like Brazil, China, Australia, Spain, Uzbekistan, Argentina, USA and Greece (Rossi *et al.,* 2004). The availability of compact genotypes, acceptance of weed and pest management technologies including transgenics, development of stripper harvesting machines and widespread application of growth regulators have made these high density cotton production systems successful in these countries. Higher productivity in Brazil was achieved through development of compact sympodial varieties suited for high density planting geometry. High density planting with specification of 90x10 cm and 75x10 cm is done with zero monopodial (sympodial) varieties. In some farms ultra narrow-row planting with 45x10 cm spacing is used. Mepiquat chloride is sprayed 3-4 times to arrest vegetative growth, which, otherwise hinders higher productivity. High density planting method is practiced which enables higher number of plants at 150,000 to 250,000/ha. Thus, with more plants/ha and with 8-14 bolls/plant at 4.0 g/boll, the productivity is high at 45 to 55 q seed cotton/ha and therefore production, is much higher.

Advantages of HDPS : The obvious advantage of this system is earliness (Rossi *et al.,* 2004) since HDPS needs less bolls / plant to achieve the same yield as conventional cotton and the crop does not have to maintain the late formed bolls to mature. The HDPS cotton plants produce fewer bolls than conventionally planted cotton but retain a higher percentage of the total bolls in the firstsympodial position and a lower percentage in the second position (Vories and Glover, 2006). The other advantages include better light interception, efficient leaf area development and earlycanopy closure which will shade out the weeds and reduce their competitiveness (Wright *et al.,* 2011). The early maturity in soils that do not support excessive vegetative growth (Jost and Cothern, 2001) can make this system ideal for shallow to medium soils under rainfed conditions, where conventional late maturity hybrids experience terminal drought. Therefore, the high density planting system (HDPS) is now being conceived as an alternate production system having a potential for improving the productivity and profitability, increasing input use efficiency, reducing input costs and minimizing the risks associated with the current cotton production system in India and enable mechanical picking.

High density planting system in India : In India, several experiments and demonstrations were carried out during the last decade to standardise and popularise the concept of HDPS by ICAR Institutes and State Agricultural Universities mainly concentrating on the development of compact genotypes, plant geometry, nutrient requirements, agronomic practices and use of plant growth regulators.

Evaluation of genotypes under HDPS : An ideal variety having better adaptation to high density planting is the first step for successful HDPS. On verticInceptisols, 5 genotypes *viz.,* (Anjali, CCH 724, NISC 50, AKH 081 and CNH 120MB) were evaluated at 5 spacings *viz.,* 60x30 cm (55,000 plants / ha), 45x20 cm, 30x30 cm (both 1, 11,000 plants/ha), 45x13.5 cm and 30x20 cm (both 1,66,000 plants/ha). Genotype AKH 081popularly called PKV 081 was found most suitable for HDPS based on yield, morphological features, earliness, tolerance to sucking pests and boll weight. Data further indicated that all genotypes do not respond favourably to high density planting and there is a need for screening genotypes under HDPS (Venugoplan *et al.,* 2015). Silva *et al.,* (2012) and Rossi *et al.,* (2007) also observed significant interaction between plant density and genotype and recommended a density dependent selection of genotypes. Further, for a particular density, the difference between a narrow row and a wide row was not significant on yield but a wider row may facilitate interculture. Earlier, Heitholt *et al.,* (1996) observed that at equal densities, narrow row may allow each plant to intercept more light and increase seasonal light interception but this advantage is seldom translated into improvements in yield**.**

Results from CICR, Nagpur and other centers indicated that genotypes Suraj, PKV 081, ADB 39 and 28I were more promising in terms of yield, morphological features, earliness and nutrient use efficiencyunder HDPS (45x15cm resulting in 148,000 plants/ha).Averaged over the 10 genotypes the yield increase with HDPS over recommended spacing was 29.5 per cent, but it was as high as 67per cent in Suraj, 44per cent in PKV 081 and 34per cent in CNH 28I. HDPS (with 148,000 plants/ha) may not be suitable for taller genotypes CNH 1108 and DSC 115. Earlier, Kerby *et al.,* (1990) also concluded that increase in yield under high plant densities was low in tall varieties with more indeterminate growth. Coffey and Davis, (1985) suggested that varieties that produce fewer and shorter and fewer fruiting branches are ideal for high density planting. During 2012-2013 thirteen genotypes developed under diverse agro climate conditions *viz.,* NH 615 and NH 545 (Nanded),ADB 39 and MDLH 1 (Ailabad), Suraj, LRK 516 (Coimbatore), KC 3 (Kovilpatti), RS 875 (Ganganagar), CSH 3178 (Sirsa), F 2383 (Faridkot), H 6 *Bt* (BG II) and H 8 *Bt* (BG II) (Surat) and PKV 081 (Akola) were evaluated at 3 spacings 45x15cm (148,000 plants/ha), 60x15cm (111,000 plants/ha) and 90x15cm (74,000 plants/ha) on a shallow black soil (Vertic Inceptisol). The effect of spacing, genotypes and spacing x genotype interaction were significant. Averaged over the 13 genotypes the yield improvement with 45x15cm over 60x15cm spacing was not significant but the yield in both were superior to 90X15 cm spacing. However, the genotypes ADB 39 (3000 kg/ha), PKV 081 (3011 kg/ha) and LRK 516 (2814 kg/ha) performed best at 45x15cm spacing whereas for genotypes NH 545 (2830 kg/ ha), KC 3 (3113 kg/ha) and Suraj (2976 kg/ha) 60x15cm spacing was found to be optimum.

Nutrient requirement under HDPS : A pertinent question to be resolved is whether the demand for nutrients is greater under HDPS since the plant population is higher. Multi location trails were conducted (under Technology Mission on cotton to determine whether the recommended fertilizer dose (RDF) for conventional cotton (at normal density) is also applicable for cotton planted under HDPS. Preliminary results indicated that 25 per cent additional fertilizers would be needed to meet the increased requirement of the crop under HDPS with a population of 148000 plants/ha

(Singh *et al.,* 2012). Studies elsewhere (Rinehardt *et al.,* 2003) also indicated that about 30 per cent more N is required under ultra narrow row cotton compared to the conventional row cotton. However, in 10 genotypes evaluated under HDPS (148000 plants/ha, there was no consistent increase in yield with (125%) RDF (Recommended Dose of Fertilizers)+2 t/ha Vermicompost over RDF alone (CICR, 2012). The plants grew taller and there was delay in maturity with additional fertilizer dose. Wiatrak *et al.,* (2000) opined that application of higher dose of N to high density cotton increased hard-locks (immature bolls) and delayed maturity. More studies are therefore needed to conclude on N requirements on HDPS.

Crop canopy management under HDPS: Mepiquat chloride (1,1-dimethyl-piperidinium chloride), a plant growth regulator is widely used to manage cotton morphoframe, regulate plant development and hasten maturity under highplating densities (Stuart *et al.,* 1984). Although plant growth regulators have been thoroughly widely tested in cotton in India, there are no specific recommendations regarding their dose and timing for modifying crop morphoframe to accommodate our varieties at high planting densitiesschedules were tested on Suraj, AKH 081 and NH 615 varieties planted at 148,000 plants/ha under rainfed condition on a vertic Inceptisol at Nagpur (CICR, 2013). There was a dose dependent reduction in plant height, decrease in height / node ratio, an increase in boll weight and a delay in maturity with the application of growth regulators but the effect on yield was not significant. Application of mepiquat chloride makes the plant more compact, with fewer nodes (Reddy *et al.,* 1990), shorter internodes and fewer reproductive branches (Bogiani and Rosolem, 2009) and these changes were also noted in all the 3 varieties. The results were slightly different under irrigated conditions at Coimabtore (Tamil Nadu) as well as Sirsa (Haryana) where there was a positive response to mepiquat chloride application. Application of mepiquat chloride reduced leaf area and increased the number of bolls/unit area at high plant density. It also helped in retention of bolls on lower sympodia and increased the synchrony of boll maturation (Gwathmey and Clement, 2010). However, the effect of mepiquat chloride on cotton is affected by environmental conditions, particularly temperature (Rosolem *et al.,* 2013) and this might have resulted in differential response across centres. At Coimbatore there was a variety dependednt response to mepiquat chloride application @ 75gai/ha in three splits at 45, 60 and 75 DAS in winter irrigated cotton planted at 45x15 cm spacing. There was a reduction in plant height, sympodial length and LAI and an enhanced the number of burst boll/ m2 leading to an increase in yield at Coimbatore. Across cultivars, application of mepiquat chloride increased seed cotton yields from 1330 kg/ha to 1530 kg/ha. Interaction effect of cultivars and application of mepiquat chloride was significant. Taller cultivars TCH 1608 and 1705 benefitted more with application of mepiquat chloride compared to the other cultivars having a compact growth habit. Cultivars with a more indeterminate growth habit responded more positively Mepiquat chloride application (Craig and Gwathmey, 2005). There is a need for detailed investigations on this aspect before any recommendations are given.

Weed management : The opportunities for interculture are limited in HDPS and hence weed management becomes more critical. Nevertheless, early closure of canopy results in reduced weed competition. However, improper plant stand due to uneven germination and seedling establishment may increase weed density within crop rows and these weeds are difficult to manage and under these circumstances, application of post emergence herbicides become necessary. Although the results on weed management exclusively under HDPS have yet not been concluded, preliminary results indicate that effective control of weeds could be accomplished with pendimethalin @ 1kg/ha *fb* interculture and then 1 hand weeding (to remove remaining weeds) fb post emergence spray of tank mixed Pyrthibac Na@75gai/ha and Quizalofop ethyl @ 50 g/ha. The option of a combination of the weedicides or single application of either of them depends upon the nature of weed flora.

Machine harvesting : Indian cotton production is mired by low productivity driven by rainfed cultivation, small farm size, increasing pest & disease and labour intensive method of cultivation. Labour cost in India is rapidly increasing and therefore Mechanization in Cotton cultivation will play a key role in keeping the cost under control. Additionally, there will be productivity increase driven by high density planting. However to bring high density planting by using pneumatic planters to maintain optimum plant stand on one hand and to use cotton picker on the other is the dire need to achieve total mechanization in cotton in order to achieve higher productivity with reduced cost of cultivation, certainly requires development of Sympodial cotton hybrids with complete transformation in agronomy practices.

In USA it took 30 years to achieve 100 per cent mechanization, Brazil took 45 years to achieve 100 per cent mechanization, Turkey reached 75 per cent of mechanization in 15 years and China took 20 years to reach 15 per cent mechanization. But the entire cotton production in India is hand picked by woman labour even today and picks only 5 kg seed cotton/h, which cost almost 10 times than irrigation and two times the weeding costs. It is reported that the labour availability has dropped from 70.3 per cent of the population in 1961 to 48.9 per cent in 2010 and cost of picking cotton from the farm has increased to Rs 10-12 a kg now from Rs 4 a kg in 2007. Therefore, mechanization is clearly the need of the hour and will play important role to sustain the cotton production in future in India. India has started its journey with mechanization with collaborative cotton mechanization project from 2012 onwards but still in development phase. Most of the seed companies in India has realized that the mechanical cotton picking is the future requirement of the Indian farmers and have started to breed hybrids that are suitable for mechanical cotton picking.

The successful cotton harvesters with 5 to 6 cotton pickers were tried in India and were not working in the cotton cultivation set up of indian cotton situations. One of the big initiative in India towards cotton mechanised is joint efforts of the John Deere India Pvt. Ltd, Bayer

Crop Science Limited and Bajaj Steel Industries Limited to develop cotton mechanization in India. The project started in 2009 with the import of 2 row cotton picker from Turkey. But this 2 row cotton picker was found to unsuitable and then John Deere started working on single row picker machine and simultaneously started to collaborate with Bayer and Bajaj steel to build the complete ecosystem for cotton mechanization in India. Currently cotton mechanization project is being operated in 4 cotton growing states such as Punjab, Maharashtra, Andhra Pradesh and Telangana. In Punjab project is being run under public private partnership and is also supported by Department of Agriculture while providing seed subsidy to farmers who adopt cotton mechanization. CICR, Nagpur is also in the process of simple tractor driven cotton harvester to meet the indian conditions.

John Deere, a leading farm mechanization company has successfully developed a single row patented tractor drawn picking machine (Model name CP 20) which is now available for Indian farmer. Machine picking requires use of harvest aids like growth regulator, defoliants and boll openers to enable machine to pick cotton easily with desired quality. Bayer is a global leader in providing harvest aid products and is currently testing few of these products for use in India and very soon these products will be available to Indian farmers to facilitate easy picking through machines. A farmer who is adopting machine picking needs to overcome the issue of high trash per cent (compared to hand picking) which is common in all countries that have adopted machine picking. Therefore, after machine picking the seed cotton has to pass through high impact pre cleaners before ginning. High impact pre cleaner is already developed in India by Bajaj steel Industries. The need of the hour is that ginning mills needs to install these pre-cleaners so that the machine picked cotton can be ginned and baled with high quality cotton without any trash and contaminants.

The mechanical picking with single row picker under high density planting system provided 25-40 per cent yield increase compared to farmer practice. Yield increase is attributed to higher plant density per unit area as compared to conventional practice. This yield increase provides a strong basis for adoption of cotton mechanization. Farmers who adopt mechanised method of cultivation spend additional costs of Rs. 75 Euro/ac towards increased seed rate and use of agrochemicals. There is no incremental cost of picking *via* machine because of as of today the cost of picking by machine is equal to average cost of picking by labour. In future, the labour cost is expected to increase at a fast pace compared to cost of picking by machine and more and more farmers will see this as a benefit and shift towards mechanical picking. This additional cost can be easily covered with incremental revenue of Rs. 137 Euro/ac on account of 25-40 per cent yield increase. Therefore overall farmer tends to get benefited if he decides to adopt mechanical cotton cultivation (Singh *et al.,*). From the initial efforts that by 2020 varities/hybrids will get launched resulting in better picking efficiencies by machines. This will lead to large scale adoption by farmers. In next 10 years we can expect 2-3 per cent of the planted area to get mechanized in India, but let us aim at still faster rate by providing technical know how effectively with good extension practices.

At the present juncture of cotton production system in India with varied climate and soil conditions, the productivity levels can be increased by adopting high density planting and mechanical harvesting to drive cotton farmers to sustained profits while breaking the staganation in the income of cotton farmers in the present situation. In this direction, concerted initial efforts have been put by Scientist, Private firms and Government agencies with Public Private Partnership (PPP) model which were encouraging and positive results were obtained to take the technology to further heights to implement at larger scale. On the other, still greater efforts and refinement is needed in bringing suitable compact genotypes for HDPS by careful planning, timely planting, rigorous monitoring, Location specific plant geometry, agronomic practices and timely interventions. On this platform standardisation of defoliants and cost effective mechanical harvester with improvement will take this technology to new heights on par with international competitors to meet the global demand.

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Best agronomic practices for higher productivity of cotton under irrigated conditions of northern India

G.S.BUTTAR*

Director of Extension Education, Punjab Agricultural University, Ludhiana - 141 004

**E-mail : buttargs@rediffmail.com*

India has emerged as the second largest producer of cotton in the world and occupies the first position in terms of total area under crop production. However, the productivity level is still below the world average and it varies from region to region. In India, there are nine major cotton growing states which fall under three zones viz. the north zone (Punjab, Haryana and Rajasthan), the central zone (Maharashtra, Madhya Pradesh and Gujarat), and the southern zone (Andhra Pradesh, Karnataka and Tamil Nadu). Cotton is grown both under irrigated and rainfed conditions. Nearly 65 per cent of the cotton crop is cultivated under rainfed conditions in the country. In irrigated area the crop is generally grown in sandy and sandy loam soil through supplemental irrigation by farmers. Cotton is best grown in soils with an excellent water holding capacity. Aeration and good drainage are equally important as the crop cannot withstand excessive moisture and water logging.

Being a cash crop, cotton is known for its intensive cultivation. Some agronomic practices like sowing time, optimum spacing, fertilizer, weed control, irrigation etc are of great significance for obtaining the potential yield of the crop. The crop traits such as indeterminate growth habit, long duration, crop susceptibility to pests and diseases at all stages of growth. These factors are also responsible for high input use in terms of nutrients and protection chemicals. The excessive use of inputs, not only escalates the cost of cultivation but also decreases the profitability along with pest resurgence, health and environmental hazards. Excessive use of inputs is laying enormous pressure on land, water and environment. In order to address these issues, best agronomic practices for cotton cultivation have been suggested which will help in balance input use with higher productivity.

Best agronomic practices, technically speaking, are more environment friendly, and promote the use of local resources, and improve the input use efficiency. The commonly used agronomic practices for obtaining potential yield of cotton under irrigated conditions are as follow:

- Optimum sowing time
- Optimum plant population
- Weed management
- Balanced nutrition
- Irrigation

Optimum sowing time : In the cotton-wheat cropping system, the sowing time of cotton staggered from April to June depending upon the supply of surface water from the canal as the ground water in majority of cotton growing regions of North India is of poor quality. The sowing of crop at proper time helps in getting the potential yield of the crop. Among different agronomic practices, sowing time is an important practice which influences the growth and yield of cotton crop greatly. Too early sown crop attains excessive vegetative growth and has negative effect on fruiting behavior of the crop. The flowering gets delayed in late sown crop and it results in reduction of seed cotton yield.

Non significant difference in seed cotton yield was observed in all the genotypes with delay in sowing from April 30 to May 15 during both the years (Table 1). However, significant reduction in seed cotton yield was recorded when sowing was delayed to May 30 in all the genotypes during both the years.

Optimum plant population : The plant population is one of the major bottle neck in achieving the potential yield of cotton. Maximum yield potential of cotton can be realized by adopting new and high yielding *Bt* hybrids with optimum plant spacing

The spacing of 67.5x75 cm and 90x67.5 cm gave the highest yield as compared to other spacings (Table 3). However, the plant spacings vary for hybrid to hybrid.

Table 1. Effect of sowing date on seed cotton yield (q/ha) of different cultivars

Treatment	Genotypes: RCH 134		RCH 317		MRC 6301		MRC 6304		MRC 1861	
Sowing dates	2006-2007	2007-2008	2006-2007	2007-2008	2006-2007	2007-2008	2006-2007	2007-2008	2006-2007	2007-2008
April, 30	37.7	38.2	32.4	34.5	32.1	32.9	28.0	28.8	25.9	26.8
May, 15	37.3	38.4	33.3	36.0	31.8	34.5	27.5.	28.3	25.1	27.8
May, 30	32.4	36.6	25.1	25.9	25.7	26.5	25.9	26.7	24.8	25.6
Mean	**35.7**	**36.6**	**30.3**	**32.1**	**29.9**	**31.3**	**27.1**	**27.9**	**25.3**	**27.4**
LSD (p=0.05) Sowing dates		1.5	2.1							
Genotypes	2.0	2.2								
Interaction	NS	NS								

Buttar *et al.,* (2010)

Table 2. Effect of spacing and nitrogen on the seed cotton yield (2006-2007)

Treatment	Seed cotton yield (q/ha)
Plant spacings (cm)	
90x67.5	24.59
90x90	21.87
90x105	20.52
CD (P = 0.05)	2.31

Buttar *et al.,* 2010

Table 3. Effect of spacing and fertilizer levels on growth and seed cotton yield of RCH 134 *Bt*

Treatment	Seed cotton yield (kg/ha)			
Plant spacing (cm)	2006-2007	2007-2008	2008-2009	**Mean**
67.5x75	2293	3045	3431	**2923**
100x60	2251	2681	3181	**2704**
100x75	2079	2652	3292	**2674**
CD (p=0.05)	NS	161	NS	

Kaur *et al.,* 2010

Transplanting of cotton seedlings: The use of single seed/hill due to higher cost of *Bt* cotton seed sometimes results in poor crop stand and ultimately sub optimum plant population. There are frequent showers in this region during the sowing period of cotton crop (April – May) which results in crust formation and ultimately poor germination coupled with poor crop stand. The higher temperature prevailing during sowing season also resulted in burning of young seedings and less plant population which adversely affects the crop productivity. These problems can be minimized by planting more seeds/hill and by transplanting of cotton seedlings in the field directly after raising its nursery in polythene bags.

For optimum population, three weeks old seedlings grown in polythene bags exhibited a significant influence on cotton survival and gave higher seed cotton yield than tray grown seedlings (Table 4 and 5). The crop should be sown by using two seeds/hill than one seed/hill for obtaining optimum plant population and potential yield. The gaps in the field can be filled by transplanting 3 weeks old seedlings raised in polythene bags filled with soil and FYM mixture (1:1). The field should be irrigated immediately

Table 4. Seed cotton yield (kg/ha) as influenced by age of nursery and time of transplanting (2006)

Age/method	Seed cotton yield kg/ha	
Date of planting	Agril 25	May 7
Transplanting (10 day old)	2465	2680
Transplanting (15 days old)	2886	2782
Transplanting (20 days old)	3082	2840
Direct sowing	3099	3043
Mean	2908	2836
LSD (p=0.05) Date of planting	NS	
Age of seedlings	317	
Interaction	NS	

Buttar *et al,* 2011

Table 5. Seed cotton yield (kg/ha) of *Bt* cotton as affected by direct sowing and transplanting nursery of different age (2007)

Treatment	Seed cotton yield (kg/ha)
Direct sowing (1 seed/hill)	3904
Direct sowing (2 seed/hill)	4491
Tray nursery (2 weeks old)	2638
Tray nursery (3 weeks old)	1223
Tray nursery (4 weeks old)	1162
Polythene nursery (2 weeks old)	3853
Polythene nursery (3 weeks old)	4727
Polythene nursery (4 weeks old)	3822
CD (p = 0.05)	249

Buttar *et al.,* 2011

Table 6. Seed cotton yield (kg/ha) and weed control efficiency under different weed management treatments (2012 and 2013)

Treatments	Seed cotton yield (kg/ha)	Weed control efficiency (%)
Pendimethalin @ 1.0 kg a.i./ha as pre-emergence + one hoeing	2741	41.9
Trifluralin @1.2 kg a.i./ha as pre plant + one hoeing	40.9	2940
Pendimethalin @ 1.0 kg a.i./ha+quizalofopethyl @50g a.i./ha+one hoeing	3318	73.7
glyphosate @ 1.0 kg a.i./ha as directed spray at 45 DAS	2331	34.7
Weed free check	3537	86.8
Farmers practice	2398	24.7
Control	1435	
LSD (p=0.05)	261	

Singh and Rathore (2015)

Table 7. Effect of nitrogen application on the seed cotton yield (2006-2007)

Treatment	Seed cotton yield (q/ha)
Nitrogen level (kg N/ha)	
150	23.43
175	22.51
200	21.03
LSD (p=0.05)	1.75
Interaction	NS

Buttar *et al.,* 2010

after transplanting of seedlings.

Weed management : Cotton is sensitive to weed competition due to slow growth during initial stages and wider plant geometry. The crop season coincide with the monsoon rainfall in northern India which further increases the incidence of wider species of weeds. These weeds compete for nutrients, water, light and thus reduce the cotton yield. In case of heavy rains, providing timely weed control becomes difficult as soil becomes sticky and wet leading to poor workability. In case of dry soil, the surface becomes hard and makes interculture difficult. Moreover, non availability of labour for interculture makes timely weed control tedious and uneconomic. Pre emergence herbicides application can manage weeds only up to 30-40 DAS and controlling the late flushes of weeds is really a challenge. Hence, application of post emergence herbicides to supplement pre-emergence treatments can provide the desired season long weed control in cotton (Table 6).

The use of herbicides in combination with cultural practices is the practical solution for economical and effective weed control in irrigated cotton.

Balanced nutrition : Most of the cotton growing tracts in northern India are characterized by low to medium levels of available Nitrogen (N) and Phosphorous (P) and medium to high levels of available Potassium (K). As cotton is a deep rooted crop, the extraction of nutrients is enormous and the nutrient uptake varies with the soil type. Imbalanced use of fertilizers may affect the vegetative and reproductive growth resulting in decline in seed cotton yield.

Table 8. Effect of fertilizer levels on seed cotton yield of RCH 134 *Bt*

Treatment	Seed cotton yield (kg/ha)			
	2006-2007	2007-2008	2008-2009	**Mean**
Fertilizer levels (kg/ha)				
RDF (75%) 112.5 kg/ha	2188	2751	3268	**2737**
RDF (100%) 150 kg/ha	2174	2785	3299	**2753**
RDF (125%) 187.5 kg/ha	2260	2842	3338	**2813**
LSD (p=0.05)	NS	NS	NS	
Interaction	NS			

Kaur *et al.,* 2010.

Foliar application of KNO_3 at flowering stage : The shedding of flowers generally happened in cotton crop which resulted in lower productivity of the crop. The shedding of flowers can be reduced to great extent by foliar application of KNO_3 at the time of flower initiation. The highest mean seed cotton yield was recorded with application of 4 sprays of (2%) KNO_3 solution at weekly interval starting from flowering onwards and lowest seed cotton yield was recorded where no spray of KNO_3 was done (Table 9).

Foliar application of MgSO4 to control leaf reddening : Leaf reddening is the major problem in cotton which adversely affects the yield of cotton crop. The photosynthesis process reduced greatly in red leaves which ultimately decrease seed cotton yield. The problem of leaf reddening can be minimized to great extent by the foliar application of various nutrients alone or in combination at the time of flowering and

Table 9. Effect of foliar application of KNO_3 on seed cotton yield

Treatments	Seed cotton yield (kg/ha)		
	LH 1556	LH 1556	MRC 6304 *Bt*
T_1 no spray	1363	1353	3514
T_2 2 sprays of KNO3 (2%)	1669	1692	3685
T_3 3 sprays of KNO3 (2%)	1780	1602	3785
T_4 4 sprays of KNO3 (2%)	1749	1735	4352
T_5 2 sprays of KNO3 (3%)	1648	1780	4069
T_6 3 sprays of KNO3 (3%)	1802	1634	4176
T_7 4 sprays of KNO3 (3%)	1738	1737	3713
T_8 Muriate of potash (split doses)	1796	1620	3952
T_9 Full muriate of potash at sowing	1596	1504	3524
LSD (p=0.05)	214	NS	332

Kaur *et al.,* (2011)

Table 10. Effect of foliar feeding of nutrients on seed cotton yield (kg/ha)

Treatment		2009	2010	2011	**Mean**
T_1	Control	2632	2652	2245	**2510**
T_2	Boron (0.1%)	3068	2743	2504	**2772**
T_3	$ZnSO_4$ (1.5%)	3412	2916	2586	2971
T_4	$MnSO_4$ @ 1.0 %	3343	2967	2569	**2930**
T_5	$MgSO_4$ (1.0%)	3124	3231	2812	**3191**
T_6	$MgSO_4$ (1.0%) + $ZnSO_4$ (0.5%)	3583	3116	2873	**3191**
T_7	$FeSO_4$ (0.5%)	3304	3052	2702	**3019**
T_8	$FeSO_4$ (0.5%) + $ZnSO_4$ (0.5%)	3374	3047	2720	**3047**
T_9	Urea (2%) + DAP (2%)	3118	2985	2666	**2923**

boll development. Foliar application of either MgSO4 (1.0%) in combination of ZnSO4 (0.5%) at flowering and boll development stage help in enhancing the productivity (Table 10).

Irrigation : With increasing concern about exploitation of limited water resources, there is renewed interest in increasing the water use efficiency in cotton. In the Indo gangetic plains of India, significant region is under cotton-wheat cropping system where the soils are sandy and underground waters are brackish. There is great need for judicious use of canal water. The excess usage causes deep percolation resulting in high water table and secondary salinization. The vegetative growth of cotton is directly governed by soil water supply. Profitable seed cotton yields can be achieved only when the vegetative growth is optimum. Excessive vegetative growth reduces the flow of air and exposure to sun light resulting in severe infestation of insects which may lead to lower productivity.

In the cotton region of northern India, the only source of good quality water for irrigation is river water supplied through canals. There is great need for judicious use of canal water and adopt specialized and efficient methods of irrigation that can help in attaining the twin objectives of higher productivity and rational use

Table 11. Seed cotton yield (kg/ha) as influenced by irrigation water quality

Treatments	Seed cotton yield (kg/ha)				
	2001-2002	2002-2003	2003-2004	2004-2005	**Mean**
Canal water of good quality	1553	1897	1736	1594	**1695**
Tubewell water of poor quality	1115	1640	1041	1521	**1329**
Pre sowing with CW and all other irrigations with TW	1307	1753	1252	1500	**1453**
LSD (p=0.05)	255	NS	190	203	**154**

Thind *et al.,* (2010)

of poor quality water. Majority of the cotton growing farmers in the irrigated areas follow flood method for applying irrigation to the cotton. The water related agronomic practices include adoption of water conservation techniques like drip irrigation, furrow irrigation, alternate furrow irrigation etc. need to be adopted.

Critical stages of moisture requirement for cotton : There are many stages during crop cultivation, when moisture is important for its growth. Moisture is critical at the entry level of each stage and if the plant undergoes water stress during these stages, yields are significantly reduced. Following are some points that should be kept in mind with respect to irrigation.

- If water is available for one irrigation, it should be provided at the flowering stage
- If water is available for two irrigations, it should be provided at the flowering and boll formation stages
- If water is available for three irrigations, it should be provided at the seedling, flowering and boll formation stages
- If water is not limited, irrigation should be provided every 15 days and water stagnation should be avoided.

Pre sowing irrigation with good quality water : Dwindling supply of good quality water for irrigation and increasing demand from other users are forcing farmers to use saline/alkali underground waters. Cotton is very sensitive to poor quality water at initial stage of the crop. The application of pre sowing irrigation with poor quality water leads to build up of salinity and sodicity problems and thus unsustainable crop yield. The period of germination and emergence of cotton seedlings is the most critical stage of crop growth, and crop can tolerate higher salinity/sodicity once good quality was substituted for pre sowing irrigation to leach out the salts from seeding zone.

Poor quality water significantly reduced the seed cotton yield (Table 11). However, pre sowing irrigation with canal water and all subsequent irrigations with poor quality tubewell water improved the seed cotton yield upto some extend when compared with tubewell water of poor quality alone

Application of first irrigation : Delay of first irrigation from 28 days after sowing (DAS) to 42 DAS, irrespective of last irrigation, resulted in an increase of 13.3 in mean seed cotton (Table 12). The delay of first irrigation from 28 days to 42 days after sowing resulted in 13.3 per

Table 12. Effect of timing of first irrigation on seed cotton yield (kg/ha)

Time of first irrigation	Seed cotton yield (kg/ha) 2000	2002	2003	**Mean**
28 DAS	1417	1110	1825	**1451**
35 DAS	1449	1121	1985	**1518**
42 DAS	1529	1270	2132	**1644**
LSD (p=0.05)	103.4	80.7	126.3	

Buttar *et al.,* (2007)

Table 13. Water expense efficiency (kg/ha/cm) as influenced by timing of first irrigation in cotton

Time of first irrigation	Water expense efficiency (kg/ha/cm) 2000	2002	2003	**Mean**
28 DAS	22.0	14.0	18.9	**18.3**
35 DAS	23.8	14.1	203	**19.4**
42 DAS	27.7	16.1	21.2	**21.7**

Buttar *et al.,* (2007)

Table 14. Seed cotton yield and water use efficiency as affected by irrigation methods

Irrigation methods	Seed cotton yield (kg/ha)	Water use efficiency (kg/ha/cm)
Border	1339	43.6
Each furrow	1390	51.7
Alternate furrow alternately	1484	70.4
Alternate furrow throughout	1464	71.9

Aujla *et al.,* 2001

cent increase in seed cotton yield and 18.6 per cent higher water expense efficiency (Table 13).

The initiation of irrigation at 28 days restricted root growth to surface layers which remained confined to 0-60 cm soil depth throughout the cropping season. On the other hand, higher root mass density and vertical distribution up to 180 cm was observed when the initial irrigation was applied at 42 days after sowing.

Furrow irrigation: Furrow irrigation method helps in reducing significant amount of irrigation water as compared to flood irrigation. The crop is generally grown on ridges/beds and irrigation is provided in furrows .

Alternate furrow alternately gave maximum seed cotton yield as compared to other methods. The highest water use efficiency was achieved in alternate furrow throughout (Table 14).

Alternate furrow irrigation for poor quality water : The underground water is of poor quality in majority of cotton growing areas of north India. There is need to adopt specialized and efficient methods of irrigation that can help in attaining the twin objectives of higher productivity and rational use of poor quality water.

The application of poor quality tubewell water significantly reduced the seed cotton yield in check basin and each furrow. The application of pre sowing irrigation with canal water improved the seed cotton yield and water use efficiency when compared with tubewell alone (Table 15 and 17). However, the yield increase was significantly only in alternate furrow irrigation and the yield obtained was at par with the seed cotton yield obtained under alternate furrow irrigation with canal water. The implementation of alternate furrow irrigation improved the water use efficiency without any loss in yield, thus reduced the use of irrigation water especially under poor quality irrigation water with pre-sowing irrigation with canal water. This technology helps in reducing the deteriorating effects on soil quality parameters under calcareous soil conditions (Table 16).

Table 15. Seed cotton yield (kg/ha) during different years of experimentations influenced by irrigation water quality and methods of irrigation

Treatments		Seed cotton yield (kg/ha)				Mean
		2001-2002	2002-2003	2003-2004	2004-2005	
CW	CB	1553	1897	1736	1594	**1695**
	EF	1375	1523	1593	1960	**1613**
	AF	1208	1667	1613	1717	**1551**
TW	CB	1115	1640	1041	1521	**1329**
	EF	1109	1434	970	1720	**1308**
	AF	1219	1478	580	1438	**1179**
CW_{Psi}+TW	CB	1307	1753	1252	1500	**1453**
	EF	1313	1521	1222	1480	**1384**
	AF	1439	1636	1251	1525	**1463**
	LSD (p=0.05)	255	NS	190	203	**154**

Thind *et al.,* (2010)

Table 16. Soil pH and electrical conductivity after 2 and 4 years of experimentation as influenced by irrigation water quality and methods of irrigation

Treatments	pH	Electrical conductivity (dS/m)			
		2003	2005	2003	2005
CW	CB	8.61	8.56	0.175	0.148
	EF	8.58	8.51	0.167	0.139
	AF	8.52	8.54	0.161	0.136
TW	CB	8.89	8.99	0.228	0.302
	EF	8.78	8.92	0.217	0.291
	AF	8.71	8.94	0.221	0.289
CWpsi + TW	CB	8.85	8.94	0.219	0.274
	EF	8.69	8.91	0.221	0.263
	AF	8.67	8.89	0.208	0.256

Thind *et al.,* (2010)

Drip irrigation method : Drip irrigation results in saving water and enhances the water use efficiency of cotton to a great extent. Regulated and slow application of irrigation water through emitters/orifices enables the water to reach the root zone of plants at frequent intervals. Drip irrigation has been found to enhance the yield of cotton significantly. Drip irrigation under normal sowing rsulted in an increase in seed cotton yield of 14 and 32 per cent during first and second year of study at Bathinda, when same quantity of water is applied through drip and check basin (Table 18). Drip irrigation under dense paired sowing in which quantity of water applied was 75 per cent as compared to drip under normal sowing produced same yield during first year and 27 per cent higher yield during second year. The results showed that dense paired sowing produced highest seed cotton yield and water use

Table 17. Water use efficiency (kg m-3) during different years of experimentation as influenced by irrigation water quality and methods of irrigation

Treatments		Water use efficiency (kg/m^3)				**Mean**
		2001-2002	2002-2003	2003-2004	2004-2005	
CW	CB	0.178	0.174	0.218	0.158	**0.182**
	EF	0.166	0.147	0.225	0.209	**0.187**
	AF	0.177	0.165	0.250	0.197	**0.197**
TW	CB	0.130	0.151	0.132	0.148	**0.140**
	EF	0.140	0.130	0.139	0.180	**0.147**
	AF	0.176	0.144	0.090	0.161	**0.143**
CW_{Psi}+TW	CB	0.149	0.161	0.158	0.147	**0.154**
	EF	0.164	0.150	0.169	0.154	**0.159**
	AF	0.200	0.176	0.188	0.171	**0.184**
	LSD (0.05)	0.0149	0.0144	0.0138	0.0129	**0.0113**

Thind *et al.,* (2010)

Table 18. Effect of method of planting and quantity of irrigation water on seed cotton yield and water use efficiency in cotton (2003 and 2004)

Treatments	Seed cotton yield (kg/ha)		Irrigation water (cm)		Water use efficiency(kg m^{-3})	
CB 0.4	2003	2004	2003	2004	2003	2004
Normal Sowing	2551	1070	301	284	0.242	0.160
Dense paired	3199	1738	300	284	0.296	0.226
Normal planting	2002	997	300	284	0.191	0.133
D0.4						
Normal Sowing	2902	1414	301	284	0.276	0.188
Dense paired	2946	1794	226	213	0.297	0.257
Normal planting	2585	1207	151	142	0.291	0.204
D0.3						
Normal Sowing	2631	1363	226	213	0.277	0.199
Dense paired	2691	1741	169	160	0.288	0.272
Normal planting	2285	1112	113	107	0.271	0.201
LSD (0.05)Methods	268	148				
Water quantity	147	76				

Rainfall during 2003: 523 mm during 2004: 315 mm Aujla *et al.,* (2008)

efficiency along with reduction in cost owing to lower number of laterals required.

Use of amendments in poor quality water : In the Indo gangetic plains of India, significant region has brackish underground water and the excessive use of it causes salinization and deterioration in soil quality. On the basis of 7 years long experiment conducted at Bathinda, the results showed that the application of saline sodic water decreased the seed cotton yield by 20.7 per cent as compared to good quality canal water. Among the different amendments, gypsum and farm yard manure

Table 19. Seed cotton yield as influenced by different organic and inorganic amendments (2004-2010) (Mean of 7 years)

Treatment	Seed cotton yield (kg/ha)
Canal water	2311
CW+Zn+FYM+gypsum	2529
CW/TW alternately	2168
SSW along	1832
SSW+Zn	1960
SSW+gypsum	2107
SSW+FYM	2084
SSW+Zn+gypsum, FYM	2153
LSD (p=0.05)	262.2

Buttar *et al.*, 2017

were more effective in mitigating the adverse effects of saline sodic water (Table 20). Seed cotton yield reduction was 9.8 per cent with addition of Farm Yard Manure and remained only 8.8 per cent with addition of gypsum as compared to good quality water. However, when saline sodic water was used alternately with good quality canal water, the recorded reduction was only 6.1 per cent (Table 19).

Table 20. Effect of quality of irrigation and amendments on soil pH and EC after 7 years of experimentation

Treatments	pH		Electrical conductivity (dS/m)	
	0-15 cm	15-30 cm	0-15 cm	0.30 cm
Canal water	8.40	8.40	0.216	0.183
CW+Zn + FYM+ gypsum	8.33	8.34	0.203	0.179
CW/TW alternately	8.79	9.12	0.240	0.237
SSW along	9.15	9.40	0.335	0.624
SSW + Zn	9.12	9.30	0.429	0.448
SSW + gypsum	9.01	9.23	0.419	0.436
SSW + FYM	9.13	9.30	0.478	0.534
SSW + Zn + gypsum, FYM	9.13	9.27	0.419	0.309
LSD (p = 0.05)	0.06	0.07	0.0675	0.0384

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Organic seed production and organic crop improvement: Challenges and opportunities

P.P.SHASTRY* AND G.K.KOUTU
R.V.S.K.V.V. College of Agriculture, Khandwa - 450 001
**E-mail : shastrypp@yahoo.com*

Organic seed is a crucial link in the chain from research, breeding, seed production to organic production. The aim is to provide the grower with appropriate and healthy seeds at a reasonable price. With organic seed the grower an complete the chain with organic input; for seed producers organic seed is the start for selecting and breeding appropriate organic varieties. Professional organic growers are making high demands on the quality of seeds. Compared to conventional seed production there are several aspects that deserve extra attention.

Since no treatment with chemicals is possible to control diseases or pests, it is important to find the optimal climate for a favourable development of the seed crop. For the same reason it can be a solution to find a region where the crop is not grown widely. Diseases and pests are then prevented because infection is unlikely.

Depending the crop or species, a wide range of cultivation methods can be developed to improve seed production. For example, like planting in a wider spacing for drier microclimate in the crop, drip irrigation instead of watering over the crop,, moderate fertilization to stimulate a generative plant development etc.

Diseases and pests: One have to distinguish between diseases, which are affecting the seed crop, and diseases which are seed transmitting and therefore seed born. The best way of precaution is to avoid a weak crop by improving cultivation conditions favourable for organic seed production. When diseases or pests appear, they can be treated with biological pesticides or predators. Seed transmitted diseases are a serious problem, since disinfection afterwards is often impossible. Such diseases must be avoided. When seeds are nevertheless infected, disinfection of the seeds is in some cases possible and effective by warm water treatment.

Weeds: Weed cannot be eliminated by chemical herbicides, so they must be avoided or removed mechanical or by hand. When there is much weeds in the seed crop, the microclimate can get humid which causes fungal diseases. Like wider plant spacing, a well weeded seed crop improves the quality of the seed. Secondly weed causes contamination with weed seeds in the harvested seed lots, which may be hard to clean. Especially here, prevention is better than cure.

Seed processing: Threshing, cleaning and grading organic seeds show no differences with conventional seeds, since only mechanical machines are used. For pelleting or priming seeds some specialized companies have developed certified organic procedures with only natural compounds and elements. With the exception of chemical treatments and coatings, almost all seed techniques are available for organic seed to meet the professional standards for high quality.

Crop improvement for organic agriculture: The need for increased sustainability of performance in crop varieties, particularly inorganic agriculture, is limited by the lack of varieties adapted to organic conditions. Hence, the crop improvement needs of organic production systems present a unique set of challenges to plant breeders. Organic consumers in some cases have different varietal preferences than consumers of conventional products. It is logical, therefore, to expect that a variety that performs well when grown under organic management and marketed to organic consumers may have a different set of traits than a variety that performs well under conventional management and is marketed conventionally. Seed companies, university-based plant breeders, private breeders and farmers are beginning to develop varieties in and for organic systems

The need for organic plant breeding : Over the last fifty years plant breeding has largely developed in response to the demands of intensive agricultural production, striving for increased yields, storability, and cosmetic perfection under a system of management based on artificial fertilizer nutrition and the use of pesticides. Until now, organic farmers have made use of these traditionally bred varieties but these varieties do not truly fulfill the needs of organic productions. The seeds and vegetative multiplication material, usually results of traditional and conventional breeding programs, are not fully adapted to the conditions of organic agriculture and sometimes unable to fulfill consumers expectation from an organic variety. Thus appropriate organic plant breeding will serve to develop improved varieties for organic systems without jeopardizing the ethical and environmental intrigrity of organic agriculture.

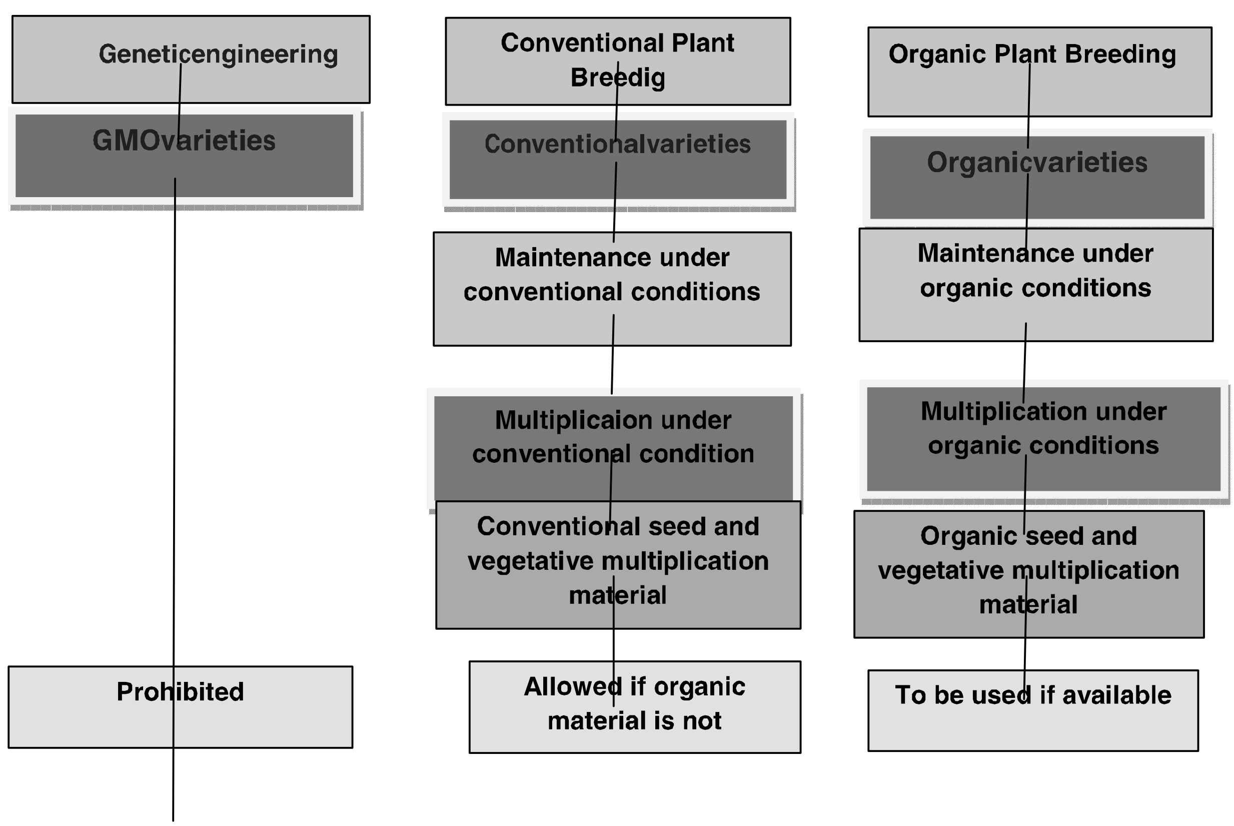
The greater dependence of organic agriculture on ecological rather than chemical approaches is opening up many different and novel ways, potentially, of dealing with both increasing variability related to climate change, and the costs of fossil fuel-based control of the environment.

Organic agriculture relies on measures that stimulate the resilience and self regulating ability of the farming system, *e.g.* by enhancing biodiversity (at the farm, crop and genetic level) and soil fertility with a high level of organic matter and wide crop rotation, and by closing the nutrient cycle as much as possible (*e.g.* Mader *et al.,* 2002). This approach implies that all parts of the agricultural system including food, water and energy, are regarded as a whole, interactions, and feedback among all parts are considered in optimizing that whole.

Required characteristics in breeding for organic agriculture : Physiological and agronomic research, together with ûeld experience, provides insights into the range of characters needed for organic agriculture. These include efficient use of a wide range of nutrients and water, weed competition, disease and pest resistance, quality for end use as well as yield and yield stability. The list of potentially important characteristics is enormous and impracticable to consider one by one. As pointed out above, new methods can help in combining traits and their interaction with the environment, but a further few considerations may also be valuable

- Try to identify pleiotropic characters that may have a positive value for a wide range of physiological needs. This could include, for example, vigorous early growth which is valuable in terms of weed competition, uptake of nutrients when they are available and competition particularly against soil borne disease and pests.
- Concentrate on major characters that integrate many minor and variable characters, such as yield of grain, yield of protein and yield of straw, or their equivalents in other crops.
- To identify characters that can contribute to the crop rotation as a whole rather than only to the cereal crop.

Breeding strategies for organic crop varieties : The diversity of agro-ecological and climatic conditions together with different cultural practices in organic ariculture represent a considerable challenge for breeders (Murphy *et al.,* 2005). Breeding for organic agriculture needs speciûc strategies that utilize genetic diversity to support or enhance the wide-ranging conditions and farmer practices.



Overview on the different levels of breeding, maintenance, and multiplication

These aspects have seldom been investigated in the context of breeding crops for organic agriculture but some lessons can be drawn from experiments in various low-input/stressed compared to conventional/non stressed environments.

Breeding for organic agriculture must be considered in the context of whole system management, through rotation and other agronomic practices that can help to buffer the system and its components against abiotic and biotic variability and stress. In this sense, selection of crops for use in organic agriculture should be driven by the needs of the whole system as well as the end use. For example crop nutrition and weed competition can both be helped by the structure of the rotation together with appropriate agronomic interventions. Crop varieties should then be selected according to different priorities in the farming system. Difficult challenges will no doubt arise because of interactions or trade offs between different selection criteria. For example, a narrow approach focused on weed control may be disadvantageous if it neglected other important criteria such as disease control. A more holistic approach in which there is integration of different system components, perhaps including selective competition among the plant components, is highly desirable. Diversity is the basis of natural selection and evolution and was the norm in agriculture until the last hundred years or so when modern genetics and plant breeding enabled farmers and end-users to exploit the beneûts of uniformity.

Considering these and other aspects, we recognize a number of key questions for the development of strategies appropriate to breeding for organic agriculture:

- Which genetic resources are appropriate?
- Should genotypes be selected for wide or speciûc adaptation?
- Stability of performance over time?
- What are the most suitable selection environments?
- Can decentralised approaches add to centralised breeding?
- Can participatory approaches add to centralised breeding?
- What is the most appropriate crop structure?

Genetic resources : In addition to the resources available from modern agriculture, there is a need to identify appropriate genetic resources among the older varieties or landraces either for direct use or as potential parental lines in breeding programmes for better adapted varieties (Hoisington *et al.,* 1999; Hammer and Gladis, 2001). Evaluating and exploiting accessions from gene banks can be of use because characteristics required for organic, low input farming might have disappeared by selection under modern, high-input conditions, such as low-input tolerance and deep or intensive root architecture. Many non-proût organisations dealing with in situ conservation of genetic resources maintain their populations under organic conditions (Negri *et al.,* 2000).However, despite the availability of large amounts of genetic resources, their real use in organic farming is still limited.

Wide or specific adaptation : Target environments can be sub divided into homogeneous sub-regions in which genotype by location (GxL) interactions are minimized and within sub regions genetic variances are increased (Comstock and Moll, 1963; Ceccarelli, 1989). However, the dilemma is that selecting the best genotype over the undivided region may or may not be more efûcient than selecting the different genotypes which are best adapted to each subregion. Furthermore, the approach to selection should be considered in relation to the global, regional and local market categories noted above and corresponding to the commercialization of varieties from widely to speciûcally adapted. To adapt these results to breeding for organic agriculture, it is necessary to identify the range of targeted environments and to carry out experiments in different organic agriculture environments assessing heritability, genetic correlations across environments and the different variance components. Moreover, it might be more appropriate to deûne the sub-regions including farming practices such as livestock on farm.

Stability over time : Varieties in organic agriculture should have a broad range of adaptability to cope with a large variability in environmental conditions; they need to have various ‘buffering capacities’ to maintain performance. This means that varieties for organic agriculture must not have any severe local weakness in any trait relevant for growth and productivity. Increase and stability of productivity of a wheat variety depend on its individual buffering. In fact, wheat has a high degree of buffering capacity within the genotype (Udall and Wendel, 2006)

Participatory approaches : Participatory plant breeding (PPB) can be deûned as the involvement of several partners (*e.g.* farmer’s, traders, consumers, breeders, researchers) in the selection process and is based on the complementarity of skills and knowledge of each partner. As organic systems are characterized by a wide range of environments and management systems and by a diversity of potential markets a more direct involvement of larger numbers of actors can raise more issues for crop characterization than may be considered in conventional breeding (Desclaux *et al.,* 2008). Such issues may include ease of harvest and storage, taste, cooking and nutritional qualities, rate of crop maturity; weed competitiveness, suitability of crop residues as livestock feed and harmony in the plant growing process (Morris and Bellon, 2004).

Crop structure : More diverse structures such as mixtures or populations which allow for complementation and compensation among different plant neighbors. This is particularly important for the more variable environments encountered in organic agriculture. Maintaining genetic diversity within a “variety” might allow for more buffering capacity at both the spatial and the temporal levels. For example, variety mixtures can provide functional diversity that limits pathogen and pest expansion thus stabilizing yields under disease pressures.

Suitability of the breeding and multiplication techniques for organic agriculture : Criteria could be derived from the basic principles of organic agriculture and translated to plant breeding.

Three basic principles in organic agriculture should be considered first

- Closed production cycles
- Natural self regulation
- Biodiversity

In order to draw up a framework for an organic breeding system these principles could be extrapolated to the level of plants. The three criteria for organic plant breeding then are:

- natural reproductive ability of plants
- ability to adapt to organic conditions
- genetic diversity with respect for natural species authenticity and species characteristics.

The future development of organic agriculture and plant breeding : There is no doubt that field trials to compare varietal performance under organic and conventional conditions have provided valuable information, confirming that there can be both differences and similarities, with some varieties showing consistent adaptation to organic agriculture or to conventional agriculture or to both. However, it is also clear that the kinds of difference and their scale are dependent on many factors, the most important being the exact type of organic agriculture and conventional agriculture system. For this reason, it may be important to resist the temptation to continue with trials comparing variety performance in organic agriculture and conventional agriculture system, unless there is a highly specific objective. Overall, for the two kinds of agricultural system, it is more important to recognize the structure of the systems and the impacts of the different inputs that are used or not used. Moreover, it is crucial to recognize how these inputs are changing, or how they will change, as climate and resource availability change. Concerning organic agriculture specifically, it is clear that the application of an ecology based approach to farming implies a primary concern for the interactions among the selected characters, and among whole farming system. Furthermore, the inherently more variable conditions of organic agriculture needs particular attention to stability of production, which means that adaptation needs to be applied among many different localities rather than over single, large geographical areas. Such an approach can be achieved only by using a range of different approaches to the breeding process (decentralisation, participation etc.) and to the forms of crop populations that are used (variety mixtures, populations, inter crops). For all of these approaches, there is a need to ensure that more and novel genetic resources are fed into the start of the breeding processes. In other words, success in any form of local selection is dependent on a broad starting array of genetic resources.

Currently, organic farmers are making use of the most appropriate varieties produced in conventional programmes, together with a relatively small amount of material bred specifically for organic systems. This amounts to a somewhat small input. However, important changes appear to be on the way, from three sources. The first relates to developments in the applications of ecology to organic agriculture, as indicated above. The second relates to other developments in plant science, particularly through a better understanding of selection for efficient use of resources also as discussed above. The third change lies in the practical observation that varieties bred under organic conditions may be more efficient in resource terms, and higher yielding, when used in conventional agriculture (Burger *et al.,* 2008).

For organic agriculture specifically, cooperation among all kinds of breeding efforts and testing in a widely distributed trial network on organic farms would enable organic farmers to choose, more rigorously, the varieties best suited to their local conditions. A combination of all of the strategies indicated above would lead to exploitation of the maximum appropriate genetic diversity for organic farming systems.

Future task for plant breeders

Ø Evaluation of existing varieties/breeding lines (both older and newer ones) for characteristic traits required in organic farming systems.

Ø Organic variety trials for varieties of crops, which were not yet widely tested for their performance under organic management practices..

Ø Research and development of seed production, processing and conservation breeding for the organic agriculture.

Ø Selection of breeding material under organic conditions. Evaluation and development of variety mixtures.

Ø Evaluation of breeding methods for organic breeding.

Ø Developing alternatives for non suitable breeding methods.

Role of ISTA and seed science in assuring organic seed production with high quality: Seed quality is of basic importance to farmers. The International Seed Testing Association was founded in 1924, with the aims at providing farmers and producers with uniform tests for analysis of seed quality. through accredited seed testing laboratories worldwide. To accomplish this ISTA has setup rules, standardizes methods and provides training of seed testing staff. The main aspects of seed quality concern trueness of the variety, purity, germinability, vigour and health. For organic farming an additional aspect is the seed production under organic conditions. Unfortunately, at present, organic production bears a great risk of contamination with weed seeds and infection with pathogens. These difficulties contribute also to higher seed production costs. In some cases disease-free production is not possible and additional non-chemical treatments are needed. These methods eradicate the pathogens without harming the seeds. Sowing in organic fields can benefit from fast germinating seeds with high vigour and increase uptake of nutrients and competition with weeds.

Seed quality testing : High quality seed is the basis of crop production. Quality of seeds has many aspects; these include trueness of the variety, purity of seed batch, its germination and emergence potential (vigour) and seed health. Uniformity in seed quality testing is very important and the main aim of the International Seed Testing Association> In ISTA presently 75 member countries work together in seed testing and 155 laboratories are member of this internationally operating association. ISTA also publishes the International Rules for Seed Testing. Organization like OECD, EU and ISF refer to ISTA rules in their standards. The performance of accredited laboratories is constantly be monitored through the international operating ISTA Proficiency Test. The results of the testing of the seed lot are reported on the ISTA International Certificate..

OECD varietal certification : The Organization for Economic Cooperation and Development (OECD), established in 1958 with its headquarters in Paris also provides an international framework for the certification of agriculture seed moving in agriculture trade. The main objective of the OECD Seed Schemes is for the varietal certification of seed to encourage the use of "quality guaranteed" seed in participating countries. Since October 2008, India is member of the OECD Council. Including Indai, 58 countries from Europe, North and South America, the Middle-East, Asia and Oceania participate in the OECD Seed Schemes (Trivedi, 2012). A total of 109 varieties of 20 crops from India have been enlisted in the OECD list of varieties

Organic seeds : For organic farming additional aspects of seed quality are important, especially the production of seeds under organic farming conditions and the restriction in methods that can be used for the treatment of the seeds Rule for organic crop production are made by international bodies such as the International Federation of Organic Agriculture Movements (IFOAM) and the European Union (Regulation 2092/91). Certification for organic production is performed by appointed national organizations that certify seed on the quality aspects.

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Recent approaches in cotton weed management

P.NALAYINI* AND K.SANKARANARAYANAN
Central Institute for Cotton Research, Regional Station, Coimbatore -641003
**E-mail : nalayiniganesh@gmail.com*

Cotton crop is subjected to severe weed pressure due to wider spacing and slow initial growth. Though, first 60 days of cotton growth is more critical in terms of cotton yield, it is essential to keep the cotton field weed free up to harvest to produce clean cotton. The incessant rain hampers the weeding operation and many times not possible to enter the black cotton soil for weeding resulting in delayed weeding and loss of crop. Weeds are being managed by cultural, mechanical, chemical and integrated approaches. The recent successful approaches for managing weeds are discussed here.

Table 1. Weed dry matter production (g/m^2) due to HDPS cotton

Spacing (cm)	2011-2012	2012-2013
30x30	4.55 (44)	4.34 (75)
45 x30	4.81 (123)	4.55(93)
60x30	5.00 (148)	4.74 (112)
90x30	5.17 (176)	4.87(128)
CD (p=0.05)	0.38	0.30
Interaction	NS	NS

Figures in parenthesis are original .subjected to Log x +2 for statistical analysis

1.High density planting system (HDPS): Under HDPS system, cotton crops compete with weeds over widely spaced cotton. HDPS method of planting is a Brazil technology and successfully demonstrated to our Indian condition and weeds problem is very much reduced under this method as compared to conventional method of planting. Studies conducted at Coimbatore on HDPS revealed that the weed density and weed dry matter production was less at closer spacing of 30 x 30 and 45 x 30 cm as compared to widely spaced cotton (ArunVenkatesh *et al.,* 2017).

2 Stale seed bed technique: : In this approach, one month in advance of cotton planting, ridges and furrows are formed and irrigation is given. On receipt of moisture, the weeds seeds are made to germinate and the young weed seedlings are targeted after 2 weeks by spraying with mixture of pendimethalin 1.0 kg (to kill the germinating weeds at the time of spraying and kills subsequently by residual action) ,glyphosate1.0 kg kills the germinated weed seedlings thereby reducing the weed pressure during actual cotton growing period (Nalayini and Suveetha,2016)

3.Growing of leguminous cover crops : This method could be followed in combination with stale seed bed technique for better weed control. Normally cotton is grown in one side of the ridges and the other side of the ridges are used to grow any one of the leguminous cover crops like sun hemp, forage cowpea, thornless mimosa or desmanthus. The legumes smother weeds and at the same time give legume effect to soil and cotton. The live mulch of legume is uprooted and spread around 45 DAS which enriches the soil (Nalayini *et al.,* 2017).

Table 2. Weed count, weed dry matter production and weed control efficiency due to stale seed bed technique in cotton

Weed control treatments	Weed count on 35- 40 DAS*	Weed DMP (g/m^2) 35- 40 DAS	Weed control efficiency (%) 35-40 DAS
SSBT glyphosate 1.0 kg - HW	132.3	54.4	54.1
SSBT pendimethalin 1.5 kg- HW	40.6	21.5	81.9
SSBT pendimethalin 1.0 kg + glyphosate 1.0 kg - HW	30.9	17.6	85.2
Pre emergence weed control with pendimethalin 1.5 kg - HW	53.59	30.5	74.4
SSBT and manual removal of weeds(thrice)	44.95	29.9	74.8
Unweeded control	555.25	118.5	-
CD (p=0.05)	0.56	4.67	

Weed count was subjected to square root transformation for statistical analysis

4. Herbigation technique : Application of herbicides through irrigation water is called herbigation, can be very efficiently done through drip irrigation. In cotton, pre emergence herbicides can manage weeds only up to 30 DAS (Nalayini and Kandasamy,2001) and controlling the late emerging weeds is really a challenge. Dadari and Kuchinda 2004 reported application of post emergence herbicides to supplement pre-emergence herbicides to have desired weed control in Cotton. As we have a very few selective post emergence herbicides, conventional spraying method for post emergence spraying is very difficult and often weeds which emerge close to cotton crop escape. Nalayini *et al.,* 2013 reported herbigation method of applying residual herbicides through drip system was more efficient than conventional spraying for post emergent weed killing. The weed dry matter production at 60 DAS revealed that herbigation recorded significant reduction in weed growth (41.02g/m^2) than in conventional spraying (51.08 g/m^2),the significant reduction in weeds growth under herbigation as compared to conventional spraying was reflected in reduced dry matter accumulation by weeds ,reduction in depletion of nutrients by weeds and favourable micro climate to crop causing 14.3 per cent enhanced seed cotton yield than conventional method of spraying. Excellent weed control with site specific recommendation of metolachlor and metribuzin through herbigation has been reported by Eberlen *et al.,* 2000.

5. Polyethylene mulching : Covering the soil with plant parts like, leaves, stem twigs etc., to control evaporation and to manage weeds is an age old practice. However, to avoid transportation cost and drudgery, live mulches are being recommended as a weed control tool. Now, plastic mulches are available which can be used as an efficient tool for managing weeds beside moisture conservation and enhancing the yield of cotton based system. Extensive studies were undertaken at Central Institute for Cotton Research, Regional Station, Coimbatore to standardize the thickness, colour of mulches, spreading technique, planting technique etc.,

Nalayini *et al.,*(2009) reported complete

Table 3. weed count, yield attributes and seed cotton yield as influenced by stale seed bed technique and leguminous cover crops

Treatments	Weed count/m^2		Bolls/ plant	Boll weight (g/boll)	Seed cotton yield (kg/ha)
	30 DAS	80 DAS			
SSBT followed by *Mimosa invisa* + one HW	67.25	174	28	6.15	2147
SSBT followed by *Crotalaria juncea* + one HW	63	182	33.4	6.08	2368
SSBT followed by *Sesbania aculeata*+one HW	46.75	171	24.8	6.28	2112
SSBT followed by *Vigna unguiculata* + one HW	49.75	158	34	6.03	2494
SSBT followed by *Desmanthus virgatus*+one HW	74	220	28.2	5.92	2275
pendimethalin 1.0 kg as pre emergence+HW (Twice)	198.7	312	24.9	5.82	2016
CD (p=0.05)	37.33 **	2.908 **	3.49	NS	226.58

Weed count was subjected to square root transformation for statistical analysis

control of weeds except *Cyperus rotundus* in cotton using polyethylene mulch of 30 micron thickness. The beneficial effects of plastic mulch for enhanced water and fertilizer utilization and weed control (Fortnum *et al.,* 2000) has been reported. The use of polyethylene mulching though used widely in high value vegetable crops, its use in cotton is so far limited and catching up in recent times.

6. Herbicide rotation : We have choice for selective pre emergence herbicides to be used but selective post emergence weed killers are very few for cotton. Repeated use of same chemical in rotation is not being encouraged to avoid development of resistant weeds. Vargas and Wright (2005) suggested rotating herbicides with different modes of action to delay the development of resistance in weeds. The choice of herbicides for broad spectrum weed control and at the same time delaying the development of herbicide resistance in weeds is crucial. Application of , pendimethalin 1.0 kg as pre emergence herbicide followed by one hand weeding at 35- 40 DAS and mixture of pyrithiobac sodium 50g + quizalofop ethyl 50 g on 60 DAS was found to be efficient and more economical for managing weeds of irrigated cotton (Nalayini *et al.*, 2012)

7. BIOTECHNOLOGICAL APPROACH

a) Herbicide tolerant genetically modified crops : Recently, genetically modified crop varieties with two biotech traits (stacked trait crops) have been made commercially available and currently cultivated in several countries. Development in plant genetic engineering and knowledge of biochemical action of herbicides on plants spurred innovative approaches to engineer crops to withstand herbicides. These strategies usually involve isolation and introduction of a gene from other organisms, mostly bacteria which is able to overcome the herbicide induced metabolic blockage.Tolerance to herbicide glufosinate (Basta ^{R}) is conferred by the bacterial gene bar, which metabolizes the herbicide into non-toxic compound (Thompson *et al.,*1987). Glyphosate resistance is achieved by the introduction of either *Agrobacterium* gene from CP_4 that codes for a glyphosate-insensitive version of the plant enzyme,EPSP Synthase or gox gene from *Achromobacter,* which codes for a glyphosate oxireductase in the breakdown of glyphosate. HTGM crops are gaining farmers' acceptance because of several advantages such as increased flexibility to manage problem weeds, prevention of multiple use of herbicides, reduction in total herbicide use, greater adoption of conservation tillage, less herbicide carry over etc.,

b) Concerns and apprehensions of HTGM crops : The use of herbicide resistant crops undermines the possibilities of crop diversification. In countries like India where multiple crops are grown such as under intercropping system wherein compatible intercrops are grown with cotton, the use of HTGM technology is not possible and non selective herbicides may wipe out all vegetation except the HTGM crops, Escape of transgenes from HTGM crops to weeds causing development of herbicide resistance in weeds, shift in weed flora etc., There is potential for herbicide resistant varieties to become weeds in other crops (Holt and Le Baron,1990).Also, strategies have been defined to delay development of herbicide resistance weeds in the case of conventional crop varieties. These include, combined or sequential use of herbicides with different mode of action, crop rotation, integrated weed control etc., In the case of genetically engineered HTGM varieties, these strategies are less relevant. When the herbicide could be applied at various stages of crop growth, farmers may not opt for integrated weed control measures. Similarly, when different crops carry

Table 4. Weed DMP, weed control efficiency, nutrient depletion by weeds on 60 DAS and seed cotton yield as influenced by herbigation and weed control treatments

Treatments	Weed DMP (g/m^2)		WCE (%)	Nutrients depletion by weeds (kg/ha)			Seed cotton yield (kg/ha)
	30 DAS	60 DAS		N	P	K	
Application method (M)							
Herbigation	15.15	41.02	88.4	17.33	7.05	19.22	3998
Conventional spraying	12.77	51.08	86.5	21.80	8.54	23.92	3498
CD (p=0.05)	NS	4.07		1.75	0.647	1.75	496.4
Weed control treatments (W)							
Pendimethalin 1.5 kg (pre)+ HW 30,60 DAS)	14.2	35.98	84.2	11.39	3.97	11.86	3949
Pendimethalin 1.0 kg + metolachlor 1.0 kg (pre) + HW (30,60 DAS)	13.7	32.73	85.7	9.96	4.11	10.76	4294
Pendimethalin 1.0 kg (pre) followed by HW (30 DAS),metolachlor 1.0 kg (30 DAS)	17.5	13.95	94.0	4.14	1.93	4.57	4669
Handweeding (20,40 and 60 DAS)	3.2	32.48	86.0	9.50	3.79	11.22	4821
Unweeded control	35.4	231.8		62.83	25.19	69.43	817.3
CD (p=0.05)	5.95	7.85		1.36	0.249	1.39	460
Interaction	NS	NS		NS	NS	NS	NS

Table 5. Weed count, weed DMP and weed control efficiency as influenced by weed control treatments on 75 DAS

W control Treatments	Weed count /m²	Weed DMP (g/m²)	WCE (%)
Pendimethalin1.0 kg (pre) – HW(35-40 DAS) – fluazifop-butyl 125 g 60 DAS	63.7 8.04)	22.7	77.39
Pendimethalin1.0 kg (pre)-HW(35-40 DAS) - fenoxoprop 100g 60 DAS	49.2 (7.09)	19.9	80.24
Pendimethalin 1.0 kg(pre) –HW(35-40 DAS) - quizalofop ethyl 50 g 60 DAS	49.5(7.11)	20.1	80.02
Pendimethalin 1.0 kg(pre) - HW(35- 40 DAS) + pyrithiobac sodium 75 g 35- 40 DAS	25.6 78.3 (8.90)	74.55	
Pendimethalin1.0 kg (pre) – HW (35-40 DAS) – pyrithiobac sodium 50 g +fluazifop butyl on 60 DAS	41.7 (6.53)	20.8	79.3
Pendimethalin1.0 kg –HW(35-40 DAS) - Pyrithiobac sodium 50 g +Fenoxoprop 50 g 60 DAS	33.6 (5.88)	17.8	82.30
Pendimethalin 1.0 kg – HW(35-40 DAS) - Pyrithiobac sodium 50 g + quizalofop ethyl 50 g 60 DAS	29.6 (5.53)	18.0	82.14
Pyrithiobac sodium 75 g (pre) - HW and pendimethalin 1.0 kg 35-40 DAS	83.4 (9.19)	37.2	63.02
Pendimethalin 1.0 kg (pre)-Paraquat 600 g 35-40 DAS	87.2 (9.39)	39.2	61.04
Pendimethalin 1.0 kg (pre)-glyphosate 1.0 kg 35-40 DAS	85.2 (9.28)	39.3	60.89
HW thrice (20,40,60 DAS)	18.4 (4.40)	13.4	86.64
Unweeded	290 (17.06)	100.6	-
CD (p=0.05)	0.417		

Figures in parenthesis are square root transformed values for statistical analysis

engineered resistance to the same herbicide, use of different herbicides may not remain an option .Once the weeds develop resistance, through either acquisition of the gene from the HR variety or by mutation, they will remain resistant against the herbicide. Replacement of the herbicide is the only option in such a scenario.

CONCLUSION

Integration of cultural, mechanical methods with judicious use of chemical methods of weed control is recommended for effective, economical and environmentally safe weed management in cotton. In future, controlling weeds with micro encapsulated herbicides will be the potential technology to achieve season long weed control with lesser costs and risks to the environment.

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Pest management in cotton for higher productivity – Journey of five decades

A K DHAWAN*

Former Head Department of Entomology, Punjab Agriculture University, Ludhiana-141 004

**E-mail: ashokdhawan@yahoo.com*

Cotton is the most economical cash crop for traditional cotton growers, but often cotton growers face decline in productivity, high cost of production and lower cotton price. In order to survive, productivity should be increased and cost of production should decrease. Cotton is susceptible to a wide range of insect pests and the efficient pest control can play a significant role. Existing options are costly and inefficient, which resulted in economic crisis in the cotton belt, leading to some suicidal deaths. The cultivation of high yielding varieties, increase in area under irrigated cotton and better pest management due to availability of toxic and effective insecticides particularly, synthetic pyrethroids resulted in higher productivity during 1990's. However, the development of cotton pest management practices relies heavily on insecticides. *Helicoverpa armigera* resistance to chemical pesticides resulted in the unprecedented pest densities of the early 1995s. Transgenic cotton that expresses a gene derived from the bacterium *Bacillus thuringiensis* (*Bt*) has been deployed for combating *H. armigera* since 2002 and have resulted in a drastic reduction in insecticide use, which usually results in a increase in populations of predatory beneficial insects and thus contributes to the improvement of the natural control of some pests. Despite success with bollworms management adoption of transgenic cultivars with insecticidal traits, cotton insect pests continue to have economically important effects due the elevated status of sucking pest. The productivity of Bt cotton is now showing declining trend and cost of pest management is increasing. The excessive exploitation of energy subsidies is also responsible for volatile economy of cotton crop as due to increase in cost of pest management and the declining the yields. The frequent failure of cotton crop in recent past has also shattered the economy of cotton belt of country and this may lead to social problems if declining trends in cotton cultivation is not reversed. Due to the non-availability of suitable alternate crop, particularly due to lack of irrigation water, the cultivation of cotton is more or less compulsion for the farmers. During the last decade pest scenario has changed which necessitated the strict adoption of IPM based on scientific line. Perhaps the most challenging aspect of implementing IPM in the 21st century is to educate and demonstrate to farmers how to use decision aids to avoid unneeded insecticide applications but critical questions remain widespread adoption. Precision agriculture approaches using site specific management have potential to reduce unnecessary costs and optimize the deployment of seed, fertilizer and pesticides needed for profitable production. The

IPM strategy formulated , demonstrated and adopted by cotton growers during last five decades is summarized and identify the critical researchable issue, policy decision and transfer of technology.

Insect pest complex : Cotton crop is inhabited by numerous insect species and it is generally recognized that various arthropod predator species play an important role in regulating pest populations. Cotton ecosystem provides home to about 1326 species of insects from sowing to maturity in different cotton growing areas of the world (Hargreaves, 1948). In North India irrigated cotton, the pest complex changed during last five decades (Table 1). At present, cotton jassid [*Amrasca biguttula* (Ishida)], whitefly [*Bemisia tabaci* (Gennadius)] are the key pests on *Bt* cotton. Bollworms pink bollworm [*Pectinophora gossypiella* (Saunders)], spotted bollworms [*Earias vittella* (Fabricius) and *E. insulana* (Boisdual)], American bollworm [*Helicoverpa armigera* (Hubner)] are not of economic importance. The thrips [*Thrips tabaci* Lindman] cause moderate damage in some locations. Meal bug (*Phenococcus solenopsis*) need careful surveillance and has potential of causing severe damage.

Arthropod fauna was recorded in cotton agro ecosystem in cotton belt of Punjab during 2006-09. 134 species of arthropods, including Hymenoptera (23.9%), Hemiptera (19.4%), Coleoptera (16.4%), Lepidoptera (14.2%), Orthoptera (8.2%), Diptera and spiders (4.5% each), Odonata (2.9%), Dictyoptera, Isoptera and mites (1.5% each) and Neuroptera and Thysanoptera (0.7% each) were associated with the cotton crop. This included 54 species of herbivorous insects and mites. Natural enemies accounted for one third of the total arthropod fauna on cotton crop (Bal and Dhawan, 2009 a,b,c; Dhawan and Bal 2009).

Pest outbreaks: During the last four decades, cotton crop in north irrigated *hirsutum* zone suffered three major pest outbreaks which resulted in heavy losses and failure of cotton crop (table 1). This significantly affected the economic development of cotton growing areas of north India. This lowered the confidence of traditional cotton growers in cotton cultivation and subsequently decline in area under cotton.

American bollworm : The first outbreak was in 1983 but only in some pocket of Punjab The maximum productivity of non Bt cotton was 636 kg of lint/ha during 1991-1992 . This was due to cultivation of high yielding undiscript varieties with higher use of fertilizers. The incidence of pink and spotted bollworm declined low due to excessive use of synthetic pyrethroids which were very effective against bollworms. This resulted in emergence of American bollworm as key pest due to the development high level of resistance to all synthetic pyrethroids and low to medium to all other insecticides, organ chlorinated organophosphates and carbamate. These insecticides lost efficacy against American bollworm. The insecticide industry relied on these molecules and no new molecules were available till 2000. This resulted in use of insecticide combination to manage the bollworm. All combinations were of synthetic pyrethroids with other insecticides. This resulted in resurgence of white flies which also significantly reduced the productivity and quality of cotton. The productivity declined to 179 kg of lint/ha in 1998-1999, 71 per cent reduction in yield as compared to 1992. The average number of sprays increased to 17.1 and cost of sprays to Rs. 9989 /ha.

Mealy bug: The *Bt* cotton was introduced in north in 2005, which provided effective control of bollworms and no sprays were directed for management of bollworms. The decline in sprays during flowering phase resulted in emergence of sucking pests during reproductive phase. The mealy bug appeared suddenly on cotton and outbreak of this pest was observed. The species was not reported earlier on cotton and even not able to ascertain the cause of appearance. This threatened the cultivation of *Bt* cotton. However, the pest was managed with the new strategy in subsequent years. The loss due to this pest was between 30-40 cent with increase in cost of protection by 22 per cent (Dhawan *et al*., 2007, Dhawan and Saini, 2009).

Whitefly: The severe outbreak of whitefly was observed on cotton in 2015 which resulted in failure of cotton crop and productivity declines to 197 kg of lint/ha in 2015-2016. However, this as result of failure of policy decision, scientific interventions and extension agencies. The incidence of this pest was on rise after 2012 but no appropriate strategy was evolved. No serious lesson was learnt from failure of cotton due to bollworm. The resistance of whitefly to triazophos and ethion commonly used pests was not monitored. The new chemistry diafenthiuorn, pyriproxyfen and spiromesifen failed to provide efficient control due to lack of proper spray technology. This also resulted in increase in cost of insecticides. The *Bt* hybrids cultivated were of busy nature and penetration of insecticides was not possible with existing spray technology. The excessive use of nitrogen 130 kg/ha for *Bt* hybrids against 65 kg in non *Bt* variety with same yield potential, use of potassium nitrate in 3-4 sprays and use of neonicotinoids compounds made the crop more susceptible to whitefly . The use of neonicotinoids compounds as seed treatment and in sprays for management jassid resulted in development of resistance to jassid which increased the number

Table 1. Change in pest scenario on cotton in North zone during the last five decades

Year	Major pest	Minor pests	New pest	Pest outbreak
Upto 1970	J, PBW	Wf, Ap, Th	SBW	-
1971-1980	J, PBW, SBW	Wf, Ap, Th	ABW	ABW in some pockets (1978)
1980-1985	J, PBW*, SBW**	Wf, Ap, Th	-	ABW (1983)
1985-1990	J*, SBW*,PBW*	Wf**, Ap, Th	TC	ABW (1990)
1990-1995	J**, SBW**, ABW**, PBW**	Wf**, Ap, Th	LM, CLCV	ABW (1995); WF (1995)
1996-2004	J, Wf**,SBW*, ABW**, PBW	Ap, Th		ABW(1997, 1998)
2005-2016	Jassid	whitefly	Mealy bug	Mealy bug (2007; whitefly (2015)

J= Jassid; Wf= Whitefly; Ap = Aphids; Th =Thrips; PBW= Pink bollworm; SBW= Spotted bollworm; ABW= American bollworm; TC = Tobacco caterpillar, LM = Serpentine leaf minor; CLCV = Cotton leaf curl virus.
Pest population declined as compared with previous period; ** Pest population increased as compared with previous period
Source: Dhawan, 1999b; 2000, 2011, 2016)

of sprays with these compounds and at higher dosages. These resulted in development of resistance to whitefly and subsequently build up population, possibly also resurgence of whitefly. The whitefly population many times build up early in season and coupled with favourable abiotic factor resulted in pest outbreak (Dhawan *et al.*, 2007).

Bolloworm ?: The incidence of pink bollworm on *Bt* cotton is reported from central India and north may face the same situation . There no resistance management strategy as farmer has not accepted the concept of refugia. Moreover, there is no scientific monitoring of development of resistance to bollworm complex to manage well in time before it spread to larger areas. The proper planning is required to address the issue.

Current status: *Bt* cotton is effective against bollworm complex and also provide effective control of *Spodoptera*. The incidence of jassid has increased and requires management during flowering phase. The whitefly population declined after introduction of *Bt* cotton due to reduction in use of synthetic pyrethroids which were responsible for resurgence. However, whitefly will be serious threat as management by farmers is based on blanket use of insecticides and lack of effective spray technology. The use of growth promoting factors need critical review for sustainable management of whitefly. The concept surveillance and threshold is not adopted by farmers as it is not providing desirable control. The other strategies like cultivation of recommended hybrids and timely sown has many constraints for adoption. These are also not based of strong scientific observations. Mealy bug population has declined after outbreak but need proper surveillance as this pest has great potential to build up in short period under favourable circumstance. The mirid bug is present in central and south India but not of major concern in north but need to have proper surveillance and develop strategy in case of build up this pest. The biodiversity of insect in cotton indicate the presence of many insects which are serious pest on cotton in other cotton growing areas of world and need proper surveillance (Dhawan,1993, 1999b, 2011, 2016).

Pest management

Agronomic interventions : The most of the cultural practices were recommended during the last five decades based on higher productivity and their impact on pest populations build were not the priority. It is well documented fact that pest population can be managed effectively by adopting recommended agronomic practices during the crop season as well as in off-season (Table 2). The adoption of such operations at appropriate time helps to reduce the damage. However, the deviations from such package help the pest to multiply and adversely affect the yield.

Planting time : Planting of crop at optimum time is important to avoid condition that synchronises crop-pest association. Due to staggered sowing, pests are able to complete 1-2 generations more in the season. Careful selection of planting date enables the plants to escape damage during susceptible growth stage,

Table 2. Performance of various insecticides against insect pests and safety to natural enemies of cotton

Insecticides	Insect Pests						Natural enemies	Remarks
	J	W	PBW/SBW	ABW		TC		
				Young	Grown up			
A. Organochlorinate								
Endosulfan	Good	Good	Good	Good	Poor	Very good	Safe	Safer to the natural enemies, low resistance to American bollworm early in the season
B. Organophosphates								
Monocrotophos	Good	Poor	Good	Poor	Poor	Poor	Highly toxic	Excessive use can cause resurgence of whitefly and American bollworm
Profenophos	Poor	Poor	Good	Good	Poor	Poor	Toxic	-
Quinalphos	Poor	Poor	Good	Good	Poor	Very good	Toxic	Excessive use can cause resurgence of jassid
Chlorpyriphos	Poor	Poor	Good	Very good	Very good	Very good	Highly toxic	Excessive use can cause resurgence of jassid
Acephate	Good	Poor	Good	Very good	Very good	Very good	Toxic	Excessive use can cause resurgence of whitefly and American bollworm
Triazophos	Poor	Very good	Good	Good	Poor	Poor	Toxic	-
Ethion	Poor	Very good	Good	Good	Poor	Poor	Toxic	-
C. Synthetic pyrethroids								
Alphamethrin, â-cyfluthrin cypermethrin, deltamethrin, fenvalerate/ **fenpropathrin**	Poor	Poor	Very good	Poor	Poor	Poor	Toxic	Excessive use can cause resurgence of whitefly and American bollworm, high level of resistance to American bollworm
D. Carbamates								-
Carbaryl	Poor	Poor	Good	Good	Poor	Poor	Toxic	Excessive use can cause resurgence of mite
Thiodicarb	Poor	Poor	Good	Good	Poor	Very good	Toxic	Excessive use can cause resurgence of mite
E. Naturalyte								-
Spinosad	Poor	Poor	Good	Very good	Very good	Poor	Safe	Safe to the natural enemies
F. Oxadiazine								
Indoxacarb	Poor	Poor	Poor	Very good	Very good	Poor	Toxic	-
G. Miscellaneous group								
Flubendiamide	Poor	Poor	V. Good	V. Good	Good	Poor	Safe	Safe to the natural enemies

J= Jassid; W= Whitefly; SBW= Spotted bollworm; PBW= Pink bollworm; ABW= American bollworm; TC= Tobacco caterpillar advance into tolerant stage before the pest attack occurs and reduces the number of generations of pests Dhawan and Sidhu, 1985). The pink bollworm the population increase by 20 fold from generation to generation and heavy build-up of population during last 4-5 generations that could be a The sowing dates were from mid-April to end May during 1980-1990’s. Due to identification of verities for late sowing dates were upto June 10 for LH 900 and F 1054. Thereafter the sowing dates were reverted to mid-April to mid-May to escape the damage by *H. armigera*. Thereafter in 2000, date of sowing was only up to end April. However, the main sowing period was in first fortnight of May. The area under late sowing varied from 10-20 per cent. The more of spays were more on late sown crop.

Plant spacing: The plant spacing has tremendous impact on host plant as it influences its health, growth and development as well as microclimate, which affect the build-up of pest species. The plant to plant and row to row spacing varies greatly with variety. The normal spacing provides optimum space for proper plant growth. The close spacing result in bushy growth of crop that affect the penetration of light, results in vertical growth of plant, hinders the spraying operation and also results in higher relative humidity that favours the higher incidence of sucking pests and bollworms. The normal row to row spacing was 60 for varieties J 34, J 205 and 320 F and LSS was 75 cm which was long duration variety. The plant to plant spacing was 30 cm during 1980. Thereafter the spacing was changed to 75x 15 cm for F 414 and LH 372 which were recommended varieties. Again in 1990 row spacing was changed to 67.5 due the introduction of mechanical sowing. The spacing for *Bt* hybrids 75 to 90 x 60 cm based on *Bt* hybrids. However, the maintenance of plant population and proper spacing was not priority in management of insect pests; it was based on productivity of cotton.

Fertilizers: The dose of fertilizers mainly depend on nutrient status of soil and is essential for adequate plant health which can escape pest damage to great extend during early stages of plant growth. Higher yield of seed cotton usually require fertilizer application but excessive use of nitrogen, produce rank growth and increase the severity of infestation of sucking pests and bollworms. The farmers never applied fertilizer based on soil testing and practically not aware of concept. This results in higher use of fertilizer particularly nitrogen. The yield potential of non-*Bt* varieties and *Bt* hybrids does not vary much but dosages of fertilizers for hybrids is double the varieties. Moreover, the use of neonicotinoids compounds for management of sucking pest on BT and blanket use of potassium nitrate spray further promoted the growth. All this is responsible for higher incidence of sucking pests during flowering phase.

Intercropping: The cultivation of mung was recommended in mid 1970 and was withdrawn thereafter okra, mung and pigeon pea in and around cotton crop was not recommended as it increases the build-up of jassid, whitefly, spotted bollworms and American bollworm. But in fact this did not have any significant impact on pest build up and area under this was negligible.

Table 3. Recommended/ approved cultural and mechanical control strategies for cotton insect -pests

S. No.	Physical/ cultural/ mechanical practices	Target pests	Impact
1.	Uprooting and destruction of weeds during off season	Mealy bug, whitefly and CLCuV	Reduces carry over infestation
2.	Deep ploughing for soil exposure before sowing and after harvest	American boll worm, tobacco caterpillar	Pupal mortality through birds and other factors
3.	Early sowing (North India)	American boll worm	Escape mechanism
4.	Proper plant spacing and maintenance of plant population	Sucking pests, bollworms and foliage feeders	Reduces incidence, proper application of insecticides through foliar application
5.	Growing *bajra*/ sorghum/ maize as barrier crop	Mealy bug	Act as a physical barrier and check spread
6.	Growing of (refugia) non Bt around Bt-cotton field	Boll worm complex	Delay of resistance to Bt mechanism
7.	Use of recommended dose of nitrogenous fertilizer	Jassids, whitefly and bollworms	Congenial over dose for population build up
8.	Non judicious use of irrigation water	Entire pest complex	Good for population build up of pests
9.	Cultivation of undescript material	Entire pest complex	More damage
10.	Installation of yellow sticky trap	Whitefly	Monitoring and managing whitefly population
11.	Collection and destruction of bad opened bolls . at the end of season	Pink Bollworm	Reduces carry over
Cultivation of adjoining crops in and around cotton crop			
12.	Okra, *moong* and *arhar*	Jassid, whitefly, spotted and american bollworm	Most preferred host, help in increase in population build up and incidence on cotton crop
13.	Okra, *moong*, castor and dhaincha	Tobacco caterpillar	
14.	Okra, *moong* and *guar*	Mealy bug	
Uprooting and destruction of weeds during the season			
15.	*Kanghi buti*, *Peeli buti*	Whitefly, mealybug	Reduces carry over and population build up
.	*Itsit* (please give scientific name)	Tobacco caterpillar, mealybug	
.	*Congress grass*	Mealy bug	
16.	Do not throw uprooted infested plant/ weeds in cotton plant/ water channel/ common place	Mealy bug	Check further spread
17.	Collection and destruction of egg masses and early instar feeding gregariously along with leaves	Tobacco caterpillar	Reduces population build up and incidence
18.	Removal of infested terminal shoots	Spotted bollworm	Reduces incidence
19.	Early termination of crop	Bollworms	Reduces carry over
20.	Grazing of cattle, sheep, goat after last pick to feed on plant debris and unopened bolls	Pink bollworm	Reduces carry over
23.	Before stacking dislodge and burn the burs and unopened bolls	Pink bollworm, mealybug	Reduces carry over
24.	Stacking of cotton stalks in open in villages	Pink bollworm & mealy bug	Reduces carry over
25.	Do not allow the movement of farm animals	Mealy bug	Reduces carry over
26.	Restrict the movement of farm workers in infested fields	Mealy bug	Reduces carry over
27.	Prevent the movement of sticks from the infested areas to the new area	Mealy bug	Reduces carry over
28	Do not cultivate cotton as a ratoon crop.	Pink Bollworm	Reduces carry over

Modified after Dhawan, 1999b, Dhawan *et al.*, 2011, 2012, 2017

Destruction of Alternate Weed Host Plant: Several weeds are preferred alternate hosts of American bollworm, spotted bollworm and whitefly. The removal and destruction of these hosts in the vicinity of cotton fields, on sides of roads, etc., can help to reduce the multiplication and carryover of these pests. This played significantly row in management of mealy bugs on *Bt* cotton.

Manipulation of Carryover Sources: In North Indian the carryover of pink bollworm is to the extent of 82,13, 5 and <1 % in unpickable bolls/burs, cotton seed, shed material and gin trash, respectively. To reduce the carryover following strategy is recommended to the farmers: allow the sheep and goats to graze cotton field after the last picking and removal of leftover bolls. The larval mortality in cotton stacks put in the open was higher (53.5 %) than those kept under tree shade (32.0 %). Similarly mortality of larvae in stacks stored in bundles in upright position was higher (53.6%) than in sticks stored horizontally (37.7%). Therefore, it is advised to the farmers to stack the cotton sticks in the open away from tree shade in the villages, preferably after tying them in bundles and storing in upright position. Moreover, the cotton stacks should not be stored in fields.

Varietal resistance : There have been constant efforts to develop varieties, which have resistance to major insect pests to suppress the pest population with least disturbance to cotton ecosystem and also reduce the dependence on insecticides. Due to availability of effective insecticides against jassid and bollworm (pink and spotted bollworms), which were the dominant pests till 90's; the development of high yielding cultivars was major priority. The high yielding and pest susceptible cultivars were evolved, which helped in increasing the yields. But with the change in pest complex, whitefly and American bollworm became the major pests and the failure of cotton crop occurred, as not very effective chemicals are available for these pests. The management of these pests by insecticide required some inbuilt resistance and need based use of insecticides. There are not good sources of resistance against whitefly, pink, spotted and American bollworm. Only the manipulation of plant type and maturity was priority to escape the damage. Cotton crop is attacked by many pest species at a time and development of varieties resistant/tolerant to a number of pests or a group of pests (sucking and bollworms) cannot be achieved easily. Evolving varieties resistant to early season pests is the top priorities with aim to conserved the natural enemies and reduce the insecticide-based stress in cotton ecosystem. Many good lines were identified for resistance/tolerant to jassid. Introduction of high yielding varieties and hybrids have increased dependence on use of insecticides. The collapse of insecticides against *Helicoverpa* due to resistance against insecticides resulted in release of *Bt* cotton which provided effective control of bollworm complex. the incidence of stem weevil and whitefly in South India. Similarly, the cultivation of LPS 141, which is resistant to whitefly, has increased the population of jassid. The cultivation of a large number of varieties/ hybrids that are more susceptible to insect pests is also responsible for extensive loss to cotton, for the last couple of years. The cultivation of resistant cultivars should be carefully integrated with other component of IPM and some level of resistance/tolerance to key pests in essential for the success of other components of IPM. The frequent failure of chemical control in recent past is the due to the cultivation of high yielding susceptible cultivars. Seven events were released in during 2002 to 2009. The Bollgard I (Mon 531- *cryIAc*) and Bollgard II (Mon 15985- *cry1Ac* and *cry2Ab*) was released for cultivation in 2003 and in 2006. JK AgriGenetics developed "Event 1" (*Cry1Ac* gene from the Indian Institute of Technology, Kharagapur) and Nath Seeds GFM event fusion *Cry1Ac/Cry1Ab)* from Biocentury Transgene Technology Company developed at the Chinese Academy of Agricultural Sciences. Central Institute of Cotton Research, Nagpur and the University of Agricultural Sciences, Dharwad developed three varieties in 2009 based on event BNLA 601 expresinf Cry1Ac. In 2009, Event 9124 developed by Metahelix, a biotechnology firm in Bangalore, was granted approval featuring synthetic cry1Ac. The largest number of hybrids has been developed using MON 15985 and MON 531, (nearly 91-95 %). Currently many SAU are involved in development of *Bt* cotton varieties in region specific high yielding cotton varieties. This will help in reducing the cotton of seeds and varieties will be more climates resilient. Due to reduction in sprays in *Bt* cotton against sucking pests during flowering phase, the incidence of sucking pets has increased. The development of resistance in jassid to neonicotinoids has increased the cost of insecticide management of this pest and therefore need is to have varieties/hybrids resistance or tolerant to jassid (Dhawan , 2004).

Insecticide in pest management : Insecticide played a significant role for management of cotton pests and most favoured option with cotton growers (Table 3). Over the past five decades cotton cultivators had to rely on the conventional groups of insecticides such as organochlorines (DDT, BHC), cyclodienes (aldrin, dieldrin, endosulfan), organophosphates (monocrotophos, quinalphos, chlorpyriphos, profenophos, dimethoate, phosalone, oxy-demeton methyl, metasystox, acephate, phorate, carbamates (carbaryl, thiodicarb) and pyrethroids (cypermethrin, deltamethrin, fenvalerate, beta cyfluthin, flycithrinate, fenopropathrin). Many insecticides have been used for *H. armigera* control over the years. Not all are equally effective, many have impacts on others insects' pest and beneficial complex and many are to a greater or lesser extent harmful to human health. In the late 1990s four chemical classes dominated cotton crop protection the synthetic pyrethroids, the organophosphates, cyclodiene and the carbamates). Mixtures of insecticide with two or more active ingredients are widely used in pest control programmes where different insect pests are being targeted simultaneously (e.g. sucking pests and lepidopterans) this may sometimes be justified. However, the use of mixtures for the control of caterpillars alone, especially *H. armigera* was more problematic (Dhawan,1993, 1999b,2011, 2017 Dhawan,1993,1999b, 2011, 2017).

Phase 1: The management of cotton pests with advent of DDT depend on chlorinated hydrocarbons till mid-1970s threeafrer organophophates and carbamates replaced organochlorines (DDT, BHC), cyclodienes

Table 4. Botanical insecticides evaluated against different insect pests of cotton

Insect pest	Formulation	Current status
Amrasca biguttula	Nimbecidine, IndNe, NO, NSKE, Navneem, Karanj oil, Repelin	Low –Moderate control
Bemisia tabaci	Castor seed oil, Karanj oil, Nimbecidine, IndNe, NO, NSKE, Neem rich. Navneem, Karanj oil, Repelin, Margocide CK, Neemgold, Achook, Rakshak gold*, Neemazal T/S*, Econeem*, Aza Fortune*	Low –moderate controlAza enrich formulations (3000- 10,000 ppm) effective control
Aphis gossypii	NO, NSE, NO+Karanj oil	Moderate control
Bollworm complex	Nimbecidine, IndNe, NO, NSKE, Neem rich, Navneem, Karanj oil, Repelin, Margocide CK, Neemgold, Achook, Aza Fortune*, Rakshak gold*, Neemazal T/S*	Aza enrich formulations (3000- 10,000 ppm) gave low- moderate controlS Early interventions in IPM gave effective control of insect pest complex

NO- Neem oil; NSE-Neem seed extract; NSKE- Neem seed kernel extract;
* - Aza enrich formulations
Source: Modified after Dhawan, 1999a,b; Dhawan and Dhaliwal,1996, Dhawan 2016.

(endrin, aldrin, dieldrin, toxaphene) which were used extensively to manage the sucking and bollworms mainly pink and spotted bollworm. Normally 5-7 sprays were used to manage the pests but the losses were 20-30 per cent in spite of the best management practices. For sucking pest mainly jassid, DDT+BHC, malathion. dimethoate, oxydmton methyl, phospamidon and formothion were recommended based on basis of jassid. Soil application of thimet and phorate were also recommended. For management of bollworm mainly pink bollworm, five spray schedule of fenitrothion DDT ednosulphan cabamate carbamate was recommended at 15 days interval. . Aerial sprays at subsidies were also carried out to manage the bollworm. In early 1970-1975, dosages for fenitrothion were quite low to provide effective control. The dosages of fenitrothion were increased for 200 ml 0.750 and endosulphan 600 to 1 l/ha. Monocrotophos, quinalphos, phosalone, phenthoate, were recommended during 1980. Thereafter monocrotophos, quinalphos, phenthoate, fenitrothion, profenophos, phosalone, and endosulphan were used for management of bollworm complex on cotton. Monocrotophos was most widely used insecticides followed by carbaryl and endosulphan.. The dominant pests were pink and spotted bollworms and cotton jassid.

Phase 2 era of pyrethroids: For control of jassid dimthoate, methyl, formothion and phophamidon were recommended. For whitefly, trazophos/ethion was approved for management along with bollworms. Fenvalerate, cypermethrin permethrin and deltamethrin were first group of synthetic pyrethroids for management of bollworms. Followed by alphamethrin, fenpropathrin, fluvalinate, bifenthrin, asymethirn, and beta cyflutrin. Among these fenvalerate, cypermethrin, alphamethrin and deltamethrin were widely used for management of bollworms and replaced the organophosphates and chlorinated hydrocarbons. These were very effective against pink and spotted bollworms which increased the productivity of existing varieties by more than 50 per cent and incidence of bollworm reduce to all time low to 1-2 per cent with use of SP. The spray interval was reduced to 10 days. Only 2-3 sprays were recommended in alternation with other insecticides. The insecticides were divided to four groups chlorinate hydrocarbon, organo-phosphates, carbamate and synthetic pyrethroids. There use in alternate spray of different insecticides were recommended. But the farmers mainly used synthetic pyrethroids. The other insecticides used were monocrotophos , quinalphos and endosulphan . Acephate, chlorpyriphos, triazophos and ethion were also recommended for control of bollworms. Among these triazophos and ethion were used for management of bollowrms and whitefly during flowering phase. Latter on fixed spay schedule OC-OP-SO-OP-SP-CM in LH 900 and F 1054 and for F 846, F 414, F 505, LH 86 , LH 1134 fixed spray schedule OC-SP-OP-SP-OP-SP-CM. The synthetic pyrethroids were highly effective at low dosages. They provide control of bollworms for longer periods (10-21 days) as compared to 7-10 days with organophosphates. The management of bollworms, pink and spotted bollworms particularly was spectacular and population bollworms declined to all time low. The productive increased tremendously by 25-40 per cent. Thereafter, the American bollworm replaced the pink and spotted bollworm and excessive use of synthetic resulted in development of high level of resistance to American bollworms. The organophosphate and chlorinated and carbamate also failed to provide effective control of American bollworm . Among these, chlorpyriphos, acephate and endosulphan were preferred insecticides at shorter interval. The excessive use also resulted in heavy resurgence of whitefly and cotton crop headed for complete failure in 1998-1999. The low productivity and higher cost of insecticides resulted in heavy loss to cotton growers. The institution also failed to provide any effective action plan. The synthetic pyrethroids were withdrawn for management of grown up larvae. Acephate, chlorpyriphos and fenitrothion were advocated for use against grown up caterpillar. The American bollworm *Helicoverpa armigera* developed high level resistance most of the insecticides (Gill and Dhawan 2006 a,b,c) and caused extensive damage to cotton crop despite repeated applications of insecticides of even up to 30 sprays.

Table 5. Impact of IPM in reduction in number of sprays and additional profit over non-IPM villages in Punjab

Parameter	2002	2003	2004	2005	2006	2007	2008	2009
No. of villages	32	30	45	121	213	230	225	225
No. of IPM farmers	300	567	900	1044	14804	27196	12919	12120
Area under IPM (ha)	1152	28282	19429	37032	44848	45262	31735	35182
Seed cotton yield (kg/ha)	1585	1969	2441	2452	2435	2260	2433	2586
Number of sprays*	10.6	9.5	5.4	3.4	3.1	4.7	4.2	3.61
Spray cost (Rs/ha)	5460	7937	4021	1793	2163	2714	1761	1955
Additional profit due to IPM (Rs/ha)	7670	7844	13111	5509	5371	9864	12456	15699

Mean of three years; * The average number of sprays in 2001 was 21.0; ***Bt* cotton was adopted as component of IPM **Source:** Dhawan 2011, 2017

Phase 3 combination of insecticides: Failure of synthetic pyrethroids to control the American bollworms which was dominant pest of cotton resulted in use of combination s of synthetic pyrethroids with chlorpyriphos, endosulphan, triazophos and ethion to manage the American bollworm by farmers. But these did not provide desired control of bollworms but were better than individual insecticides and failure of cotton crop was observed. Mixtures may still be cost-effective for controlling insect pest complex in cotton, however rational use of mixture as insecticide resistance management strategy. The use of mixtures in controlling *H. armigera* can result in the simultaneous enhancement of multiple resistance mechanisms and significant cross resistance to other compounds.

Phase 4 new chemistry

Sucking pests: Neonicotinoids were introduced for management of sucking pests' as seed treatment and foliar application. Imidacloprid (Bayer Crop Science), acetamiprid (Nippon Soda, 1995), thiamethoxam (Novartis, 1998), thiacloprid (Bayer Crop Science, 2000), clothianidin (Sumitomo Chemical Takeda Agro Company, Bayer Crop Science, 2000) and dinotefuran (Mitsui Chemicals, 2002) were registered. Among these, imidacloprid was cost effective and replaced the organophosphates dimethoate, oxy-dmeton methyl for control of jassid. The next commonly used insecticide was thimethixam. Acetmiprid was preferred by farmers for cotton whitefly. However, these compounds lost effectiveness due to development of resistance. In new chemistry, flonicamid (pyridine carboxamid) a novel compound effectively manages jassid and whitefly. Diafenthtiouron, pyriproxyfen and spiromesifen are recommended against whitefly in addition to flonicamid. Among these pyriproxyfen and spiromesifen are more effective against whitefly.

Bollworms complex : Indoxacarb, spinosad, pyridalyl, novaluron, flubendamide, chlorantraniliprole were introduced and provided effective control of bollworms.

Mealy bug(*Phenococcus solenopsis)*: For management spot treatment was recommended for management based on regular survey. Profenophos was most effective insecticides Buprofenzin was recommended early in the season as it was safe to natural enemies. Other recommend insecticides were quinalphos, carbaryl and thiodicarb (Dhawan *et al*., 2011, Dhawan 2016) .

Tobacco caterpillar *(Spodptera litura)*: Acephate, chlopyrophos, quinalphos, thiodicarb and endosulphan were recommended for control of *S. litura* but most effective insecticide used by farmers was novaluron (Dhawan 2016).

Economic threshold levels **:** The sprays against jassid and bollworm were based on calendar based schedule till 1970, thereafter economic threshold of sprays against jassid was recommended (spray when leaves show yellow and curling on 50 plants of the plants observed). Similarly the economic threshold of 6 adults/ leaf in early vegetative phase and appearance of honey dew on 50 plants during flowering phase was recommended. Against bollworm mainly pink bollworm which was key pest the initiation of sprays 15 days after flowering was suggested, thereafter sprays should be done at 10 days interval. The sprays after synthetic pyrethroids can be delayed up to 15 days. . The sprays based on 4 pink bollworm /trap for two consecutive nights was also found effective. With the appearance of American bollworm, economic threshold of 5 per cent damage in shed floral forms was approved. The main aim was to promote the judicious use of insecticides to increase the productivity with least possible disturbance to cotton ecosystem and to enhance the life of chemical insecticides. For this proper sampling plan for surveillance was implemented. In recent past due to failure of cotton it is essential to decide the right insecticide, dosages and time of and method of application The monitoring is very essential at macro level to avoid such failures in future and intervention is justified based on the economic threshold levels (ETL) of the pest. Identifying these threshold levels requires a background understanding of the relationships between the pests, their natural enemies and the crop damage which may result from particular pest populations at particular stages of crop growth. The complete understanding of tritrophic interaction is required to have suitable ETL. However, this aspect is lacking in developing and under developing cotton growing countries. Moreover, counting insects remains a problem, particularly in small scale farming systems. Samplings for majority of pest are not standardized even till today and counts are only relative and not absolute. The multiple pest attack may results in the adoption of ETL based sprays more difficult. The population based ETL are not favoured by farmers in developing and under develop countries. The need is to make the concept of ETLs more farmer friendly for judicious use of insecticides (Dhawan *et al* 2012, Dhawan 2016).

Insecticide resistance management (IRM) strategy: IRM is component of Integrated Pest Management (IPM) programme. The adoption of this strategy helps in reducing/ delaying the insecticide resistance to insects. It also increases functional life of the insecticides. After the failure of cotton crop due to bollworms 4 window IRM was suggested for non *Bt* cotton varieties/hybrids- i. Sucking pests management (Sowing – first week of July), ii. Sucking pests and bollworms management (second week of July – first week of August) iii. Bollworms and tobacco caterpillar management (Mid to end August) and bollworms and tobacco caterpillar management (September-October). For *Bt* cotton to avoid the development of resistance in *Bt* cotton to bollworms, 20 per cent area should be sown under non *Bt* cotton hybrids around *Bt* cotton and non *Bt* hybrids should be protected against damage by insect pests as mentioned in case of non *Bt* cotton hybrids. Alternatively 5 per cent area of non *Bt* hybrids can be sown around *Bt* cotton and this should be kept unsprayed. The concept of refugia is bag is another strategy to manage the management. However, the adoption of this strategy is not adopted by farmers as the 20 per cent non *Bt* seed was poor yielder and was not suitable for specific region due to variable growth and flowering patter. This result in higher cost of *Bt* cotton to compensate for 20 non *Bt* with *Bt* hybrid. The improper implementation of resistance management strategy will result development of resistance in *Bt* cotton to bollworms and may result in higher cost of plant protection. The improper planning also resulted in failure of good neonicotinoids compounds against jassid and farmers has to spend 4-5 more for management of sucking pests. Seed treatment of non *Bt* cotton was not desirable as this resulted in faster development of resistance to neonicotinoids compound. Similarly, there is no proper monitoring of resistance to bollworms and sucking pests for development of IRM strategy. Failure of crop due to American bollworm whitefly in past in north in past was the result of non-adoption of IRM strategy. Similar is the case with failure of neonicotinoids compound against jassid (Dhawan 2016).

Spray technology: The proper adoption of spray technology can provide adequate coverage of target sites and to some extent the amount of insecticide load can be reduced. Effective spraying technology must focus on pest control with reduced pesticide rates and rapid dissipation of the insecticide to target site. Such application results in a high and uniform spray deposit on both the upper and under sides of the leaves. Effective delivery, distribution and deposition of pesticide will ensure effective management. Farmers rarely adopt efficient spray technology. The use of high discharge nozzles, low and higher spray material, higher swath width and poorly maintained spray equipment adversely affect the bio efficacy of insecticide (Dhawan, 2016). The farmers are using various type of spraying equipments with high volume which results in loss of more than 50 per cent insecticides which does not hit the target. Recent failure of cotton due to whitefly in north was mainly due to lack of proper spray technology which could not hit the target site, underside of leaves, where the immature stages survive and are immobile. Very effective insecticides failed to provide efficient control of whitefly.

Resurgence of sucking pest: The over-reliance on insecticides for bollworm control has caused the resurgence of sucking pests (jassid and whitefly). Dhawan and Simwat (1997) observed the resurgence of cotton jassid with repeated use of chlorpyriphos and quinalphos and reported it to be major cause for increase in population of jassid during the flowering phase in recent years due to the extensive use of these molecules for the management of *H. armigera* (Hubner) on cotton. Similarly, the resurgence of whitefly during 1993-2000 was due to the excessive use of synthetic pyrethroids and after introduction of BT cotton the use of synthetic pyrethroids was phased out and no resurgence of whitefly was observed (, Dhawan *et al.*, 2000,Dhawan 2016).

Botanical bio pesticides : Potential of neem in management of insect is reviewed by (Dhawan and Simwat 1986, Dhawan and Dhaliwal, 1996, Dhawan, 1999b, Dhawan 2016). One of the biggest constraints in adoption of botanicals is comparatively low control as compared to insecticides and higher cost. The delayed action result in economic loss and not non acceptance farmers. Field trials with neem formulations in cotton have not shown consistent results. The neem seed kernel which can be used economically does not find favour with farmers due to high cost of spray application and low control. The second constraint is the availability of standard and economically viable formulation of neem and is rapidly inactivated by UV light, temperature, leaf surface pH conditions.

Microbial Control : Among different micro agents, Nuclear Polyhedrosis Virus (NPV) and Bacillus *thuringiensis* (*Bt*), have been tested against bollworm complex of cotton and are documented as safe to natural enemies. However, natural enemy complex in cotton does not paly significant role in management of insect pests. Due to the unreliable performance, the commercial products have not been popular with the cotton farmers(Dhawan *et al.*, 2012, Dhawan 2016).

Monitoring of bollworms/tobacco caterpillar with sex pheromones : The monitoring of bollworms should be done with the initiation of flowering stage of crop. Observations on moth catch should be recorded on every alternate day. This monitoring strategy will help in making decision for effective management of bollworms. For pink bollworm use Sticka/Delta trap with at least 10 micro litre of gossyplure and place it at 15 cm above crop canopy. Replace the lure after 15 days and use 1 trap/ha. Similarly, for tobacco caterpillar, spotted/spiny bollworms and American bollworm use sleeve traps and replace the lure at 2 weeks interval. Place the trap at 15 cm above the crop canopy and use 2 traps/ha (Dhawan *et al.,* 2012).

Decision support systems : Farmers need assistance in interpreting pest monitoring data. Simple "expert systems" were made available to farmers in form charts, special booklets, radio and television programmers or more advanced aids such as computer-based systems. Development and provision of up-to-date information is a key factor enabling farmers to implement IPM programmers. The Decision Support System on cotton IPM (www.pauipmcottondss.com) was provided for extension agencies and farmers. The state department was provided with infrastructure along with training on decision support system, but there was not much success in adoption by farmers.

Transfer of technology : During the green revolution in mid 1960s, use of pesticides, high yielding varieties and fertilizers were on agenda to increase productivity. There was more reliance on insecticide based insect pest

Table 6. Impact adoption of IPM strategies with special reference to mealy bug management in Punjab

Sr. No.	Parameter	IPM	Non IPM	Per cent increase/ decrease over non IPM
1	Number of villages	800		
2	Number of farmers	48537		
3	Number of sprays	3.65	6.70	37.17
4	Spray cost (Rs/ha)	1917	4282	62.16
5	Seed cotton yield (q/ha)	2663	1922	38.55
6	Net profit (Rs/ha)	44442	30753	39.94

Source: Dhawan 2017

management. The subsides were given on insecticides and spray equipment. Soon the policy planners, entomologists and extension agencies realised the negative impact of pesticide use and evolved pest management option to use all options from sowing to picking to keep pest below economic threshold and use insecticide as last option. Many projects were initiated to transfer the IPM technology.

Operational research project (ORP) on integrated pest management. This was initiated in in 15 villages Punjab in 1975 to 1990 under World Bank funded project by Indian Council of Agricultural Research. Farmers were educated by ORP staff about different insect pest problems, side effects of excessive use of insecticides and cultivation of susceptible long duration varieties and concept of ETL/IPM strategy. There was shift from long duration varieties, mainly LSS (*G. hirsutum*) to medium duration and insect-tolerant variety *Bikaneri narma* an early maturing varieties. The adoption of IPM technology resulted in 73.7 and 12.4 per cent reduction in the number of insecticide sprays for control of sucking pests and bollworms, respectively. The reduction of bollworm incidence in ORP villages was 38.55 per cent higher than non-ORP villages leading to 23.1 per cent higher yield and 31.1 per cent higher net income. The yield potential of seed cotton in demonstration fields was 20.45 q/ha as against 10.17 q/ha in other fields (Sidhu *et al.*, 1990).

American bollworm management: The project to manage *Helicoverpa* was initiated during 1995 to 2000 with available technology, but failed to provide economic return to the farmers.

Insecticide resistance management based IPM programme: The CICR, Nagpur launched the IRM programme in six cotton-growing states of India, focusing on 26 districts, which among them, were consuming 80 per cent of insecticides for cotton crop. This project was implemented in Punjab during 2002 to 2011. Under the project insect insecticide monitoring lab were set up to monitor the development of resistance to *Helicoverpa*. In order to transfer the technology IPM centres were set up in each villages which were maintained by scouts which were specifically trained for this purpose. The IPM center display of the complete technology for pest management. The weekly data in these villages was processed and advisory was given individual to farmer, through public address system and was displayed n IPM centres. Scouts regularly visit farmers fields, document the operations, advise them and monitor the performance of advisory. In each district, the district coordinator monitors the implementation of action plan. The progressive farmers were given training about production and protection strategy at PAU campus by experts. The street plays were also organised to transfer the technology. The impact of adoption of IRM strategies resulted in the reduction of insecticidal spray and increased in seed cotton yield and net profit as mentioned in Table (Table 5).

Management of mealy bug: The project on management of mealy bug was also initiated in 800 villages to create awareness among framers about the technology to be adopted. The project was successful as famers were able to properly survey the pest build and adopt non chemical method to manage the pest during and in off season. They adopted the concept of spot treatment which resulted in considerable saving in cost of insecticides (Table 6).

Future action plan and thrust areas : The need is to give orientation to the research to evolve effective and economical IPM technology for cotton pests for wider adoption. The main area of research includes:

- **Increased knowledge of ecological principles**: The challenge of IPM is to analyse and select tactics, including pesticides, that suppress the pest population below damaging levels while minimizing negative impact on cropping system
- **Decision making**: There is need to improve the decision making capability of farmers with new informative tools. At present decision is based on advisory of private sector. Decision making in cotton IPM must be information intensive, giving due consideration to economic and safety to environment
- **Adoptable economic threshold**: The economic threshold (ET) is concept is basis of IPM but the recommended ETL are not adopted by farmers as they fail to provide desired control. These are of academic importance only. These must be redefined and adoption must be ensured.
- **Post treatment monitoring:** This will indicate the need for a second follow-up application and inadequate control due to several possible factors. The failure of any insecticides will give indication for development of resistance and quality of insecticides used. Recordkeeping, the final step in the process, forms the basis for future pest management decisions.
- **Development of better surveillance methodology for accurate decisions**: By regularly monitoring pest and beneficial populations, growers can achieve the best timing and effectiveness of pesticide application. Better control means fewer applications and less opportunity for contamination of water.
- **Agronomical innervations :** Critical evaluation of agronomical intervention to reduce the pest population. Many interventions are cannot be adopted due to constraints and does not provide desired results but increase cost of pest management.
- **Understanding the tritrophic interaction in cotton ecosystem** : This is to encourage the build-up of natural enemy complex which include natural occurring biotic control agents and their role in suppressing pest and potential pest species
- **Pest phenologies**: These relate to injury potentials and timing of control measures, cultural and agronomic practices and development of insect population management strategies.
- **Management of insecticide resistance**: Regular monitoring and management of resistance to insecticides and *Bt* toxin should be part of development of IRM based IPM.

- **Design of efficient spray equipment and spray technology**
- **Dissemination of technology**: The most challenging aspect of implementing IPM in is to educate and demonstrate to farmers how to use decision aids for pests management and to analyse the impact various interventions. The critical questions remain widespread adoption. The need is improve the review the role of KVK and different extension agencies for implementation of programme. Regular monitoring of programme should be done to identify the impact and constraints. The need is to document the impact of various training programme on adoption by farmers. The data base for regular surveillance as per standard methods should be maintained and analysed by experts.
- **Policy decision**: The impact of policy decisions needs review at regular interval for impact analysis and modification. .

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Present and future scenario of insect pests of cotton for the changing climatic situations

A.G.SREENIVAS*, G. N. SHREEVANI, S. G. HANCHINAL AND P.R. BADARIPRASAD
Department of Entomology, University of Agricultural Sciences, Raichur - 584 104
**E-mail : agsreenivas@gmail.com*

Over the past few decades climate has become erratic. Even sceptics are now inclined to believe that 'Climate Change' effects are for real. Climate change can result in expansion of deserts, reduced glaciers ice and snow, severe droughts heavy rains, severe heat waves, ocean acidification, rise in sea levels, disturbed agricultural systems leading to reduced food production and loss of habitats, species extinction and loss of diversity. The increase of temperature and atmospheric CO_2 have been very significant during the last three decades (Stern, 2007) affecting all sectors of agriculture. It has been reported by federal agencies that, CO_2 concentration has been increased by approximately 30 per cent since the industrial revolution which is believed to be responsible for an increase of about 0.66°C in mean annual global surface temperature. Meanwhile, the temperature is anticipated to increase further by 1.4 to 5.8 °C by 2100 with equally increasing atmospheric CO_2. The atmospheric CO_2, which is considered to be chiefly responsible for the greenhouse effect, has increased from approximately 310 ppm in 1950 to about 400 ppm in the year 2011. This concentration is estimated to reach levels of 421 to 936 ppm by the end of the 21st century, depending on the magnitude of future human activities (IPCC, 2013).

Within agriculture, how the climate change impacts insect pests and diseases is an important research area that is engaging biological scientists. Climate change projections made for India indicate an overall increase in temperature from 2 to 4°C with no substantial change in precipitation quantity by 2100 (Krishna Kumar *et al.,*2011). Global changes are responsible for wide range of anthropogenic and natural environmental variation. These climatic and weather changes not only affect the status of insect pests but also affect their population dynamics, distribution, abundance, intensity and feeding behaviour. Intensity of change in climatic ecosystem noted by meteorological science has showed a direct and indirect affect on the prey host relationship, their immune responses and rate of development, their fecundity and various physiological functions.

Climate change and crop yields : Increased GHGs and the consequent global warming has resulted in climate changes including change in the amount and pattern of precipitation, more restricted water availability, more frequent occurrence of extreme weather events including heat waves, droughts and heavy rainfall (Battisti and Naylor, 2009), longer growing seasons, and possible changing geographical regions suitable for cotton production. These changes in climate are expected to have profound effects on world agriculture, because any changes in weather will influence plant growth and increase uncertainty regarding food production due to decreasing crop yields and the loss of cropping areas. Along with these changes, will be longer growing seasons and possible changing geographical regions suitable for cotton production. There is considerable debate about the effects of global warming on agricultural production. There has been a tendency in the literature towards the view that agricultural damages over the next century will be minimal, and that a few degrees Celsius of global warming would be beneficial for agriculture (Cline, 2007). A global assessment of the potential impact of climate change on world food supply by Rosenzweig *et al.,* (1993) suggests that "doubling of the atmospheric carbon dioxide concentration will lead to only a small decrease in global crop production." Investigations regarding the effect of global climate change on crop yield have proposed substantial losses in productivity under the global surface temperature increases projected to result by the end of the twenty first century (Reddy *et al.,* 2002). Climate model projections were summarized in the latest IPCC report (2013). They indicated that during the 21st century the global surface temperature is likely to rise a further 1.1 to 2.9 °C for their lowest emissions scenario and 2.4 to 6.4 °C for their highest. The ranges of these estimates arise from the use of models with differing sensitivity to greenhouse gas concentrations. Future climate change and associated impact will vary from region to region around the globe.

Effect of climate change on cotton : Agriculture is extremely vulnerable to climate change. Higher temperatures will eventually reduce yields and increase the prevalence of pests and diseases. Changes in precipitation are likely to lead to crop failures and production declines. While there will be some gains depending on crops grown and regions, the overall impacts on agriculture are expected to be negative, thus threatening global food security. This assessment applies largely to the regional impacts of cotton production.

Cotton is grown commercially in more than 70 different countries, mostly in the longitudinal band between 37°N and 32°S. Cotton is especially adapted to semi arid and arid environments, where it is either grown rainfed or through irrigation. About 53 per cent of the world's cotton growth areas and 73 per cent of all fibre growth areas benefit from full or supplementary irrigation.

Cotton has certain resilience to high temperatures and drought due to its vertical tap root. The crop is, however, sensitive to water availability, particularly at the height of flowering and boll formation. Rising temperatures favour cotton plant development, unless day temperatures exceed 32°C. Limited increases in atmospheric CO_2 also favour the cotton plant's development. Insects are expected to adapt to climate change through their capacity to adapt their body temperature to the temperature of the environment. The insects currently plaguing cotton are expected to continue to live and possibly thrive in new environmental conditions.

Effect of climate change on transgenic cotton and its pests : Environmental factors such as soil moisture, soil fertility and temperature have strong influence on the expression of *Bacillus thuringiensis* (*Bt*) toxin proteins deployed in transgenic plants (Sachs *et al.*, 1998). Cotton bollworm, *Heliothis virescens* (F.) destroyed *Bt*-transgenic cottons due to high temperatures in Texas, USA because of reduced production of *Bt* toxins (Kaiser, 1996). Cry1Ac levels in transgenic plants decrease with the plant age, resulting in greater susceptibility of the crop to insect pests during the later stages of crop growth (Sachs *et al.*, 1998; Adamczyk *et al.,* 2001; Kranthi *et al.,* 2005). Similarly*, H. armigera* and *H. punctigera* (Wallen.) destroyed the *Bt* transgenic cotton in the second half of the growing season in Australia because of reduced production of *Bt* toxins (Hilder and Boulter, 1999). Possible causes for the failure of insect control in transgenic crops may be due to inadequate production of the toxin protein, effect of environment on transgene expression, *Bt* resistant insect populations, and development of resistance due to inadequate management (Sharma and Ortiz, 2000).

The increased consumption rates by pest insects, brought about by warmer conditions or changes in leaf quality caused by CO_2 enrichment, will lead to a greater intake of pathogens such as *B. thuringiensis* (*Bt*) (Coviella and Trumble, 2000). Interestingly, Coviella *et al.,* (2002) found that the changes in the C: N ratio caused by elevated CO_2 reduced the efficacy of *Bt* toxin expression in transgenic cotton leaves. Wu *et al.,* (2007) reported that genetically modified *Bacillus thuringiensis* (*Bt*) cotton shows less *Bt* toxin after exposure to elevated CO_2, which might affect plant bollworm interactions. Possible causes for the failure of insect control in transgenic crops may be due to inadequate production of the toxin protein, effect of environment on transgene expression, *Bt* resistant insect populations, and development of resistance due to inadequate management (Adamczyk *et al.*, 2001). It is therefore important to understand the effects of climate change on the efficacy of transgenic plants for pest management.

Climate change and cotton insect pests : Current and projected increases in the concentrations of CO_2 and other radioactively-active gases in the earth's atmosphere lead to concern over possible impacts on agricultural pests. All pests would be affected by the global warming and consequent changes in precipitation, wind patterns and frequencies of extreme weather events, which may accompany the greenhouse effect. Cotton cultivation is a difficult task because it is harboured by about 1326 insects and mites all over the world; out of which 162 species are found on cotton in India; of these phytophagous pests, 24 have attained the pest status, out of which 9 are key pests (Dhawan, 1998).

Studies on the relationship between insect incidence and weather factors would enable an ecological maneuvering, which may have economically relevant impact on pest incidence. The loss in seed cotton yield due to leafhopper is accounted to 390 kg/ha (Pandi, 1997). Multiple regression analysis showed that leafhopper population on cotton plants under complete protection (during reproductive phase as well as vegetative phase) increased with the increase in maximum temperature (R2 =0.53, Murugesan and Manish, 2007). Morning relative humidity had positive and evening relative humidity had negative influence on the larval population of pink boll worm (Ramesh kumar *et al.,* 2007). Other factors did not contribute significantly to the larval population. The contribution made by weather parameters on the larval population was 90.90 per cent (Patil *et al.,* 1992). These studies further evidenced the climate susceptibility of cotton pests.

Temperature is identified as the dominant abiotic factor directly affecting herbivorous insects. There is little evidence of any direct effects of CO_2 or UV-B. Temperature directly affects development, survival, range and abundance. Species with a large geographical range will tend to be less affected. Insect herbivores show a number of distinct life-history strategies to exploit plants with different growth forms and strategies, which will be differentially affected by climate warming (Jefferys, 2002).

Plants, grown under low-nutrient conditions, do have higher concentrations of carbon based allelo chemicals than plants grown under high nutrient conditions (Fazer *et al.,* 1992). Host plants growing under enriched CO_2 environments exhibited significantly larger biomass (+38.40 %), increased C/N ratio (+26.57 %), and decreased nitrogen concentration (–16.40 %), as well as increased concentrations of tannins (+29.90 %) and other phenolics (Heagle, 2003). In contrast to the C/N balance hypothesis, plants grown in elevated (700 ppm) CO_2 conditions had similar, or lower, concentrations of carbon based allelochemicals than plants grown in ambient (350 ppm) CO_2 conditions. Larvae fed with foliage grown in elevated CO_2 with low N fertilization consumed significantly more plant material than insects fed with foliage grown in ambient CO_2; but, again, no differences were observed with high N fertilization and found that insects fed on low N plants had significantly higher mortality in elevated CO_2 (Coviella and Trumble, 2000).

The production of the nitrogen-based toxin was affected by an interaction between CO_2 and N; elevated CO_2 decreased N allocation to *Bt*, but the reduction was largely alleviated by the addition of nitrogen, thus indicated that future expected elevated CO_2 concentrations by climate change, alter plant allocation to defensive compounds and have enough impact on plant herbivore interactions. Increases of carbon defensive compounds by elevated CO_2 or low N availability or both, adversely affected growth and survival of *Spodoptera exigua* in *Bt* cotton, was reported by Carlos *et al.,* (2002). It was observed that feeding guild, in which some species have shown increases in population density in elevated carbon dioxide, are the phloem feeders (John, 1999). It is likely that climate change will not minimize the outbreaks; on the contrary it might benefit some pests, which might increase the consumption of pesticides in some regions (Flores Araya and Jesserina, 2008).Chewing insects have shown no change or reduction in abundance, though relative abundance may be greatly affected since compensatory feeding is common in these groups.

The abiotic parameters are known to have direct impact on insect population dynamics through modulation of developmental rates, survival, fecundity, voltinism and dispersal. Among the climatic factors, temperature is an important factor. Warmer conditions are likely to increase the importance of some existing pests (although possibly decrease the pest status of some species) and also encourage other insect species, which may themselves become new pests (Cammell and Knight, 1992). The response of insect herbivores to elevated levels of atmospheric CO_2 will depend on their feeding strategy (Bezemer and Jones, 1998) and how their host plant responds. Leaf chewing insects reared on plants grown in elevated CO_2 typically show an increase in foliage consumption, (Williams *et al.*, 1994; Lindroth, 1996; Stiling *et al.*, 1999), reduced weight (Lindroth, 1996) and slower development rate (Johnson and Lincoln, 1991).

Elevated carbon di oxide is known to effect the nutrition of the foliage and thus increases foliage consumption by the pests will be detrimental to the crop plants, especially if the herbivores are not otherwise adversely affected by the CO_2 induced changes within the plant (Williams *et al.*, 1994; Lindroth, 1996). Increased CO_2 may also cause a slight decrease in nitrogen-based defenses (*e.g.*, alkaloids) and a slight increase in carbon-based defenses (*e.g.*, tannins). Acidification of water bodies by carbonic acid (due to high CO_2) will also affect the floral and faunal diversity. Lower foliar nitrogen content due to CO_2 causes an increase in food consumption by the herbivores up to 40 per cent (Sharma *et al.*, 2010). Phloem feeding insects, such as aphids, have been shown to benefit from CO_2 enriched foliage (Stacey and Fellowes, 2002). For instance, cotton is attacked by aphids, *Aphis gossypii*, which are in turn attacked by the ladybird beetle. Under elevated CO_2, cotton aphid survival significantly increased but ladybird larval development took significantly longer time (Gao *et al.*, 2009).

Investigations of Shreevani *et al.,* (2016) revealed that, the eCO_2 and temperature favoured growth and development of *Bt* cotton which in turn increased seed cotton yield in eCO_2 and temperature treatments. Biochemical analysis of *Bt* cotton showed increased chlorophyll content, carbon and carbon based compounds *viz.,* tannins, phenols and sugars in eCO_2 as compared to a CO_2 treatments. On the contrary, nitrogen (N) and N based compounds *viz.,* proteins and amino acids decreased in eCO_2 conditions which inturn altered C: N ratios and hence, resulted in decreased *Bt* toxin production. Further, when aphid biology was studied on such biochemically altered *Bt* cotton plants, resulted in decreased nymphal period, adult longevity and total life cycle while, fecundity increased leading to increased aphid population with reduced fitness. Therefore, the aphids may become pests that are more serious in the future. Further, when in tri trophic interactions were studied, the negative effect posed by aphid on crop was nullified by predator as the natural enemy devoured the aphids greatly, but, the predator fitness cost has slightly effected. This means, tri trophic interaction has positive effect to crop even after slight reduction in fitness of the predator.

Bollworms : Global warming will result in pest outbreaks which are more likely to occur with stressed plant's as a result of weakening of plants' defensive system, and thus, increasing the level of susceptibility to insect pests. Global warming will lead to earlier infestation by *H. armigera* in north India (Sharma, 2010 and 2014), resulting in increased crop loss. Overwintering of insect pests will increase as a result of climate change, producing larger spring populations as a base for a build up in numbers in the following season. Many insects such as *Helicoverpa* spp are migratory, and therefore, may be well adapted to exploit new opportunities by moving rapidly into new areas as a result of climate change (Sharma, 2005).

Pink bollworm range expansion *:* The distribution and abundance of pink bollworm, *Pectinophora gossypiella* Saunders (PBW) in cotton in Arizona and California was examined using a validated weather driven, physiologically based demographic model of cotton and PBW integrated into a geographic information system (GIS). Survival of diapause larvae during winter as affected by low temperatures is a key factor determining the range of PBW. The distribution of pink bollworm is predicted to be restricted to the relatively frost free cotton growing areas of Arizona and southern California where it currently reaches pest status. The model predicts that extension of PBW's range into the central valley of California is unlikely. The analysis questions the efficacy of an ongoing area-wide effort to prevent the establishment of PBW in the central valley of California. Four global warming scenarios were examined to estimate the effects on the potential geographic range of PBW. Average observed daily temperatures were increased 1.0, 1.5, 2.0 or 2.5 °C, respectively, in the four scenarios. Scenarios with average increase of 1.5-2.5 °C predicted that the range of PBW would expand into the central valley of California and the severity of the pest would greatly increase in areas of current infestation (Gutierrez *et al.,* 2005).

Pink bollworm reports in Gujarat *:* Reports of pink bollworm damage in BG II were received in July 2015. Farmers complained of pink bollworm in Amreli, Dhari, Jambusar in Bharuch, Karjan, Shinor-Padara and Daboi in Vadodara during July 2015. Pink bollworm damage was reported from Garaidar Taluka of Bhavnagar in August 2015. CICR deputed a team of scientists to survey the regions and collect samples for analysis. The team reported extensive occurrence of rosette flower symptoms that are caused due to pink bollworm damage. The damage ranged between 0-80 per cent on Bollgard II at Bharuch, Vadodara, Anand, Bhavnagar, Amreli, Junagadh, Rajkot, Surendranagar and Ahmedabad districts. Damage ranged between 11.0 to 67.0 per cent in Amreli on BGII. Occurrence of pink bollworm, so early in the cotton crop of Bollgard II was unusual, but not unexpected (Kranthi, 2014).

Sucking pests : Most studies on responses of insects to eCO_2 have been made using short term exposures to treated food plants and have involved measurements of responses of growth, reproduction, food consumption and efficiencies of conversion at specific stages of the life cycle. The longer-term studies recently published where whole generations have been reared in chambers with simultaneous treatments of plants and where insects have been free to select their food and micro-environment. In such studies, they have concluded that in studies to date, the only feeding guild in which some species have shown increase in population density under eCO_2 are the phloem feeders (Whittaker, 1999). Elevated temperatures can have serious effects on increasing populations of the whitefly and the cotton leaf curl virus disease (Kranthi, 2014). According to "*The Hindu* (Oct 18, 2015)", whitefly attack in Punjab has damaged over 75 per cent crop across cotton belts. *The Times of India* (Oct 8, 2015) reported that, whitefly has destroyed 2/3rd of Punjab's cotton crop. Due to aberrant weather, whitefly havock was noticed in Punjab, Haryana and Rajasthan states state which caused heavy yield losses to the cotton crop.

CONCLUSIONS

Insects are a recognized threat to cotton production throughout the world. Most insects can adapt their body temperature to the temperature of the environment. The effect of global warming on living organisms is slow enough for cotton insects to adjust to rising temperatures and other changes accruing from global warming. Thus, the insects currently plaguing cotton are expected to continue to be live and possibly thrive in new environmental conditions.

Many fear that global warming will affect insects' metabolism, allowing them to increase their multiplication rate. Rising temperatures will open new areas for colonization by insects and more of them will spread to newer areas. Increase in the populations of most important insects, such as bollworms, may also take place as a result of higher multiplication rates, along with the elimination of the need to go into diapauses during winter to avoid colder temperatures. The effects could be further amplified under conditions where alternate host plants are already available for wintering.

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Emerging insect pests and their future management strategies of *Bt* cotton in india

B. V. PATIL*, M. BHEEMANNA AND L. RAJESH CHOWDARY
University of Agricultural Sciences, Raichur - 584 104
**E-mail: bvp2001@rediffmail.com*

ABSTRACT : Cotton is livelihood for about 60 million Indian including farming, textile and trade sectors. With about 352 lakh bales of cotton production in 2015-2016 in the country, it is the second largest in the world next to China and productivity of 527.49 kg/ha which is much lower than that of China, Brazil and USA. The production and productivity of cotton in India has increased constantly with adoption of improved hybrids, at present there are six commercially released *Bt* cotton events with 1167 *Bt* cotton hybrids. Over the years, there has been an increasing trend to adopt double gene *Bt* cotton hybrids by cotton farmers in India, but apart from increase in the trend of cultivation the productivity remained constant due to several problems in cultivation of *Bt* cotton of which insect pests still play a major role. The pest scenario in cotton ecosystem has changed significantly and is assailed by multitude of pests as it evolves through various production levels. Unforeseen insect pests have emerged as potential threats in India due to large scale cultivation of *Bt* cotton. Upto 69 per cent reduction in usage of pesticides has been achieved and reliance on synthetic pyrethroids, broad spectrum highly toxic organophosphates has been almost ceased, paving way for dominance of emerging pests. The incidence of several emerging insect pests like mealy bugs, mirid bugs, flower midge and yellow mite on cotton has shown an increasing trend. Sap sucking pests like aphids, jassids, thrips and whiteflies are major pests and economically important of which whitefly outbreak in North India was severe and significant. Recently, the occurrence of resistance in *Bt* cotton to *Helicoverpa armigera* under laboratory and *Pectinophora gossypiella* under field situations in different regions of India had been reported. The present paper analyses the dominant factors influencing cotton production, factors involved affecting cultivation, primarily emerging pests on *Bt* cotton and the future strategies for *Bt* cotton cultivation in India.

Among the different GM crops cotton is the most important commercially cultivated in different parts of the world. Cotton (*Gossypium hirsutum* L.) is one of the principal commercial crop playing a key role in economic, social and political affairs of the country and it is a gift of the Indian sub continent to human civilization.Globally *Bt* cotton is cultivated in an area of 31.11 million ha with production of 21.81 million tons (Anonymous, 2016) among which India ranks first with an area of 11.76 million ha and third in production with 6.21 million tons (ICAC, 2016). After China, India is the largest producer and consumer of cotton, the country accounting for a little over 21 per cent of the global cotton production. Much of this success owes itself to the introduction of *Bt* cotton in 2002 prior to which cotton production suffered huge losses due to its susceptibility to insect pests.

Adoption of *Bt* cotton : Among the various GM crops that gained commercial acceptance, cotton is important for both the developed and developing countries as: a) A cash crop supplementing the livelihoods of millions of farmers, including small and marginal; and b) As a strategic raw material for the textile industry. Though cotton is grown in about 100 countries, almost 73 per cent of the world cotton area (35 million ha) and 80 per cent of production (43 million MT) is contributed by six countries, *viz.*, US, China, India, Pakistan, Brazil and Uzbekistan (FAO, 2010). Nevertheless, differences exist across countries in terms of the basic crop/commodity performance indicators, such as area, production, productivity, trade, etc for a host of reasons that are quite known. Following the introduction of the GM crops, the Monsanto Company developed the *Bt* cotton (*Bacillus thuringiensis* cotton) and there has been significant rise in *Bt* cotton area, especially the US, China, India, Australia, Argentina and South Africa. The wide scale switch over to *Bt* cotton in these countries may be seen as an outcome of farmer expectations that the technology would make the new cotton varieties insect resistant and herbicide tolerant and thereby help increase production and productivity as compared to the conventional and the hybrid non *Bt* cotton.

In India, the Genetic Engineering Approval Committee (GEAC) of the Ministry of Environment and Forest (MoEF) has made a formal approval for commercial release of *Bt* cotton in 2002. It was supposed to have major impact on the cotton sector in the country in terms of effective control of bollworms and thereby leading to rise in production and productivity of cotton. It was observed that following the introduction of *Bt* cotton, there has been tremendous expansion in area under *Bt* cotton in the country from 44,500 ha in 2002 - 2003 to about 11.76 million ha in 2015 - 2016. At present, there are as many as 1167 *Bt* hybrids available in the markets in India, a vast majority of which have been widely adopted by the farmers in Maharashtra and Gujarat in particular. It may also be observed that following the release of *Bt* cotton, there has been a tremendous increase in cotton production in all the states and often the increasing output levels. India's cotton sector directly supports about 5 million farmers spread across 9 states and it occupies a pivotal position in the domestic economy as a strategic industrial raw material for the textile industry. With a cultivated area of around 11.76 million ha, India ranks first in world cotton area and is the third largest cotton producer after US and China. Even though India ranks first in cotton area, its productivity is one of the lowest in the world, because almost 65 per cent cotton cultivation is rain dependent. Continued presence of cotton in the Indian subcontinent spread over a crop cycle of 8 - 10 months makes it home for pest, diseases and other biotic stress agents to survive, multiply and cause frequent epidemics.

The adoption of *Bt* cotton in India increased by 600,000 ha to a record 11.76 million ha, equivalent to a high adoption rate of 95 per cent of total cotton area. The number of *Bt* cotton farmers increased to 7.9 million in 2016 from 7.3 million in 2013. In the thirteen year period, 2002 to 2016, India tripled cotton production from 13 million bales to 39 million bales in 2014, with a projected 42 million bales in 2016. World cotton production is 151 million bales in 2015, and impressively, India contributed one quarter of this global total.

Concerns and the way ahead : *Bt* cotton has evoked unprecedented interest and debate among a large section of Indian public comprising biotechnologists, plant breeders, economists, social scientists, environmentalists, civil society and farmer organizations. A number of concerns were highlighted in the first edition of this publication quite a few of which have now been addressed. For example, *Bt* cotton seed price has reduced substantially making it more affordable to the farmers. Adoption of Event based approval mechanism by GEAC has greatly simplified commercialization of hybrids incorporating events with already proven biosafety. Apart from this there are several issues related to cultivation of *Bt* cotton and future challenges with respect to their management which are discussed below.

Impact of *Bt* cotton on Indian agriculture : Impact of *Bt* cotton on Indian agriculture appears to be the replacement of large tracts of varietal areas of north India, with *Bt*-hybrids, since the technology is available in India only in the form of hybrids. *Bt* cotton seems to have reduced the overall quantity of insecticide substantially, in many parts of the country, coupled with spectacular yield increases reported from Gujarat, while rest of the states have been showing mixed results despite increase in the area and production under *Bt* cotton. Six events have been approved by the GEAC for commercial release in India. Currently more than 1167 *Bt* hybrids covering all the events and developed by more than 45 seed companies have been approved for commercial cultivation. Out of this, majority of hybrids belong to intra *hirsutum* category and the few to the inter specific (*G.hirsutum x G.barbadense*) category.

Emerging pests on *Bt* cotton in India : The pest scenario in cotton ecosystem has changed significantly and is assailed by multitude of pests as it evolved through various production levels. American and spotted bollworms attained secondary pest status, and tobacco caterpillar, pink bollworm, mirids, yellow mites and mealy bugs are emerging as major pests. Sap sucking pests like aphids, jassids, thrips and whiteflies are major pests and are economically important. Adoption of *Bt* cotton has not only changed the cultivation profile, but also the pest scenario. While there is a decline in the pest status of bollworms; the sap feeders, *viz.,* aphids, jassids, mirids and mealy bugs are emerging as serious pests (Vennila, 2008). Recently, mirid bugs, *Ragmus* spp. and *Creontiades biseratense* (Distant) appeared in epidemic form in Dharwad and raichur (Karnataka) and Coimbatote (Tamil Nadu). Also, some of the minor pests like thrips, *Thrips tabaci* Linderman; shoot weevil, *Alcidodes affaber* Aurivillius and stem weevil, *Pempherulus affinis* (Faust) are becoming serious on *Bt* cotton (Sarode *et al.,* 2009).

Various species of mealy bugs have started appearing in serious proportions on field crops, vegetables, fruits and ornamentals (Tanwar *et al.,* 2007). In fact, mealy bugs have become indicator insects for the current ecosystem alterations due to slow changes in climate during the period from 2002 to 2009. Among these, *Phenacoccus solenopsis* Tinsley on cotton and *Paracoccus marginatus* Williams and Granara de Willink on papaya have become quite serious. During 2006, *P. solenopsis* appeared for the first time on cotton crop in Punjab and caused severe losses in some pockets of Ferozepur, Muktsar and Bhatinda districts (Dhawan and Saini, 2009). Since then this pest has spread to several states like Haryana, Rajasthan, Maharashtra and Gujarat and southern states (Atwal and Dhaliwal, 2009; Nagrare *et al.,* 2009). Besides cotton, *P. solenopsis* has been recorded on several economic crops like okra, tomato, brinjal, chilli, grape, fig, date palm, apple, avocado, banana, citrus, etc. (Mohindru *et al.,* 2009). A nymphal parasitoid, *Aenasius bambawalei* Hayat, of *P. solenopsis* has been recorded (Hayat, 2009), which caused upto 80 per cent parasitization on cotton (Ram *et al.,* 2009) and 30 per cent on tomato (Mohindru *et al.,* 2009).

Helicoverpa armigera (Hubner) had become a menace in pulse growing regions and started causing considerable damage to chickpea and pigeonpea. The last epidemic of *H. armigera* on these crops was reported in 2001. However, after the introduction of *Bt* cotton in 2002 and its subsequent rapid adoption, its infestation in these crops has significantly declined in the cotton based cropping systems. *H. armigera* sequently moves from cotton to pigeonpea and then to chickpea. As *H. armigera* is not able to survive on *Bt* cotton, its cycle gets disrupted and there is no significant movement of the pest from cotton-to-pigeonpea-to-chickpea (Bambawale *et al.,* 2009).

As *Bt* (Cry 1Ac) cotton provide least protection against tobacco caterpillar, *Spodoptera litura* (Fabricius), it continues to inflict economic damage in several cotton growing regions of India. Recently, there was an outbreak of *S. litura* on soybean in Kota region of Rajasthan and a loss of Rs 300 crore was estimated. The pest also struck in epidemic form on soybean in Vidarbha region of Maharashtra in August 2008 and caused widespread losses (Dhaliwal and Koul, 2010). Moreover, the intensity of *S. litura* is likely to further increase under the potential climate change, as it has been found to consume more than 30 per cent cotton leaves at elevated CO_2 levels (Kranthi *et al.,* 2009).

Cotton plantations in Punjab have come under a major 'Whitefly' attack, triggering fears of a massive yield loss in the *kharif* crop in the state. With cotton growing areas witnessing the "worst" attack of whiteflies in past five years, experts are blaming humid weather conditions for the widespread attack. Over all whitefly attack in Punjab that damaged over 75 per cent crop across the cotton belt. The damage to the cotton crop, over 95 per cent of which is *Bt* cotton, is estimated to be around Rs. 4,500 crore (Anonymous, 2015).

Resistance development in *Bt* cotton : It is expected that any competitive biological system would respond to high level of selection pressure by mechanisms that would either avoid or mitigate it. Random genetic changes that keep happening in a population of insects might include resistance alleles at very low frequency, which can rapidly increase when challenged. *H. armigera* has already developed resistance to many potent insecticides, especially to pyrethroids (McCaffery *et al.* 1989, Armes *et al.*, 1996; Kranthi *et al.*, 2001, Fakrudin *et al.,* 2004). There is also an indication that mechanisms of detoxification for different insecticides do overlap (Vijaykumar and Patil, 2005). In this context, wide spread use of *Bt* cotton and other *Bt*- crops has to be considered. Like with chemical insecticides, *H.armigera* has a potential to develop resistance to Cry toxins under field conditions due to continued selection pressure, throughout the crop growth period, if proper resistance management tactics are not implemented. So far there is no field resistance observed for *Bt* Cotton. However, wide geographic variation in susceptibility of *H. armigera* to Cry1Ac toxin has already been reported in India (Gujar *et al.,* 2000; Kranthi *et al.*, 2001; Fakrudin *et al.,* 2003; Jalali *et al.*, 2004), China (Wu *et al.*, 1999) and in Australia (Liao *et al.,* 2002). The ability of lepidopterans to develop resistance to Cry toxin under laboratory conditions was demonstrated well before the commercial release of *Bt* transgenics (Tabashnik *et al.*, 1994; Gould *et al.*, 1995; Kranthi *et al.,* 2000) and subsequent studies in laboratory and on field collected larvae do point to this fact (Vijaykumar and Patil, 2005).

Development of resistance to Cry protein is a concern, which is being addressed by evolving different management strategies. Besides refuge crop, there are other ways of resistance management *viz.*, gene pyramiding, application of insecticides and biorationals at a critical stage of the crop and other IPM strategies for delaying resistance build up in the insect population or to keep it at strategically low levels. Predictions based on a stochastic model with input parameters for Indian conditions, Kranthi and Kranthi (2004) have estimated that it required *H.armigera* 11 years to reach resistance allele frequency of 0.5. Semi dominance for resistance to the toxin, 40 per cent cotton area under *Bt*- cultivars, very low initial frequency of resistance allele were some of the assumptions and refuge crop at 20 per cent would delay resistance development by two more years. In fact, 11-13 years is a good period for resistance to hold under modern agriculture. However, resistance development in insects is real and it has to be 1) managed with a sound IRM strategy, 2) *Bt*-technology used as a component of IPM, 3) limited use of insecticide molecules in case of partial or complete failure of Cry toxin and 4) gene pyramiding whenever necessary. As of now, ETL based application of chemical pesticides in *Bt*-cotton is recommended once after 90 DAS (Kranthi *et al.* 2004) or 1-2 times (Rajanikantha and Patil, 2004) based on ETL.

The All-India Coordinated Cotton Improvement Project (AICCIP) reported high catches of *P. gossypiella* with pheromone traps in Gujarat, especially at Surat and Junagarh, during the last week of November 2009 to January 2010, and in Rajasthan at Sriganganagar from August to October 2009, as compared with ten other locations in the country. The presence of larvae in green bolls of *Bt* cotton has also been reported in some locations in the country (private communication, http://www.cicr.org.in). However, on 6 March 2010, Monsanto India Limited reported pink bollworm resistance to *Bt* cotton producing Cry1Ac planted in 2009 under field conditions in four districts of Gujarat, namely Amreli, Bhavnagar, Junagarh and Rajkot, on the basis of bioassays and the presence of larval incidence and damage to *Bt* cotton (www.monsantoindia.com). The data reported here constitute the first evidence of field evolved resistance of pink bollworm to Cry1Ac and this initial evidence spurred more extensive evaluations during the 2009–2010 growing season, which confirmed field-evolved resistance to Cry1Ac in Amreli. The lack of cross-resistance to Cry2Ab2 suggests that plants producing this toxin are likely to be more effective against resistant populations than plants producing only Cry1Ac (Sanyasi Dhurua and Govind Gujar, 2011). Among the bollworms in the recent past the incidence of pink bollworm, *Pectinophora gossypiella* started to appear on both single and staked cotton hybrids. In the present year the pink bollworm damage is noticed in the cotton fields at various places at Raichur, Karnataka. The damage on both flowers and bolls was noticed. Over all the boll damage at different locations in Raichur district ranged from 30 per cent to 80 per cent.

FUTURE STRATEGIES OF *Bt* COTTON CULTIVATION

Resistance management strategies-new insights for the Indian conditions : In India 5 border rows of non *Bt* cotton surrounding *Bt*-Cotton per acre has been recommended. The area accounts for 20 per cent refugia. However, modeling studies showed that maintenance of a 20 per cent refugia may not confer significant advantage in delaying resistance development. This is mainly due to the natural availability of non structured refugia in the form of alternate host crops in the cotton eco system. The most important strategies in *Bt* resistance management would be to reduce the *Bt* cotton surviving population of *H. armigera* through any pest management practices. The extent of reduction in the surviving population, which represents resistant genotypes, would determine the longevity of the technology utilization. Therefore the strategies that would enable extending the usefulness of *Bt* technology would be.

Use alternate genes that do not share common resistance mechanisms as that of Cry1Ac, in transgenic plants either in rotation or alternation or mixtures.

Use eco friendly methods such as cultural control or handpicking of surviving bollworms in *Bt* cotton fields. Biopesticides that are neem based or HaNPV would be useful to manage younger larvae on 60-90 days old crop. Alternatively, conventional insecticides such as, thiodicarb and chlorpyriphos, or new molecules such as spinosad, emamectin benzoate, novaluron or Indoxacarb etc., can be used on 90 and 120 days old crop to reduce populations of resistant genotypes.

Identify and use attractive synchronous alternate host crops for *H. armigera* which could be used as intercrop or trap crop refuges.

Avoid use of *Bt* based biopesticides that may contribute to selection of a broad-spectrum resistance to several useful *Bt* genes of interest.

Refuge in bag (RIB) : To ensure refuge compliance as a proactive measure towards insect resistance management (IRM), a new approach has been developed wherein *Bt* and non *Bt* seeds are pre mixed in a recommended proportion and made available to farmers in the same packet or bag. This technique is referred to as ‘refuge in a bag’ (RIB) in USA, where it is deployed for the *Bt* corn products and in India as 'refuge in mixed bag'. For the sake of uniformity and better clarity, the name 'refuge in seed-mix' (RISM) appears to be more appropriate and is used in this note (Manjunath, 2007).

The objective of RISM in *Bt* cotton is to ensure that non *Bt* plants are randomly distributed among *Bt* cotton plants in a field in a pre-decided proportion. The presence of such randomly distributed non *Bt* plants may raise certain concerns such as:

Potential movement of the later instar larvae of *Helicoverpa armigera* from non *Bt* to *Bt* plants, thus causing crop damage and exposure of such migrant larvae to sub lethal dose of *Bt* protein, thereby increasing the chances of resistance development. These concerns appear valid, but their actual impact needs to be examined in the Indian context from a practical perspective, especially in view of certain data available elsewhere on the adverse fate of the *Bt* fed later instar larvae and also that RISM is considered as a practical strategy towards IRM in pursuit of preserving a remarkable technology like *Bt* cotton (Manjunath, 2007).

The role of alternative hosts in IRM, particularly in developing countries : Of particular importance in defining refuge strategies for developing countries is the role of alternative hosts of the target pests. If the target pests are utilizing a wide variety of alternative host crops, and they are not being controlled using *Bt* on these other hosts, then structured refuges for *Bt* crops may not be necessary under these conditions; the alternative host plant species will act as an adequate source of refuge for the *Bt* crop (Siegfried *et al.,* 2006; Sivasupramaniam *et al.,* 2007). In these cases, both cropping practices and the degree of polyphagy of the target insect species will be important. For IRM approaches based on alternative host plant species to be effective, several conditions should be examined:

The target pest species must utilize multiple host plant species that overlap in both space and time;

The performance on the different host plant species must be comparable to allow the different alternative hosts to produce sufficient susceptible insects at the right time to interbreed with any resistant insects emerging from the *Bt* crop;

The distribution of these different host plant species must overlap at a sufficiently fine scale and consistently enough to act as a functional refuge in all relevant areas; and the pest insects must move freely between the different host plant species

Combining insect control methods : The next general approach to resistance management combines elements of both old and new ideas. It is assumed that resistance is less likely to evolve to two control methods simultaneously than to only one method. Thus, with two methods, resistance to the combination will be delayed more than using each individually in a temporal or spatial arrangement. Using two or more control methods at a time is like having insurance in case one of them begins to lose efficacy. Similar to this is a method of heightening effectiveness of a toxin by using a high dosage like having one dose as the first control method and a second dose as the other, though the underlying theory is different.

Use of economic thresholds and integrated pest management (IPM) : Integrated pest management (IPM) that uses *Bt* cotton as one of the component is the ultimate option of IRM including cultivation of sucking pest tolerant *Bt* genotypes, seed treatment (Imidacloprid 70 WS or Thiomethoxam 70WS @ 5-7g/kg),Inter cropping with cowpea, soybean and blackgram, Stem application of acetamiprid or thiomethoxam or imidacloprid at 40 DAS, Avoidance of broad spectrum organophosphates as early season sprays, Identify and use attractive synchronous alternate host crops for *H. armigera,* which could be used as intercrop or trap crop refuges, Use alternate genes that do not share common resistance mechanisms as that of Cry1Ac, in transgenic plants either in rotation or alternation or mixtures.

High density planting system : The manipulation of row spacing, plant density and the spatial arrangements of cotton plants, for obtaining higher yield have been attempted by agronomists for several decades in many countries. Several leading cotton producing countries like USA, Australia, Brazil, Uzbekistan and China have developed suitable plant types to accumulate plant densities varying from 1 lakh to 2.5 lakh plants/ha with using narrow and ultra narrow row spacing. The most commonly tested plant densities range from 5 to 15 plants/m2 (Kerby *et al.,* 1990) resulting in a population of 50000 to 150000 plants/ha. The concept on high density cotton planting, more popularly called Ultra Narrow Row (UNR) cotton was initiated by Briggs *et al.* (1967). UNR cotton has row spacing's as low as 20 cm and plant population on the range of 2 to 2.5 lakh plants/ha, while conventional cotton is planted in rows 90 to 100 cm apart and has a plant population of about 100,000 plants/ha. However in India, the recommended plant density for cotton seldom exceeded 55000 plants/ha.

The UNR system is popular in several countries like Brazil, China, Australia, Spain, Uzbekistan, Argentina, USA and Greece (Rossi *et al.,* 2004). The availability of compact genotypes, acceptance of weed and pest management technologies including transgenics, development of stripper harvesting machines and widespread application of growth regulators have made these high density cotton production systems successful in these countries.

The obvious advantage of this system is earliness (Rossi *et al.,* 2004) since UNR needs less bolls / plant to achieve the same yield as conventional cotton and the crop does not have to maintain the late formed bolls to mature. The UNR cotton plants produce fewer bolls than conventionally planted cotton but retain a higher percentage of the total bolls in the first sympodial position and a lower percentage in the second position (Vories and Glover, 2006).The other advantages include better light interception, efficient leaf area development and early canopy closure which will shade out the weeds and reduce their competitiveness (Wright *et al.,* 2011). The early maturity in soils that do not support excessive vegetative growth (Jost and Cothern, 2001) can make this system ideal for shallow to maturity hybrids experience terminal drought. Therefore the high density planting system (HDPS) is now being conceived as an alternate production system having a potential for improving the productivity and profitability, increasing input use efficiency, reducing input costs and minimizing the risks associated with the current cotton production system in India. High density planting of short duration, early maturing straight varieties that will deliver more cotton at a lower cost and hopefully move farmers in dry, rain dependent areas of Maharashtra and Telangana from distress to financial comfort. Plant population of 110,000/ ha, which is ten times more than what farmers do. Each plant will yield just four bolls against eighty which farmers take from hybrids by prolonging their life. The longer the duration of the crop the higher is the susceptibility to pests. Bolls mature in one go, plant protection becomes easier. This means lesser use of insecticides and lower cost (CICR, 2016). CICR is expected to incorporate the toxic gene derived from a soil bacterium in its straight varieties and hybrids suitable for central India.

CICR is promoting a non *Bt* variety called Suraj for Rs 750 a bag of 5 kg. *Bt* hybrids are under price control and cannot sell for more than Rs 830 a pack of 450 g in many states. This is a reduction of Rs 100 from last year. Many states imposed the discount because of a slump in cotton prices earlier this year. Seed companies moved court, but did not get relief. High density planting is viable only if seeds are cheap but availability is an issue. *Bt* technology in CICR varieties may help persuade farmers to try out high density planting, as it will assure them that their crop will be protected. Private seed companies say high density planting is possible only with machine sowing and harvesting. For that the plants must be of uniform height and the bolls must form and burst at the same time. They are themselves experimenting with densities of 33,750 and 50,000 hybrid plants/ ha.

CONCLUSION

Future research should focus on the gaps in our knowledge listed above, especially regarding pest behaviour of different insect pests and the characteristics of insect resistance that we do not yet fully understand. This will lead to more reliable pest management programs. Care must also be taken that growers are fully aware of the details of these management programs and what they should do to ensure their crops are in compliance. Biotechnology can be used for or against our advantage in resistance management. Further research can tell us which way to go. *Bt* based transgenic crops represent the state of art in pest management. *Bt* is nearly an ideal pesticide and the loss of its use would be an extremely unfortunate occurrence. It is therefore necessary to enrich and preserve the life of such an excellent eco-friendly pest management strategy. Research into time-specific technologies should also continue. While existing technologies continue to break down, new technologies continued to be invented, almost all of them for short term gains but care should be for development and execution of appropriate management strategies are imperative to ensure sustainability of the technology. Each of these elements must be assessed with a specific focus on the local conditions and agricultural practices that should be considered in the development of pest management plan, because no matter how detailed the scientific information, these local conditions are critical for successful deployment.

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Cotton pathology researches in India- Salient achievements and the way forward

D. MONGA AND ASHISH KUMAR TRIVEDI

Central Institute for Cotton Research, Regional Station, Sirsa - 125 055

**E-mail : dmonga2009@gmail.com*

ABSTRACT : Cotton is a commercial crop of great value in terms of raw material for textile industry and also as an important oil seed crop. India ranks first in area and production in the world but lags behind in productivity to 36th position. India is the only country in the world where all the four species *i.e., G. hirsutum*, *G. arboreum*, *G. herbaceum* and *G. barbadense* are commercially cultivated. In addition to that we also have inter and intra specific hybrids of all species popular in farmer fields. India introduced *Bt* cotton hybrids in 2002, the only transgenic crop permitted for commercial cultivation till date, which became popular with farmers and have occupied more than 90 per cent of cotton area. During the past two decades, PCR based molecular diagnostic tools for important cotton diseases have been developed and used for getting important information especially in case of viral diseases. Work on the development of prediction equations has been carried forward to develop robust forewarning systems. Resistant sources for major diseases have been identified after extensive screening programs. Other components of integrated diseases management (IDM) were strengthened by way of identification of new fungicides, cultural practices and bio control agents. Location specific IDM modules were also standardized under AICRP on cotton. In this paper recent research findings in the field of cotton pathology have been presented.

Cotton is a commercial crop of great value in terms of raw material for textile industry and also as an important oil seed crop. India ranks first in area and production in the world but lags behind in productivity to 36th position (Anonymous, 2017). India is the only country in the world where all the four species *i.e., G. hirsutum*, *G. arboreum*, *G. herbaceum* and *G. barbadense* are commercially cultivated. In addition to that we also have inter and intra specific hybrids of all species popular in farmer fields. India introduced *Bt* cotton hybrids in 2002, the only transgenic crop permitted for commercial cultivation till date, which became popular with farmers and have occupied more than 90% of cotton area. Cotton pathology basic research is mainly carried out by Central Institute for Cotton Research in the country whereas its applied aspects are dealt with by the All India Coordinated Research Project on Cotton with 22 centers spread across 17 Agricultural Universities. The research work in bits and pieces is also conducted at other research centers in public and private sector. Work carried out on cotton diseases was nicely summarized by Srinivasan (1994) in his book entitled "Cotton Diseases" more than two decades back. In this paper some more recent research findings have been presented.

New disease reports, their symptoms and diagnostic : Tobacco streak virus and cotton leaf roll dwarf virus are the two viral diseases of recent origin reported from the country. Disease caused by tobacco streak virus (TSV) is found to be one of the prominent emerging viral disease. The tobacco streak virus belongs to genus Illarvirus and family Bromoviridae (Johnson 1936; Fauquet *et al.,* 2005). Occurrence of TSV in India was first diagnosed from sunflower and ground nut crops affected with Sunflower necrosis disease (SND) and Peanut stem necrosis disease (PSND) respectively (Prasad *et al.,* 2000; Ramaiah 2001; Reddy *et al*., 2002).

The cotton mosaic disease is reported to occur globally such as Brazil, USA, Australia and Pakistan (Cauquil and Folin 1983; Sharman *et al.,* 2008; Ahmed and Nelson 1997; Waqar *et al.*, 2003). But in India, first description of natural infection of TSV on cotton was reported from samples collected from Aurangabad, Maharashtra by Bhat and coworkers 2002. However, an outbreak of TSV on cotton was reported in Khammam and Warangal districts of Andhra Pradesh during 2005 on 20,000 ha of cultivated fields (CSA, 2006). Various methods have been employed to detect TSV, including enzyme linked immunosorbent assay (ELISA) (Bhat *et al.,* 2001and Ahmed *et al.,* 2003) and RT-PCR (Bhat *et al.,* 2002). These diagnostics are based on detection of proteins and nucleic acid specific to the pathogen or disease. Development of new diagnostic tools with high sensitivity, specificity and rapidity, will have immense role to play in timely detection and management of new virus diseases. Recently, the protocol for rapid diagnosis of TSV infected samples by using RT-LAMP was standardized (Gawande *et al.,*2017) and this is also the first report of use of RT-LAMP technique for rapid diagnosis of TSV on cotton (*G. hirsutum*). The colorimetric detection for diagnostic simplicity of amplified RT-LAMP product by using different dyes lead to enhanced applicability of this technique.

Extensive studies on various aspects of the virus and disease were carried out by Vinod Kumar *et al.,* 2016 Symptoms associated with Tobacco streak virus (TSV) in cotton are usually disparate, based upon the host pathogen interaction. Chlorotic or necrotic, irregular or circular, purplish or dark brown to black spots are observed on the infected leaves, scattered or confined to a particular area. Presence of TSV in the infected leaves, stem and square samples were serologically detected through DAC-ELISA. Besides, selected isolates were subjected to RT-PCR amplification of coat protein (CP) gene, pertaining to TSV. They were further confirmed by sequencing the CP gene. Reverse Transcription - Polymerase chain reaction (RT-PCR) studies on the cotton seeds, pollen and *Parthenium* pollen revealed the presence of TSV in the cotyledon and pollen of cotton. TSV was also detected in the pollen of *Parthenium* plants. Sodium phosphate buffer – 0.5M (pH 7.2), ammended with (0.1%) sodium sulphite, (0.01%) sodium EDTA, and (0.1%) mercaptoethanol was found consistent for mechanical transmission of TSV to suitable indicator hosts. Physico-chemical studies revealed that TSV was thermally inactivated at 53^0C. Moreover, cowpea (CO7) produced maximum number of lesions (29.33/cm^2) when incubated at 12 hrs alternate light and dark hours compared to other light and dark conditions. Bioassay studies on various indicator hosts revealed that *Chenopodium quinova* and *C. amaranticolor* were highly suitable indicator hosts, with highest virus titre. Screening of cotton endophytes, PGPRs (plant growth promoting rhizobacteria), and antiviral principles against cowpea plants, artificially inoculated with TSV revealed that, Cotton endophyte (M2), *Baillus amyloliquefaciens* (VB7) and *Mirabilis jalapa* were notably effective in reducing the number of lesion produced by TSV. TSV has a broad host range comprising of more than 200 plant species consisting of 30 different plant families (Fulton, 1985; EPPO, 2005), making it one of the most important plant viruses with economic significance. Further studies on effective rating scale, germplasm and commercial hybrids screening to identify resistant sources, loss estimations and epidemiological studies are needed for its management.

The cotton leaf roll dwarf virus (CLRDV) is one of the most devastating pathogens of cotton. This malady, known as cotton blue disease, is widespread in south America where it causes huge crop losses. Mukherjee *et al.,* (2012) made first report of *Polerovirus* of the family *Luteoviridae* infecting cotton in India. This positive sense single stranded RNA virus is transmitted by aphids (*Aphis gossypii*) in a circulative-persistent manner. Cotton plants affected by this disease show stunting, leaf rolling, intense green foliage, vein yellowing, brittleness of leaves, reduced flower and boll size, sometimes resulting in sterility in plants. Leaf samples from plants with symptoms suggestive of CLRDV and apparently healthy plants were collected from cotton fields at Nagpur, Maharashtra and washed with *RNase*-free sterile double distilled water before total RNA isolation. RNA was extracted from leaf samples using Spectrum Plant Total RNA kit (Sigma USA). RT-PCR was performed using Qiagen One Step RT-PCR kit (Qiagen, USA) following the manufacturers' instructions with the primers PL4F(5'- GCGACAAATAGTTAATGAATACGGT-3') and o3R (5'-GTCTACCTATTTBGGRTTNTGGAA-3'). The primers were designed to amplify a region of approximately 600 bp of the capsid protein sequence of CLRDV (Corrêa *et al.,* 2005). PCR conditions were: denaturation at 94°C for 45 s, primer annealing at 49°C for 45 s, extension at 72°C for 45 s for 35 cycles and final extension at 72°C for 10 min. PCR from symptom-bearing samples resulted in the amplification of a 600 bp band which is the expected size. PCR from healthy samples did not produce an amplicon. The PCR products were sequenced directly and the resulting sequence was deposited at gene bank (Accession No. JN033875). The coat protein sequences derived from the PCR products from symptom bearing plants showed more than 90 per cent similarity with Cotton leafroll dwarf virus and Chickpea stunt virus (another member of *Polerovirus*) as reported by earlier workers (Corrêa *et al.,* 2005; Silva *et al.,* 2008; Distefano *et al.,* 2010)**.** Utmost vigil is needed to ascertain the extent of occurrence of this disease in various cotton growing areas in India and plans to take up further studies need to be formulated.

New diagnostic tools development : Grey mildew immune lines *viz.,* G 135-49, 03805, 30814, 30826, 30838, 30856, EC-174-092 and susceptible check AKA 8401 were subjected for

RAPD analysis. OPERON kit primer OPC and OPD were used for PCR amplification. A total of 762 products were obtained out of which 28% were polymorphic in nature. OPC 2 primer produced unique fragment of 1.5 kb size which is present invariably in all immune lines and absent in the susceptible check. The PCR derived RAPD product OPC 02 1500 can be used as diagnostic tool for identifying the Grey mildew resistant line in the germplasm gene pool (Anonymous, 2003-2004).

· The PCR based diagnostic methods were developed during 2003-04 for rapid detection and diagnosis of strains of *Xanthomonas axonopodis* p.v. *malvacearum* and cotton leaf curl virus that infect cotton. *Xanthomonas axonopodis* p.v. *malvacearum* specific primers amplified a 426 bp fragment of pathogenicity gene pthN present in all strains of this bacterial pathogen, irrespective of their pathogenic race or geographic area of origin. The method is capable of detecting the bacterium in plant materials without the need of using purified DNA in PCR. This is the first report of PCR based detection of strains of *Xanthomonas axonopodis* p.v. *malvacearum*. The Cotton leaf curl virus-specific primers precisely detected the virus in infected cotton as well as in symptomless plants by amplification of 771 bp coat protein gene. Both the methods are rapid with amplifications accomplished between 1.30-1.45 hr and are routinely employed in our lab for detection of these pathogens of cotton *Polymerase chain reaction-based detection* of *Xanthomonas axonopodis* p.v. *malvacearum* and cotton leaf curl virus (Chakrabarty, *et al.,*2005).

· Twenty arbitrary primers (Operon Technology) from kit OPR were tested for their RAPD pattern by using genomic DNA from *Ramularia areola*. Primer OPR-3 successfully amplified most of the isolates. RAPD- PCR pattern of amplification with primer OPR -3 from the isolate of the three cultivated species of *G. arboreum*, *G. herbaceum* and *G. hirsutum* gave the clear identification variation among the isolates at species level (Anonymous, 2005-2006).

· Two species-specific primers were developed ITS-Rb-F and ITS-RB-R for quick identification of *Rhizoctonia bataticola* sp. The primer showed good specificity for the sp. *R. bataticola* and product ranging 410-462 bp was amplified exclusively when tested with isolates of *R bataticola.* PCR sensitivity ranged from 1pg to 10 ng for DNA extracted from *R. bataticola* mycelium. No amplification products were detected from isolates *Rhizoctonia solani* using the primers. The assay is useful for rapid identification of *R. bataticola* sp. culture and their differentiation from *R. solani* in mixed infections (Anonymous, 2005-2006).

· PCR based protocols were developed and improvised for specific detection of four major foliar fungal pathogens of cotton *viz.*, *R. areola*, *R. bataticola*, *R. solani* and *A. macrospora.* Primers were developed based on variable nucleotide sequences in the ITS 1 and ITS 4 of the ribosomal RNA genes of these pathogens. Four sets of primers *viz.,* pRSol, pRBat, pAMac and pRare could specifically detect strains of *R. solani*, *R. bataticola, A. macrospora* and *R. areola* by amplification of rDNA fragments of 255, 400, 542 and 372bp, respectively (Chakrabarty, 2006).

· A species specific PCR primer capable of detecting all strains of *Rhizoctonia bataticola* was also developed and validated at Sirsa center. The new set of primer detects all strains of *R. bataticola* by amplification a fragment of 450bp

(Chakrabarty, 2006).

Epidemiology : Prediction equations for important diseases like Cotton leaf curl virus disease, Bacterial leaf blight, Alternaria leaf spot and Grey mildew have been developed under All India Coordinated Project of cotton in recent years (Monga *et al.,* 2011; Bhattiprolu and Monga, 2017, Anonymous 2014-2015a, Anonymous 2016-2017).

Yield loss assessment trials under AICRP: Based on pooled results (2007-2009) it was estimated that Alternaria leaf spots cause loss up to 26.59 per cent. Five sprays of Propiconazole (0.1%) at 35, 50, 65, 80 and 95 DAS decreased PDI from 31.59 to 20.85 per cent thereby reducing yield loss due to Alternaria leaf spots in variety LRA-5166 by 26.59 per cent. CBR was in range of 1.68 to 1.92 as compared to 1.62 in control. Four to five sprays of Propiconazole (0.1%) at 15 days interval is cost effective against Alternaria leaf blight. (Monga *et al.,* 2013).

· There years pooled results of leaf rust at Dharwad (2009-2011) showed reduction of PDI from 32.8 to 7.73 and reduction of yield loss up to 21.7 with four sprays of Propiconazole (0.1%) at 15 days interval from 75 days after sowing in Bunny *Bt*. CBR varied from 2.44 to 2.68 as compared to 2.39 in control. Three to four sprays of Propiconazole (0.1 %) at 15 days interval is cost effective against leaf rust in *Bt* cotton hybrid, Bunny .Pooled data using *Bt* cotton hybrid, RCH 2 BG II for rust at Guntur Andhra Pradesh also showed four sprays of Propiconazole (0.1%) at 15 days interval from 75 days after sowing reduction of PDI from 29.0 to 10.72 and reduction of yield loss up to 34.05. CBR was in the range 1.55 to 1.82 whereas it was 1.26 in control. Highest CBR of 1.82 obtained with four sprays of Propiconazole (0.1%) at 15 days interval is cost effective against leaf rust in *Bt* cotton hybrid, RCH 2 BG II (Monga *et al.,* 2013).

· On the basis of three year trial, pooled results showed that Five sprays of Propiconazole (@ 0.1%) at an interval of 35, 50, 65, 80 and 90 DAS at Khandwa showed reduction of *Myrothecium* leaf spots PDI from 22.51 to 7.44 per cent and reduction of yield loss up to 29.15 per cent (Monga *et al.,* 2013).

· Five sprays of Carbendazim at 35,50,65,80 and 95 days after sowing showed maximum reduction of PDI due to grey mildew at all the three locations ie Dharwad, Guntur and Nanded. Based on Pooled data (2008-2010) lowest per cent disease index (PDI) of 8.10 was observed after five sprays as mentioned above as compared to 20.87 in control. There was reduction of loss upto 29.20 per cent with the application of five sprays of Carbendazim (Monga *et al.,* 2013).

· Pooled data for three years (2010-2012) at four centre (Dharwad, Guntur, Surat and Akola), revealed that five sprays of copper oxy chloride and streptocycline at 35, 50, 65, 80 and 95 days after sowing showed reduction of bacterial blight PDI from 28.8 to 12.0 and reduction of yield loss upto 22.0 per cent. CBR varied from 1.41 to 1.51 as compared to 1.11 in control. Three to five sprays of COC (0.3%) and Streptocyclin 100 ppm at 15 days interval is beneficial against bacterial blight disease (Monga *et al.,* 2013).

· The seed cotton yield reduction due to cotton leaf curl virus disease was maximum in RCH 134 BG during 2009-2010 in Punjab. During

2010-2011 also, 42.9 per cent reduction in seed cotton yield was observed in experiments conducted at Faridkot and Hisar. The seed cotton yield reduction ranged from 25.2 per cent in MRC 7031 BG II to 46.6 per cent In SP 7007 BG during 2011-2012 (Monga *et al.,* 2013).

INTEGRATED DISEASE MANAGEMENT:

(i) Plant quarantine : To check the spread of CLCuD and other viral diseases like Cotton leaf roll dwarf virus (CLRDV) reported few years ago, effective quarantine measures are required. Recent evidence suggests that we are already seeing the first instances of the spread of CLCuD from Africa to Pakistan. The African CLCuD associated *begomovirus*, CLCuGeV has been identified in cotton in southern Pakistan (Tahir *et al.,* 2011). However, the African cotton betasatellite, Cotton leafcurl Gezira betasatellite, has not been found in Pakistan and there is no evidence yet for recombination between the African and Asian viruses.

· Far more worrying is the recent outbreak of CLCuD in southern China (Cai *et al.,* 2010), geographically far removed from the areas of Pakistan and India that are affected. The disease was first reported in *Hibiscus rosa-sinensis* (Mao *et al.,* 2008) and subsequently okra (Xie *et al.,* 2012). In each case, the disease was shown to involve CLCuMuV and CLCuMuBMul. Analysis of the sequences showed them to be most closely related to virus and betasatellite isolates identified in India/Pakistan in *H. rosa-sinensis.* Three strains of CLCuMuV are recognized at this time and the isolates in China are all of the 'Faisalabad' strain the strain prevalent in Pakistan prior to resistance breaking. *H. rosa-sinensis* is a well known alternative host of the CLCuD complex and this strongly suggests that the disease was introduced into China in infected *H. rosa-sinensis* from India or Pakistan. Pakistan exports ornamental plants, including *H. rosa-sinensis*, mostly to the Gulf States, and the source plants from which cuttings are taken are almost universally symptomatic. The sequence evidence for the CLCuD outbreak in China indicates that it is the 'Multan' strain that has been introduced. This suggests that the resistance seen in Pakistan during the 1990s (Rahman *et al.,* 2005) could potentially be useful in controlling the outbreak, at least in cotton.

(ii) Resistant variety development : The AICCIP entries (333 nos.) consisting of National (124), Central Zone (119) and South Zone (90) were screened under poly house conditions separately for their reactions against grey mildew. After the development of the symptoms the plants were assessed for disease development. Eight lines viz RG 459, GAM 67, GAM 141, HLSa 802, KWA 225, AKA 9703 and ARBHA 35 *(G. arboreum)* and CCHB 727 were found to have resistance to grey mildew and 58 moderate resistances. Breeder's lines (77 nos.) were screened for their reaction against grey mildew and eleven lines exhibited moderate resistance to grey mildew (Anonymous 2006-2007a).

· From among 5000 *G. hirsutum* lines during 2013-2014 and 2128 lines during 2014-2015 screened against CLCuD, none of the line was found to be resistant/ immune. However, lines identified as tolerant to disease are being used in pyramiding resistance against this disease (Anonymous 2013-2014 and 2014-2015a).

· Genotype SVA 1118 was identified as resistant to *Alternaria* blight, Bacterial blight, Grey mildew and Rust. Genotypes NDLH 1938, TCH 1707 were identified as resistant against Alternaria leaf blight under AICRP (Anonymous 2014-15a).

(iii) Cultural practices : Growing of okra crop in around the cotton field should be discouraged and intercropping with wild brinjal (*Solanum khasianum*) for management ClCuD is advocated (Anonymous, 2014).

· Planting of 150 *Bt* cotton hybrids in north India at five locations at normal and late sowing conditions during 2014 season revealed much higher Percent disease intensity (PDI) when the hybrids were sown late. Four experiments [Released (100) and pre released (50) hybrids in normal (14-24 May, 2014) and late sown (4-7 June, 2014) conditions] were carried out at five locations in north India (Hisar and Sirsa in Haryana, Faridkot and Abohar in Punjab and Sriganganagar in Rajasthan). Each hybrid was sown in two rows of 10 plants each with a row length of 5.4 meters. A spacing of 67.5x60 cm was kept in all the trials. A design of 10x10 lattice was kept for released hybrids trial whereas the pre released hybrids were tested in RBD. Standard susceptible check was planted after every four lines of the test entry hybrids. Observations on the cotton leaf curl disease were recorded using 0-6 rating scale and average grade and per cent disease intensity (PDI) was calculated using standard formulae. The PDI in normal sown released hybrids ranged from 8.3-61.7 whereas it was 15.0-79.1 in late sown conditions. Similarly, The PDI in normal sown pre released hybrids ranged from 12.5-61.6 whereas it was 21.5-72.7 in late sown conditions. This clearly indicates less PDI during normal sown conditions (Monga *et al.,* 2017).

(iv) Biological control : Out of thirteen rhizosphere bacterial isolates, four were found to exhibit maximum inhibition and disease suppression of *Fusarium* wilt pathogen *Fusarium oxysporum* f. sp. *vasinfectum* and dry root rot pathogen *Macrophomina phaseolina* a part from promoting seedling vigour. The most promising bacteria belonged to *Pseudomonas fluorescence* and *Bacillus* spp.(Anonymous, 2006-2007a).

· Seed treatment with *Pseudomonas fluorescens* Pf-1 @10 g/kg seed plus foliar spray @ 0.2% on 30, 60 and 90 DAS is recommended for the management of foliar diseases in cotton (Anonymous, 2008-2009).

· *Fusarium pallidoroseum* was identified as an effective entomopathogen against cotton mealy bug *Phenococcus solanopsis* in north zone and its compatibility with insecticides was worked out for its integrated management (Monga *et al.,* 2010).

· Pooled results (2010-2012) of management of foliar diseases through application of Systemic acquired resistance (SAR) inducing chemicals at Dharwad, Guntur, Coimbatore suggest that SAR chemicals like Salicylic acid (SA) and Isonicotinic acid (INA) at 100 ppm protect cotton from fungal (*Alternaria*, Grey mildew and Rust) as well as bacterial (bacterial blight) disease with good yield and cost benefit ratios (Bhattiprolu *et al.,* 2014).

· The potential of cyanobacteria-based compost formulations was evaluated in cotton crop at two agro ecological locations (Nagpur and Sirsa) as plant growth promoting (PGP) and biocontrol agents. In the fungi infected ûelds at Sirsa, *Anabaena T. viride* bioûlmed formulation performed the best, recording 11.1 per cent lower plant mortality than commercial *Trichoderma* formulation. Scanning electron microscopy conûrmed the colonization of inoculated cyanobacteria/bioûlms on roots. Signiûcant correlation between mortality, increased activity of hydrolytic enzymes and fresh weight of plant roots were recorded. *Calothrix* sp. and *Anabaena sp.* proved promising as both PGP and biocontrol agents, while bioûlmed formulations substantially reduced mortality of cotton plants in sick plots (Prasanna *et al.,* 2014)**.**

· The performance of cyanobacteria and *Trichoderma* based biocontrol formulations was evaluated in two cotton varieties (*Gossypium hirsutum* F1861 and *Gossypium arboreum* CISA 310). Evaluation of mortality after 4 weeks revealed a significant reduction, particularly in *G. hirsutum* F1861, with values of 13 per cent (lower by 2% over the *Trichoderma* commercial biocontrol agent). The per cent mortality after drenching with the compost tea prepared using respective formulations, ranged from 28 to 75 per cent in *G. arboreum* CISA 310, with significantly lower values of 6–37.3 per cent in *G. hirsutum*. The *Anabaena laxa* RPAN8 formulation showed the lowest mortality. The activity of hydrolytic enzymes—â-1, 3 glucanase (EGase EC 3.2.1.39), â-1, 4 glucanase (EGase EC, 3.2.1.4) and chitosanase (EC 3.2.1.99) showed a significant enhancement in the inoculated treatments (T1–T6), with *Calothrix* sp. being among the top ranked treatments in both varieties (Babu *et al.,* 2015).

· Formulations of four promising native entomopathogenic fungi *viz.*, *Lecanicillium lecanii, Metarhizium anisopliae, Fusarium pallidoroseum* and *Cladosporium cladosporioides* were developed. Talc based formulation and novel formulations with additive were prepared and stored at room temperature and refrigerated condition. Formulation developed with additives recorded maximum spore viability up to six months when stored at room temperature. Two formulations of *L. lecanii* and *M. anisopliae* were sent to 17 AICCIP centres for multi location testing. These entomopathogenic fungi were tested against whitefly nymphsunder laboratory condition. Spraying of fungal suspension at 1 x 10^4, 1 x 10^5, 1 x 10^6, 1 x 10^7, 1 x 10^8 and 1x10^9 spores/ml significantly reduced the survival of nymphs. Among them, *L. lecanii* recorded maximum mortality of nymphs (Anonymous 2014-2015 and 2015-2016).

· Native isolate of five entomopathogenic fungi *(L. lecanii, Metarhizium anisopliae, Fusarium pallidoroseum, C. cladosporioides and F. semitectum)* were tested against whitefly nymphsunder laboratory condition. Spraying of fungal suspension at 1 x 10^4, 1 x 10^5, 1 x 10^6, 1 x 10^7, 1 x 10^8 and 1x10^9 spores/ml significantly reduced the survival of nymphs. Among them, *L. lecanii* recorded maximum mortality of nymphs (Anonymous 2015-2016).

· The suppressive effects of microbial inoculants on cotton seedling mortality were assessed in *Rhizoctonia solani* infested soil. Percent mortality ranged from 16 to 32 (60–120 days after sowing, DAS) and signiûcant differences were recorded at 120 DAS, especially after drenching with compost tea of *Azotobacter sp.* and *Anabaena torulosa—Trichoderma viride* bioûlmed formulations. The activity of hydrolytic enzymes was reduced in diseased root tissues due to a majority of the microbially inoculated treatments, compared with healthy root tissues. Per cent changes in the amounts of glomalin-related soil proteins (GRSPs) were 2 to 85% greater than those of the uninoculated experimental controls. These microbial inoculants altered the rhizosphere bacterial communities as evident from the Denaturing gradient gel electrophoresis (DGGE) banding patterns and also reduced the population of *R. solani.* While the copy numbers of the internal transcribed spacer (ITS) gene of *R. solani* in the un inoculated (infested soil) were approximately 1.47X 10^{11}/g soil, they were 1.34– 1.42 X 10^{5}/g soil after the application of *A. torulosa, Anabaena laxa* and *A. torulosa–Bacillus* sp. Increases in yield (ranging from 3 to 23%) due to various microbial inoculants relative to un inoculated controls illustrated their promise as plant growth-promoting and disease-suppressing agents (Prasanna *et al.,* 2016).

(v) Chemical control : The fungicide captan + hexaconazole (Taqat @500g/ha) tested at Coimbatore, Junagarh, Faridkot, Guntur and Dharwad during 2007-2008 and 2008-2009 significantly reduced fungal foliar leaf spots (*Alternaria, Myrothecium*, Grey mildew, *Helminthosporium* and *Cercospora* leaf spots) with an increase in seed cotton yield of 12 per cent over control (Anonymous, 2007-2008 and 2008-2009).

· Evaluation of copper hydroxide (Dharwad, Surat, Akola, Khandwa, Nanded and Rahuri) during 2007-2008 and 2008-2009 revealed significant reduction of bacterial blight and *Alternaria* spots at 1500g/ha with maximum increase of seed cotton yield of 20.8 per cent over control (Anonymous, 2007-2008 and 2008-2009).

· Tetraconazole (11.6%) w/w @ 900 ml/ha showed effective control (%) disease index 9.9 compared to 28.1 in control) of Alternaria leaf blight (tested at Arupkotai, Junagarh, Rahuri, Nanded during 2009-2010 and 2010-2011) and led to 30.5 per cent increase of seed cotton yield over control (Anonymous, 2009-2010 and 2010-2011).

· Kresoxim methyl (Ergon 44.3 per cent @ 500ml/ha) when tested against foliar pathogens (Aleternaria blight, Myrothecium leaf spot and grey mildew) at seven locations showed significant reduction of per cent disease index (Anonymous2009-2010 and 2011-2012).

· Based on pooled results of three years (2012-14), the minimum seedling mortality was observed with maximum seed cotton yield when seed was treated with Carboxin (37.5%)+ Thiram (37.5 %) DS at 4.5 g /kg at Dharwad, Guntur and Coimbatore (Anonymous, 2014-2015a).

(vi) IDM modules : Experiments conducted further to probe the sequence of coating / pelleting with nutrients and seed protectants indicated that coating of cotton seeds with Thiram @ 2g kg"' + Gypsum @ 60 g kg" + Micronutrient @ 20 g kg"' + Imidacloprid @ 7g kg"' + DAP @ 20 g kg"' in five layers sequentially were found to significantly enhance the viability. (Anonymous 2006-2007)

· The fungicide treatments with Propiconazole (0.1%) (2.5 PDI) and Carbendazim (0.1%) (14.6 PDI) were found to be the most effective treatments for the management of the grey mildew disease. Among the bio-agents, the combination spray of *T. harzianum* + *P. fluorescens* Pfl and *T. virens* + Pfl were effective in reducing the disease to limited extent when sprayed at 10 day intervals (Anonymous 2006-2007).

· Integrated management of cotton diseases (ALB, BB and Rust) at Guntur for three years (2011 -2013) showed that maximum IBCR of 1.35 was recorded with module 3 in *Bt* hybrid Jadoo BG II(ST- *Pseudomonas fluorescens* @ 10g/kg seed, SA– *Trichoderma viride* @ 2.5kg/ha, Foliar spray with kresoxim methyl @ 1ml/l at 60 DAS and captan + hexaconazole (Taqat) 1g/l at 90 DAS for fungal diseases) (Anonymous-2014-2015a).

· Integrated management of cotton diseases (Root rot and ALB) at Coimbatore (2012 -2013) showed that the incremental cost benefit ratio with Module 2 (ST – *Bacillus subtilis* (BSC5-TNAU1) + SA @ 2.5 Kg/ha + Foliar spray with *B. subtilis* @ 1 per cent on 60, 90 and 120 DAS.) using Bunny *Bt* was 1.16 as against farmers practice. Likewise the ICBR with respect to the same module in RCH II *Bt* was 0.94 in comparison with that of farmers practice (Anonymous 2014-2015a).

· Integrated Management of ALB at Rahuri (2012 -2013) showed that the seed treatments of bioagent with chemical sprays was found most effective in minimizing the ALB disease intensity by 63.20 per cent (module 3- Seed Treatment - PF TNAU1 @ 10g/kg of seed, SA- *T. viride* @ 2.5 KG/ha (TV- TNAU1) in 250kg of Compost or FYM., Foliar spray with Ergon @ 1ml/L @ 60 DAS and Taqat @ 1.5g/L @ 90 and 120 DAS for fungal diseases) in *Bt* hybrid krishi dhanrakhi (Anonymous -2014-2015a).

The way ahead : During the past two decades, PCR based molecular diagnostic tools for important cotton diseases have been developed and used for getting important information especially in case of viral diseases. Work on the development of prediction equations has been carried forward to develop robust forewarning systems. Resistant sources for major diseases have been identified after extensive screening programs. Other components of integrated diseases management (IDM) were strengthened by way of identification of new fungicides, cultural practices and biocontrol agents. Location specific IDM modules were also standardized under AICRP on cotton. Innovative management options like spray of cow urine, butter milk and homoeopathic medicines for CLCuD management are at multi location field trials stage and likely to yield useful results.

Plant quarantine and enforcement in future can help in checking spread of diseases to newer areas. Containment of CLCuD in north zone is very important as its spread to central and south zone will be catastrophic for the cotton production. In the coming years emphasis is being laid on the introgression of resistance against CLCuD from diploid cottons as few sources of resistance/tolerance in the existing germplasm are available. New whitefly management programs through viruliferous entomopathogens will give significant results and shall help in CLCuD management through vector control. Basic studies to understand factors leading to development of virulent strains of CLCuV and their management to avert losses will be a real challenge. Research on endophytes shall open new avenues for plant disease management. In future, screening for new forms of host resistance, use of DNA markers for their rapid incorporation of resistance into adapted cultivars over laid with transgenic and using genome editing by CRISPR/ Cas system would be instrumental in adding multiple layers of defense to control the diseases affecting cotton crop.

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Integrated Management of Whiteflys in cotton

A. RAMI HOROWITZ*, PETER C. ELLSWORTH, ROBERT MENSAH AND ISAAC ISHAAYA
Department of Entomology, Agricultural Research Organization, the Volcani Center, Rishon LeZion-7505101
**E-mail : hrami@volcani.agri.gov.il*

ABSTRACT : The sweetpotato whitefly *Bemisia tabaci* is a major agricultural pest in various field and vegetable crops worldwide. It causes extensive damage by direct feeding on plants, reducing quality, secreting honeydew and transmitting plant viruses. In cotton, the honeydew may cause fiber stickiness that interferes with the spinning process. Cotton leaf curl virus, which is transmitted by *B. tabaci,* is a major disease of cotton in Asia and Africa. *Bemisia tabaci* is known for its genetic diversity, which is expressed in a complex of biotypes or, as recently suggested, a complex of distinct cryptic species. Management of whitefly species in cotton relies on the use of insecticides; however, the whitefly ability to develop resistance to major insecticide classes creates a serious challenge to pest managers. In this paper, we focus on three strategies that target the whitefly *B. tabaci* along with other major pests such as heliothines (*Helicoverpa armigera* and *H. zea*), plant bugs (Miridae), and the pink bollworm (PBW), *Pectinophora gossypiella*. The Australian strategy is a 'window' based chemical scheduling approach that uses a *B. tabaci* threshold matrix based on percent *B. tabaci* adult infestation to support IPM-IRM strategies. The key goals of the "threshold matrix" is to assist in the interpretation of field population monitoring data with the aim of properly timing chemical controls to minimize lint contamination, and to prevent over reliance on chemical control. The Israeli IPM-IRM also uses a window strategy to combat insecticide resistance in cotton pests, especially in *B. tabaci* by limiting the use of insect growth regulators (IGRs) and other novel insecticides. The Arizona cotton IPM plan depends on multiple elements of "Sampling" and "Effective Chemical Use" built on a foundation of "Avoidance" and is a successful strategy that resulted in major reductions in pesticide use, largely through careful integration of both chemical and biological controls.

Key words : *Bemisia tabaci*, IGRs, insecticide resistance, IPM-IRM strategies

The whitefly (*Bemisia tabaci*) : The whitefly *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) is a global, serious pest of vegetable, field, and ornamental crops. It is ranked among the top 20 of the world's worst invasive insect pests (Byrne and Bellows 1991, Oliveira *et al.,* 2001, Stansly and Naranjo, 2010, Global Invasive Species Database, 2017). It directly damages plants by feeding on phloem sap, and excretes honeydew on leaves and fruit; the sticky honeydew forms a substrate for the growth of black sooty mold that stains the leaves, thus, impairing photosynthesis. In cotton, the honeydew may cause fiber stickiness that interferes with the spinning process in the textile mills, and greatly reduces the product's value (Ellsworth *et al.,* 1999, Hequet *et al.,* 2007). *Bemisia tabaci* is a vector of more than 100 plant viruses (Jones, 2003, Hogenhout *et al.,* 2008) and in some cases, the resulting viral diseases are limiting growth factors and may cause total crop loss. Cotton leaf curl virus, which is transmitted by *B. tabaci*, is a major disease of cotton in Asia and Africa.

Bemisia tabaci is known for its genetic diversity, which is expressed in a complex of biotypes (Brown *et al.,* 1995, Perring, 2001, Xu *et al.,* 2010) or, as recently suggested, a complex of distinct cryptic species (De Barro *et al.,* 2011, Boykin *et al.,* 2012). The biotypes/species are largely differentiated based on biochemical or molecular polymorphism, and differ in their characteristics such as host plant range, the capacity to cause plant disorders, attraction by natural enemies, expression of resistance, and plant virus-transmission capabilities (*e.g.,* Bedford *et al.,* 1994, Sanchez Campos *et al.,* 1999, Horowitz *et al.,* 2005, Kontsedalov *et al.,* 2008). The most widespread biotype B was identified in the late 1980s (Costa *et al.,* 1993), following extensive outbreaks of *B. tabaci* in the southwest USA, and has a worldwide distribution. An additional common biotype, Q, which probably originated in the Iberian Peninsula, has since spread globally (Horowitz *et al.,* 2003, Boykin *et al.,* 2007, Chu *et al.,* 2010). Biotype Q is considered more resistant than the biotype B to the new insecticides such as pyriproxyfen and neonicotinoids, and they may select for biotype Q, which would survive to greater extent than the B biotype (Horowitz *et al.,* 2005). Based on De Barro *et al.,* (2011), biotype B belongs to the group 'Middle-East Asia Minor 1' (MEAM1), and the Q biotype belongs to the 'Mediterranean' (MED) group. So far, the genetic groups of *B. tabaci* are composed of at least 34 morphologically indistinguishable species (Dinsdale *et al.,* 2010; De Barro *et al.,* 2011; Boykin and De Barro, 2014). Active management of *B. tabaci* in the field in cotton would appear to be largely confined to the MEAM1 and MED cryptic species.

This paper consists of a short review comparing the well-known strategies developed in Australia, Israel and Arizona and other approaches for managing the whitefly, *B. tabaci* in cotton, and concludes with some recommendations.

Insecticide resistance in *Bemisia tabaci* : Insecticide resistance in *B. tabaci* is widespread and it has evolved to most of the insecticides used, in cotton and other crops. Resistance to organophosphates (OPs) is well established in *B. tabaci* in many countries including India (*e.g.,* Horowitz *et al.,* 2007, Naveen *et al.,* 2017). It was attributable in part to modified AChE, the target sites of these insecticides (Byrne *et al.,* 1994; Byrne and Devonshire, 1997). Metabolic mechanisms such as elevated monooxygenases and carboxylesterases may also contribute to OP resistance in some insect populations (Denholm *et al.,* 1996). Pyrethroid resistance in whiteflies is also widespread although the magnitude and pattern of resistance and cross-resistance varies considerably among countries and cropping systems (Cahill *et al.,* 1995, 1996, Denholm *et al.,* 1996).

Until the mid-1990s, spray mixtures of synergized pyrethroids had been the most effective combination for controlling *B. tabaci* populations, especially in the southwestern USA (Horowitz and Ishaaya, 1996, Prabhaker *et al.,* 1998, Palumbo *et al.,* 2001, Castle *et al.,* 2010). These involved combining high levels of pyrethroids with moderate levels of compounds from a different chemical class such as OPs and carbamates. However, the uncontrolled use of these synergized pyrethroids to control whitefly populations in cotton fields resulted in reduced susceptibility in *B. tabaci* populations (Simmons and Dennehy, 1996, Dennehy *et al.,* 1997). As a result of the inability to control whiteflies, an emergency approval (US-EPA Section 18) of the insect growth regulators (IGRs), buprofezin and pyriproxyfen, was granted for US cotton in 1996 (Ellsworth and Diehl, 1996, Dennehy and Williams, 1997, Dennehy and Denholm, 1998). Constrained use of these compounds in a conservative resistance management program has, over several years, resulted in area-wide suppression of *B. tabaci* and contributed to substantial reductions in overall insecticide use (*e.g.,* Ellsworth and Martinez-Carrillo, 2001, Ellsworth and Jones, 2001, Crowder *et al.,* 2008, Naranjo and Ellsworth, 2009a).

Among the newer groups of insecticides that followed are the IGRs, buprofezin and pyriproxyfen, and the neonicotinoids, both subject to variable resistances in *B. tabaci* around the world, along with the ketoenols and diamides. In many cases, the resistance to neonicotinoids was associated with the Q biotype (*e.g.,* Nauen *et al.,* 2002; Horowitz *et al.,* 2004; Dennehy *et al.,* 2010), although a few cases of neonicotinoid resistance have been described also in B biotype strains (Byrne *et al.,* 2003). Rauch and Nauen (2003) studied the involvement of target site modification and metabolic enzymes in neonicotinoid resistance. Biochemical analyses of metabolizing enzymes such as esterases, GSTs, and cytochrome P450 dependent monooxygenases showed that only the monooxygenase activity was correlated with imidacloprid, thiamethoxam, and acetamiprid resistance. The involvement of P450 dependent monooxygenases activity in resistance to neonicotinoids was also supported by molecular data (*e.g.,* Karunker *et al.,* 2008). Resistance to some of these newer insecticides has been reported widely from many countries globally (*e.g.,* Horowitz *et al.,* 2005, 2007, Nauen and Denholm, 2005, Crowder *et al.,* 2008, Wang Z. *et al.,* 2010, Naveen *et al.,* 2017, Ahmad *et al.,* 2017).

Ryanodine receptors are a class of ligand-gated calcium channels controlling the release of calcium from intracellular stores. Ryanodine is a plant alkaloid used as a natural botanical insecticide. So far, two principle insecticides are being studied and registered: chlorantraniliprole, which is more potent against lepidopteran pests; and cyantraniliprole, which targets sucking pests such as whiteflies and aphids (Sattelle *et al.,* 2008; Lahm *et al.,* 2009). However, a short time after its use in China low to moderate resistance has evolved to cyantraniliprole, especially in the Q biotype (MED) of *B. tabaci* (Wang *et al.,* 2017).

***Bemisia tabaci* pest management :** Pest management practices evolve in response to the demands of the grower community, consumer perception, governmental regulation and available technology and supporting services (*e.g.,* Extension) to meet these demands. Often times the immediate solutions to pest problems have been insecticides, because of their efficacy and convenience. However, consumer, regulatory, and food safety and environmental protection concerns create even greater needs for integrated solutions like integrated pest management (IPM). Furthermore, very often pest complexes respond to insecticide use with greater selection for resistance. Therefore, there is general agreement to reduce insecticide use to the lowest practical levels, as the first principle of resistance management (Horowitz *et al.,* 2007, Crowder *et al.,* 2013). By enhancing and increasing the use of non chemical control measures, selection pressures for pesticide resistance are reduced with consequences for successful management. Therefore, it is important to use control tactics based on IPM principles, including the integration of natural enemy conservation and biorational insecticides (*e.g.,* Horowitz *et al.,* 2009, Naranjo and Ellsworth, 2009a,), but also employing other technologies such as *Bt* cotton and mating disruption as selective controls of other cotton pests.

Integrated management of whiteflies in cotton in Australia : The whitefly *B. tabaci*, B biotype or MEAM1 (also known as silverleaf whitefly [SLW], *B. argentifolii*) is a major pest in cotton in Australia due to contamination of cotton lint with honeydew and its resistance to many synthetic insecticides. With the commercial adoption of transgenic *Bacillus thuringiensis* (Bt)-cotton (Bollgard II®), there has been a reduction in the use of insecticides for controlling *Helicoverpa spp.* However, the ineffectiveness of the Bt toxin against sucking pests such as whiteflies resulted in continued use of insecticides for controlling this pest.

Mensah and Young (2017) reported that once the number of nymphs increased to <“70/ leaf (but with just few adults/leaf), a negative feedback regulatory effect reduced the survivorship of the nymphs and adults and/or caused the emigration of the adults from the contaminated leaves in search for new host plants. Several species of *B. tabaci* parasitoids (*Encarsia* spp. and *Eretmocerus* spp.) and predatory insects (big eyed bugs, pirate bugs, lacewing larvae, apple dimpling bugs, brown smudge bugs and lady beetles) have been observed in cotton crops in Australia, which are effective in controlling *B. tabaci* at low populations. Therefore, any control measure that has minimal effect on beneficial insects has a potential to supplement IPM programs against whiteflies in cotton.

Sampling : Sampling cotton plants for *B. tabaci* prior to flowering is considered not essential but can be helpful when decisions have to be made for controlling sucking pests and conserving beneficial insects for the rest of the cotton season. The conservation of beneficial insects early in the cotton season through to squaring, flowering, boll formation and maturation is very important as they may help to delay build-up of *B. tabaci* and other sucking pests.

Sampling of *B. tabaci* adults and nymphs occur once every week from first flower (777 DD) and twice weekly (every 3 days) from peak flower (1300 DD) at base temperature of 30-35^{o}C. The field is divided into *B. tabaci* management units which are no larger than 25 ha. There are two sampling sites in each management unit.

Twenty leaves are randomly selected from the 3rd, 4th or preferably the 5th node below the terminal. Sampling is commenced at early morning hours, 9–10 am, when adults less likely to be disturbed into flight. *Bemisia tabaci* adults are counted visually by carefully turning the leaf over and counting the number of individual adults present. Leaves with two or more *B. tabaci* adults are scored "infested" and leaves with 0 or 1 as "uninfested".

Thresholds : In Australia, a Threshold Matrix has been developed to assist with management decisions that are appropriate for a range of *B. tabaci* density and crop stage situations. The Matrix threshold is based on rates of population increase relative to day degrees and crop development. Thus, the threshold matrix provides a framework for using the sampling data / information gathered in field sampling to (1) determine time of *B. tabaci* control-intervention, and (2) make a decision on intervention with currently registered products to control *B. tabaci* populations and delay and population build up.

The Israeli IPM Insecticide Resistance Management (IRM) strategy : The Israeli strategy was introduced in 1987 in response to increasing failures to control *B. tabaci* by pyrethroids, carbamates and OPs. The first initiative was to combat resistance to conventional insecticides through pre-planned rotations of insecticides (a 'window' plan). Following the registration of the IGRs, buprofezin and pyriproxyfen, the primary objective has been to preserve susceptibility to these novel insecticides by optimizing and restricting their use to a single treatment/year (*e.g.,* Horowitz and Ishaaya, 1994, Horowitz *et al.,* 1994, Denholm *et al.,* 1998). Since the Israeli cotton system does not apply transgenic *Bt*, growers are guided to use more selective insecticides against the bollworm, *Helicoverpa armigera*, and to exploit the pink bollworm (PBW, *Pectinophora gossypiella*) pheromones for mating disruption, which is used in most cotton fields in Israel. The strategy is therefore designed to cope with the entire pest complex but especially against the main insect pests, PBW and *B. tabaci*. One of its primary achievements has been a dramatic reduction in the number of insecticide applications against the entire range of cotton pests, but especially against *B. tabaci* resulting in less than two treatments per year. Insecticides other than the IGRs were further introduced (*e.g.,* neonicotinoids and diafenthiuron) and they are available to cotton growers as well. Resistance monitoring is a vital component of the Israeli strategy, and through this program, high resistance to pyriproxyfen has been detected associated with the Q (MED) rather than with the B biotype (MEAM1) (Horowitz *et al.,* 2005). A practical outcome of this research would be the possible reuse of pyriproxyfen in areas where the B biotype is predominant; however, this should be complemented with a strict biotyping determination before pyriproxyfen application, to prevent any field failure (Horowitz and Ishaaya, 2014). Therefore, biotyping survey in the various cotton regions of Israel is conducted every year during early July, prior the treatments against the whitefly (ARH, pers. comm., November, 5 2017)

The Arizona IPM strategy : The IPM

system in Arizona was developed and progressively improved upon over many years and has successfully served cotton growers as well as growers of other crops who are challenged each year by the presence of *B. tabaci* (MEAM1) (Ellsworth *et al.,* 1996, Ellsworth and Martinez-Carrillo, 2001, Ellsworth *et al.,* 2006, Ellsworth *et al.,* 2016a). In addition to relegating this pest to a level of sustainable management, this IPM model is one of the most well studied, where very detailed mechanistic studies reveal the function and efficacy of the tactics involved that support IPM recommendations (Naranjo and Ellsworth, 2009a). A culture has been created and maintained with stakeholders, such that there are high degrees of trust and confidence in the IPM strategy. This has resulted in high levels of uptake and compliance with these voluntary guides and the management system (Ellsworth *et al.,* 2016a). Furthermore, in a rare opportunity to examine the translation of an IPM strategy to a different, but similar agroecosystem resulted in major gains in the nearby Mexican cotton production system (Ellsworth *et al.,* 2016b). This strategy demonstrates the complexity of integration that makes IPM both successful and stable, which is a result of appropriate investments in both "hard" and "soft" technologies. Hard technologies alone, such as transgenic *Bt* cotton plants and selective insecticides are insufficient alone to affect wholesale change of a system (Ellsworth and Naranjo, 2017). Soft technologies including human-centered knowledge domains and translational research are also necessary to support technology uptake and user adoption. In the U.S., the highly developed system of Cooperative Extension has been critical to the implementation of IPM within these systems. The IPM system in Arizona cotton is a rare example of creating integrated value, where growers and pest managers have appropriately internalized externalities to accomplish a smart, secure, satisfying, shared and sustainable solution to pest management (*sensu* Visser 2017). Those externalities include the shared values of preservation of susceptibility to product chemistries, reputation for stickiness prevention and high fiber quality, high functioning key regulatory ecosystem services like biological controls, and preservation and protection of the environment.

The IPM strategy in Arizona is rooted in three fundamental keys, sampling and effective chemical use resting on a broad foundation of avoidance practices. The building blocks of this IPM plan can be represented as a multi-faceted pyramid with each facet addressing one key pest in the system (Ellsworth and Martinez Carrillo, 2001). Historically, Arizona cotton has been challenged by three key pests, the pink bollworm (*P. gossypiella*), the Lygus bug (*Lygus hesperus*), and *B. tabaci*. When these pests are properly managed, secondary pests are generally held under natural control. After failure of very inefficient, mainly adulticidal chemical control programs for *B. tabaci*, it was apparent a more durable approach would require greater selectivity of chemical controls and greater reliance on non chemical approaches such as biological and cultural control tactics. As well, gains made in these two areas for *B. tabaci* management were susceptible to erosion by broad spectrum, chemical controls deployed for PBW and Lygus bugs. So, a systems solution was needed.

A series of hard technologies were developed that enabled the development of more sustainable plans including the introduction of: *Bt* cottons in 1996, selective IGRs pyriproxyfen and buprofezin in 1996, and a selective Lygus feeding inhibitor flonicamid in 2006. Other important hard technologies included soil usage of the neonicotinoid imidacloprid in melons and vegetables starting in 1993 (Palumbo *et al.,* 2001), the foliar neonicotinoid acetamiprid in cotton in 2002, the ketoenol spiromesifen in cotton in 2005, and the selective Lygus insecticide sulfoxaflor in 2012 (Ellsworth, 2017, Ellsworth and Peterson, 2017).

These technological advances would be of limited value without accompanying soft technologies being simultaneously developed. These included knowledge domains and grower education on plant health and crop management tactics, progress on exploitation of *B. tabaci* biology and ecology, and commitment to tactics with areawide impact throughout the system. This required: recognition of *B. tabaci* as a systems-level pest impacting and exploiting multiple host crops throughout our agroecosystem, commitments to source reduction and sharing of technologies (*e.g.,* Palumbo *et al.,* 2003), and dedication to natural enemy conservation measures in cotton that contribute to technology extending efficacy in the management of whiteflies (Naranjo and Ellsworth 2009b). These avoidance tactics support the monitoring of whitefly populations, timing of effective and selective chemistry, and rational approach to resistance management (Ellsworth and Martinez Carrillo, 2001, Ellsworth *et al.,* 2006).

Perhaps a keystone to the high functioning of the IPM system in Arizona cotton has been the conceptual development, teaching, and use of "bioresidual" by growers when electing to use putatively expensive, but selective chemical controls (Ellsworth and Martinez-Carrillo, 1996, Naranjo and Ellsworth, 2009b). Bioresidual was discovered and defined by measurement of extended periods of *B. tabaci* suppression after the use of a selective IGR. These periods of suppression far exceeded the chemical residual of these IGRs and reflected the greatly increased efficacy of predators in suppressing whitefly populations as well as the additional time for exposure to other natural mortality factors (*e.g.,* weather like severe dust-blowing haboobs). Ellsworth and Martinez-Carrillo (2001) defined bioresidual "...as the overall killing power of an insect control technology including the direct effects of the technology as well as the associated natural biological mortality." Naranjo and Ellsworth (2009b) further defined it as the "combined contribution of all natural mortality factors...that allow for lowering of the general equilibrium position of the target pest and long term pest control following the use of selective insecticides." As a result of these findings, Arizona routinely tests for both the efficacy and selectivity of new insecticides in the cotton system before they are introduced commercially (PCE, unpubl. data). All products are organized and taught to growers as either being fully selective (buprofezin, pyriproxyfen, and moderate rates of spiromesifen), partially selective (acetamiprid and several other neonicotinoids), or broad spectrum / non selective (synergized pyrethroids, organophosphates, carbamates, and novaluron). Along with flonicamid and sulfoxaflor for Lygus control and *Bt* cotton for PBW and lepidopteran control, growers now have access to a fully selective arsenal to control all three key pests of the system, the latter one since eradicated from the U.S. and northern Mexico. This full integration of biological and chemical controls has likely been one reason why this IPM system has continued to function despite resistances being present to three modes of action (*e.g.,* to synergized pyrethroids, acetamiprid, and pyriproxyfen).

CONCLUSIONS AND RECOMMENDATIONS

This paper summarized three strategies that target the whitefly *B. tabaci* along with other major pests. The Australian strategy is a 'window' based chemical scheduling approach that uses a *B. tabaci* threshold matrix based on percent *B. tabaci* adult infestation to support IPM-IRM strategies. The goals of the threshold matrix are to assist in the interpretation of field population monitoring data with the intention to minimize lint contamination, and to prevent over-reliance on chemical control. The Israeli IPM-IRM also uses a window strategy to combat insecticide resistance in cotton pests, especially in *B. tabaci* by limiting the use of insect growth regulators (IGRs) and other novel insecticides. The Arizona cotton IPM plan depends on multiple elements of "Sampling" and "Effective Chemical Use" built on a foundation of "Avoidance". It is a successful strategy resulted in major reductions in pesticide use, largely through careful integration of both chemical and biological controls.

Have the strategies completely prevented resistance? Not completely! However, it has led to a dramatic reduction in insecticide applications, and effective control; in addition, the use of more selective pest control practices and encouragement of natural enemies, resulted in reduced grower expenses.

Integrated whitefly management should be based on adult and nymphal population monitoring, along with economic thresholds for chemical pest control; delaying and reducing use of pyrethroids and broad-spectrum insecticides, conservation of natural enemies of whiteflies, and use of selective insecticides. Scientists, extension, farmer organizations and chemical companies should open an educational campaign for developing a simple policy for cotton IPM and IRM strategies in India and elsewhere.

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Synergistic transfer of technology approach for profitable and sustainable cotton production in India

S. USHA RANI*, A. H. PRAKASH AND S. M. WASNIK
ICAR-Central Institute for Cotton Research, Regional Station, Coimbatore – 641 003
**E-mail : ushajoshua@rediffmail.com*

ABSTRACT : India was producing 3.04 M bales (170 kg lint/bale) of cotton in 1950-1951 and now it produces around 35.00 M bales (2016-2017). The visible changes created in the production were the evidences for the effectiveness of the cotton extension programs executed in the country to disseminate the efficient cotton varieties / hybrids, production and protection technologies. Regularly, the Indian cotton researchers develop the best technologies to improve the yield and income of the crop and there is always a pressing need for transfer of technology innovations to translate those technologies for the benefit of cotton growers. This enduring challenge forces the scientists to recurrently invent novel and farmer friendly TOT approaches for profitable and sustainable cotton production in India. Analysis on the laurels and let downs of cotton TOT initiatives in India revealed that many technologies released from the cotton research system and the individual TOT efforts tried PAN India to disseminate those technologies could not bring out a breakthrough in increasing the average national productivity of cotton. The TOT endeavors tried were all individual efforts of different kinds effective in exclusive attempts. A TOT approach with combination of all successful extension methods which are not repetitive but complementary is lacking in cotton TOT sector. This paper proposes a synergistic TOT approach for profitable and sustainable cotton production in India.

Indian cotton is historical, ancient and age old in nature. It is believed that it might be the origin for one of the cultivated species of cotton. The cotton pieces in a silver vessel found as archaeological evidences from the Mohenjo-Daro excavations in 1921 confirmed the existence of cotton in Indian sub-continent in earlier days. At present, India is the largest cultivator and producer of cotton in the world. The improved genotypes, yield enhancing technologies and protection strategies developed by the public and private research industries are the major contributors for the country to reach the top position in cotton production. Similarly, the various efficient and effective Transfer of Technology (TOT) mechanisms formulated by the public and private research and development institutions also favored our Indian cotton to achieve the first place. The influence of extension / outreach programs / TOT programs in Indian cotton sector is time immemorial, influential and imperative. India was producing 3.04 M bales (170 kg lint/bale) of cotton in 1950-1951 and now (2016-2017) it produces around 35 M bales. The visible changes created in the production were the evidences for the effectiveness of the cotton extension programs executed in the country to disseminate the efficient cotton varieties / hybrids, production and protection technologies. Regularly, the Indian cotton researchers develop the best technologies to improve the yield and income of the crop and there is always a pressing need for TOT innovations to translate the technologies for the benefit of cotton growers. This enduring challenge forces the scientists to recurrently invent novel and farmer friendly TOT approaches for profitable and sustainable cotton production in India.

History of transfer of technology efforts in cotton : The TOT efforts in cotton development in India started during the pre-independence *era*. The extension efforts in spreading cultivation of cotton started during the American civil war, when the Confederacy has stopped sending cotton to British which prompted the Britain to turn to Indian cotton. Literature say that the extension efforts taken by the British government in India helped them in filling up the gap during war time making up only 31 per cent of British cotton imports in 1861, but 90 per cent in 1862. The spread of American and Egyptian cotton in Indian soil was the evidence for the existence of cotton extension in the country in 18th and 19th centuries. Until the middle of the 18th century, only indigenous *Gossypium arboreum* and *Gossypium herbaceum* varieties of cotton were grown in different regions of the country, which produced the short staple and coarse cotton, but converted into very fine yarn by the then skilled and talented Indian artisans. In 1788, the Governor General (at Calcutta) was requested by London to encourage growth and improvement of Indian cottons to meet the requirement of the Lancashire textile industry. Then in an attempt to develop an alternative source of supply, the east India company initiated trials with exotic cottons (new world cotton varieties) introduced into India. The various attempts like growing Bourbon (*G. hirsutum*race *punctatum)* variety introduced from Malta and Mauritius in the Bombay and Madras Provinces in 1790 AD, trials with exotic American cotton in Gujarat, the Deccan and the Konkan in 1840 AD, growing New Orleans seed *(G. hirsutum*race *larifolium*) in 1842 in Hubli taluk of Karnataka, the efforts in the Madras province commenced with Bourbon variety in 1790 and subsequent trials with New Orleans and Sea Island in Coimbatore, spread of variety Cambodia in Madras Province in 1905 and variety Cawnpore in 1909 were the evidences for the efforts of cotton extension in India. Due to all these extensive extension efforts, India was then the largest cotton producing in the British Empire and the second largest in the world.

The establishment of various institutions expedited the extension work of cotton in India in 20th century. In 1917, the Governor General in Council set up the "Indian Cotton Committee" under the under the Chairmanship of MacKenna, Agricultural Advisor to the Government of India and six other members, to investigate the possibilities of extending the growth of long staple cottons in India. The major recommendation of the MacKenna Committee was that a Central Cotton Committee should be set up at Bombay on a permanent basis. This was set up in 1921 as a Technical Advisory Body to the Government. In 1923, legislation was enacted to levy a cess of cotton consumed by the textile mills or exported from the country. Thus the Indian Central Cotton Committee became a statutory body with disposable funds for promoting agricultural and technological research in cotton. In 1924, the Indian Central Cotton Committee set up under its aegis the cotton Technological Research Laboratory [now know as Central Institute for Research on Cotton Technology (CIRCOT)] at Bombay (now Mumbai) with Dr A J Turner as its first Director who joined on 1 January 1924. From 1924 to 1937, the Indian Central Cotton Committee provided the entire expenditure for various 'schemes' operated by the Departments of Agriculture of the Provincial Governments for improvement of cotton cultivation, including breeding and varietal improvement, seed multiplication, agronomy, control of pests and diseases, and physiology. The pattern of funding assistance was subsequently modified with the Provincial Governments also sharing the expenditure after 1938 until 1966, when the Indian Central Cotton Committee was wound up and the functions transferred to the Indian Council of Agricultural Research (ICAR), New Delhi. The council started the All India Coordinated Cotton Improvement Project (AICCIP) in 1967 at Coimbatore.

Few of the Successful TOT Programs in cotton : The AICCIP implemented various first line extension programs of Indian Council of Agricultural Research facilitated the effective transfer of latest cotton technologies both in last as well as in the current century. Those programs created an effective scientist farmer linkage for the successful transfer of latest cotton production technologies. Several programmes *viz.*, Lab to Land Programme, Operational Research Project (ORP), Front Line Demonstrations (FLD), Integrated Pest Management (IPM), Integrated Resistance Management (IRM), Institute Village Linkage Programme (IVLP), Intensive Cotton Development Programme (ICDP), Farmers Field Schools (FFS) etc., have been launched and are being implemented with the active cooperation of the ICAR Institutes, State Agricultural Universities and Extension personnel of the State Department of Agriculture for increasing the production of Indian cotton. During the 21st century, the development in Information and Communication fields forced the TOT sector to adopt Information and Communication Technology (ICT) for transferring the knowledge. Cotton sector too developed and executed many web based and mobile based advisory programs to manage knowledge transfer. "*e-Kapas*" is a fantastic example for the success of the ICT usage in cotton for technology transfer.

Among the various attempts of technology transfer in cotton in India, few programs implemented by the ICAR-CICR and ICAR-AICRP on cotton *viz.*, FLDs and e-Kapas created desirable changes in the cultivation behavior and socio economic status of cotton growers.

Front Line Demonstration in Cotton : The field demonstration conducted under the close supervision of scientists of the National Agricultural Research System in India is called Front Line Demonstration (FLD). The objectives of FLD are demonstrating the usefulness of the latest improved crop production and protection technologies to the farmers as well as extension workers with a view to reduce the time gap between technology generation and its adoption. It also enables the scientists to obtain direct feedback from cotton farmers and suitably reorient their research programs, develop appropriate technology packages and to create effective linkage among scientists, extension personnel and farmers. "Seeing is believing" is the principle of FLD and "Yield Enhancement" is its major motive. This programme has been implemented for cotton crop through Indian Council of Agricultural Research All India Coordinated Research Project on cotton since 1996-1997. Until 2016, around eighty eight million rupees had been spent by the Ministry of Agriculture, Government of India for conducting 18700 FLDs in the eleven cotton growing states of India. Analysis on impact of FLD revealed that all through the 20 years, the major technologies contributed for yield increase under FLD were high yielding new cotton varieties and hybrids, integrated weed, water, disease and pest management techniques, intercropping, growth regulators, agro techniques and cotton farm implements. Analysis on yield enhancement due to FLD revealed that an average of 1631 kg/ha seed cotton yield was obtained in the demonstration which was 18.70 per cent increase over the normal farmers' practices of the locations. The average yield gap observed between the FLD and normal farmers' practices was 257 kg seed cotton yield. In addition a significant reduction in the cost of production was observed in FLD as compared to the farmers own practices.

***e-Kapas* network :** Viewing the modern advancements in ICT and advantages in mobile phone technology, the ICAR- Central Institute for Cotton Research has been executing a novel extension mechanism called "*e-Kapas* network" for effective knowledge transfer among Indian cotton growers in the current plan period. "e" meant for electronic and "*Kapas*" in Hindi (one of the major Indian languages) means cotton. '*e - Kapas*' essentially refers to the utilization of electronic devices - mobile phones for delivering cotton technologies to farmers, extension workers and other development workers engaged in cotton sector. The project is functioning under Technology Mission on Cotton-Mini Mission I, to increase the productivity of cotton in the country. The project has been functioning in 17 centres across the ten cotton growing states of the country under the leadership of Central Institute for Cotton Research, Nagpur. Farmers interested in *e-Kapas* network register with their local state centres by registering their mobile numbers. Centres send regular voice SMS about cotton genotypes, production and protection technologies in their local languages to the registered growers (Usharani *et al.,* 2014). Around 0.5 million farmers were registered as beneficiaries of the project in eleven cotton growing states and until 2016, more than 1.4 crore voice SMS alerts have been sent to the registered growers (Wasnik *et al.*, 2017).

Challenges faced in these individual TOT efforts : Even though India owns the laurels of being first in world acreage and production, it has been facing challenges with regard to increasing and sustaining its productivity for many years. Many technologies released from the cotton research system and the individual

TOT efforts tried PAN India could not bring out a breakthrough in increasing the average national productivity of cotton.

Analysis on the laurels and let downs of cotton TOT initiatives in India revealed that they have high farmers' acceptability due to its focus on problem solving and the practical application of knowledge. But the acceptability of these TOT programs by the women farmers was remained as a less attempted researchable problem. The acceptability of any TOT programs by the farmwomen generally depends upon the women friendliness of the programs. The study on women friendliness of cotton extension programs by ICAR-CICR revealed that the cotton extension programs both FLD and *e-Kapas* network were having medium level of women friendliness (Usharani and Anuradha (2016)).

Even though, the introduction of "*e-Kapas*" nullifies the criticism that results and advisories of cotton research did not reach the farmers in time, still there are needs to include other extension innovations and technology forecasting aiming inclusive development with the current program (Usharani, 2015).

FLD and e-Kapas are individual efforts of different kinds effective in exclusive attempts. A TOT approach with combination of all successful extension methods which are not repetitive but complementary is lacking in cotton TOT sector.

Opportunities ahead : There is an urgent need to create a novel integrated package of best TOT practices to be adopted step by step chronologically during various stages of cotton cultivation either by the change agents or by the farmers to deliver or get extension support for doubling the yield and income from cotton cultivation. This integrated package should be a convergence of all customary and contemporary extension methods tailored for cultivation of cotton crop in India. This TOT package must include artificial intelligence to facilitate the farmer to select a variety / hybrid suitable for their locality, season long technical guidance to manage the crop, tools to accurately understand the technologies, advisory to tell "dos and don'ts", ways to market their produce. It should guarantee the protection of soil health, crop husbandry, bumper yield and doubled income. It should also preserve the environment and long established knowledge.

Proposed synergistic TOT approach for profitable and sustainable cotton cultivation in India

Need for a Synergistic TOT approach in Cotton : The study conducted at ICAR-CICR on yield and knowledge gap in cotton revealed that the cotton yields are stagnated for the past few years due to various factors. Cotton research system released many technologies to improve the yield under various conditions. But there is always a gap between the potential yield of the technologies claimed by the technology inventors and the actual yield realized by the farmers in the fields. Studies say that yield gap between potential and realized yield on farmers' field is more than 30 per cent. There are possibilities of bridging the gap in cotton yield by properly identifying the causes of gap, appropriate management options to close the gap, fitting TOT innovations to disseminate the gap reducing technologies and implementing the technology plus TOT innovation package in small and marginal farmers' fields. Analysis on yield enhancement due to FLD revealed that an average of 18.70 per cent increase over the normal farmers' practices was obtained in various locations. It is factual that only few TOT practices are successful and farmers friendly. But they are all scattered and attempted independently. An idea was thought of integrating all the best farmers friendly TOT practices in a package as like the best package of practices to facilitate the farmer to double the yield and thereby income.

Methodology adopted : An attempt was made to document all the TOT innovations available in cotton. The impact of popular TOT practices in cotton was studied. Based on the impact, few best and farmer friendly TOT practices available for convergence were selected. Based on the need of the farmers and the suitability of the TOT practices for the need, few of the TOT practices were selected. The selected TOT innovations were chronologically arranged for the entire season. A pilot study on this Integrated management of extension innovations in a typical cotton growing area is planned at CICR. The module will be validated and a synergistic TOT approach for sustainable and profitable cotton cultivation will be developed as outcome of the project.

Few of the TOT innovations identified for the synergistic approach : The proposed synergistic TOT approach for profitable and sustainable cotton production in India will be a convergence of all customary and contemporary extension methods tailored for cultivation of cotton crop in India. It includes, Decision Support System for selecting a suitable variety / hybrid, Front Line Demonstration for cultivating a new variety / hybrid, Soil sampling and soil health card before land preparation, A booklet with entire package of practices for ready reference during cultivation, weekly voice SMS during the entire crop season, weekly advisory through website for knowing the do's and don'ts in cotton cultivation, short duration video films to accurately understand a particular technology, using whatsapp group for clarifying the suddenly occurring pests / diseases / disorders, Mobile apps to know the strategies to manage the pests and diseases, method demonstration to disseminate the best harvesting and post harvesting practices, market intelligence to sell the seed cotton for the best price, personal field visits by the Scientists and exposure visits by the farmers to see and believe the advantages of technologies, specialized training programs to improve the skill and radio broadcast and video telecast for spreading the success of this package to mass farmers.

CONCLUSION

Indian cotton yield has to be doubled. The best production and protection technologies to improve the yield and income of the crop are available with the research system. There is a pressing need for best TOT practices to translate these technologies. This paper proposes an integrated package of best TOT practices to be adopted step by step chronologically during various stages of cotton cultivation either by the change agents or by the farmers to deliver or get extension support. Implementation of the package of best production technologies with appropriated TOT practices through groups of cotton farmers with procurement guarantee will lead to profitable and sustainable cotton production in India.

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Cotton picking bag user friendly drudgery reducing technology

NIRMAL YADAV*

Department of Textile and Apparel Designing, I.C.College of Home Science, CCS Haryana Agricultural University, Hisar - 125004

**E-mail : nirmal404@gmail.com*

India is a leading country in terms of grains, fruits, vegetables, horticulture and cotton production worldwide. It has got first (1) rank in cotton production in the year (2016). Cotton is grown mainly in the states of Maharashtra, Gujarat, Rajasthan, Punjab, Haryana and western Uttar Pradesh. In Haryana, cotton is cultivated in the districts of Hisar, Fatehabad, Sirsa, Jind, Bhiwani and Jhajjar district. A hot climatic condition is required for cotton plant. Sowing of cotton is done in the months of April and May and it becomes ready for picking 70-190 after sowing in northern India. In cotton cultivation, picking is the most tedious job and no instrument or machine is used for it as the farmer has land holdings. Picking can only be done mechanically in our conditions, most of the States of India, especially in Haryana where it is mostly done by women. For this purpose, women use a jholi (bag) made by traditional method including own *chunary* or head covering cloth.

Traditional bag (*Jholi*) : Farm women use a cloth sheet, which is generally her own *chunni/ dupatta/ odhni* (head cover) for collecting cotton from balls. They tie this cloth in the form of a bag on their shoulder and back. In local language it is called '*Jholi*' which is tied in the form of a bag on their shoulders and back. This tradition is passed on from generation to generation as there has been no better alternative. This is practiced in the entire cotton growing areas of the country with some variations. Another practice to tie *jholi* is on the head for support having knot tied at head in which the load is shifted from shoulders to head. Picking activity with traditional bag causes lots of drudgery to the men and women and hinders their working efficiency as found during study. This '*Jholi*' is of inappropriate size and of not suitable material. Hence, cotton balls get collected at the bottom of bag forming a ball like structure which drops down at her back and extended. This touches her lower thighs and preoptic area and causes hindrances while walking during the activity. Moreover, the opening of the bag for putting picked cotton is at the back side. So she has to turn back her wrist and forearms for putting balls in bag. It results in dropping of many cotton balls on the ground leading to frequent bending of women to pick the dropped cotton from the ground causing muscle-skeletal problems. The quality of cotton also gets deteriorated due to soiling of cotton at ground. Emptying the bag after filling was also inconvenient with '*Jholi*'.

Scientific facts related to use of tradional bag : Most of the (90%) of women accepted that using traditional bag causes pressure on shoulders while 83.75% of women reported to feel pain in hand after cotton picking for 5-6 hours. During use of traditional bag, women feel pain in shoulders and wrist because in dropping the cotton balls into the bags, they have to twist their wrist again and again. Whereas 85% of women believed that while using traditional bag for picking cotton balls dropped on the soil, they have to bend again and again to pick them up which caused pain in their waist. Due to the absence of straps and dart, an upper part of the traditional bag puts pressure on neck and caused pain in neck. Women who use traditional bag reported pain in muscles due to lack of well organized compact structure. All the ‘jholi’ users reported that they feel tired and reduce the efficiency (100%). (Gandhi *et al.,* 2002)

In ergonomic assessment to determine the activity profile and biomechanical stress of women after seven hours on the activity, data revealed that women perceived heavy exertion, felt overall discomfort depicting it a painful activity with head-load cot bag. Regarding musculo-skeletal discomfort, very severe discomfort was reported in legs, lower back and shoulder. Severe discomfort in head, neck, hips and thighs was observed. Moderate discomfort was reported in upper back and upper and lower arms. Sever pain was reported in fingers and palm as they get abrasions while plucking cotton bolls. (Gandhi *et al.,* 2011)

Conclusively, traditional *jholi* causes pain in neck, shoulders, upper back, and lower back. It resulted that the farm women were able to pick only 20-25 kg of cotton after continuous working of 5 to 7 h. Keeping all the problems in mind, user friendly pick bag has been developed on the similar pattern of tying and usage pattern of making traditional *jholi*.

Cotton pick bag : Pick bag is an improved version of traditional cotton picking bag. It is used like traditional bag for tying and usage. This bag is made with scientific method and designed with functional features to improve efficiency of farm women and men by reducing their time and efforts.

Drudgery reduction of end users using cot bag in cotton picking : Output of operation was found to be 20.3 per cent more in terms of picked cotton using cot bag than the existing bag. It resulted that 25 per cent more distance was covered in each load cycle while collecting cotton as in traditional way cotton balls fell down leading to frequent bending to pick the cotton from the ground. Therefore, cot bag helped the women to perform the picking activity faster covering more distance in the same time duration. (Gandhi *et al.,* 2004, (Gandhi *et al.,* 2012)

Physiological stress studied in terms of heart rate, energy expenditure, total cardiac cost of work, physiological cost of work. It was found that there was 3.1 per cent decrease in heart rate (90.8 bpm) as heart rate of average working person was 93.8 bpm during cotton picking with existing bag. It revealed that cot bag was easy to carry and handle and made the activity easier. The energy expenditure rate indicates the level of bodily stress. The use of cot bag resulted in 6.5 per cent decrease in energy expenditure. Similarly, use of cot bag leads to 14.8 per cent reduction in total cardiac cost of work (TCCW) during the activity. Physiological cost of work (PCW) was found to be decreased by 15.1 per cent over the existing bag (*jholi*). Average PCW using existing method was 20.5 beats /min whereas using cot bag it was 17.4 beats /min. (Gandhi *et al.,* 2004, (Gandhi *et al.,* 2012)

Rating of perceived exertion study resulted that rural women considered cotton picking activity was light with cot bag (2.0) whereas it was considered as heavy (4.0) with existing bag. Hence, use of cot bag reduced 50 percent drudgery in terms of rating of perceived exertion. (Gandhi *et al.,* 2004, (Gandhi *et al.,* 2012)

Biomechanical stress was studied for Grip fatigue and postural stress. Study resulted less grip fatigue due to less pressure on the wrists, shoulders and upper arms using cot bag while performing cotton picking activity. Postural stress resulted in to decrease that is standing posture 44.4 per cent and bending posture 46.7per cent as cotton balls do not fall down while picking and they need not to bend to get fallen cotton balls from the ground. (Gandhi *et al.,* 2004, (Gandhi *et al.,* 2012)

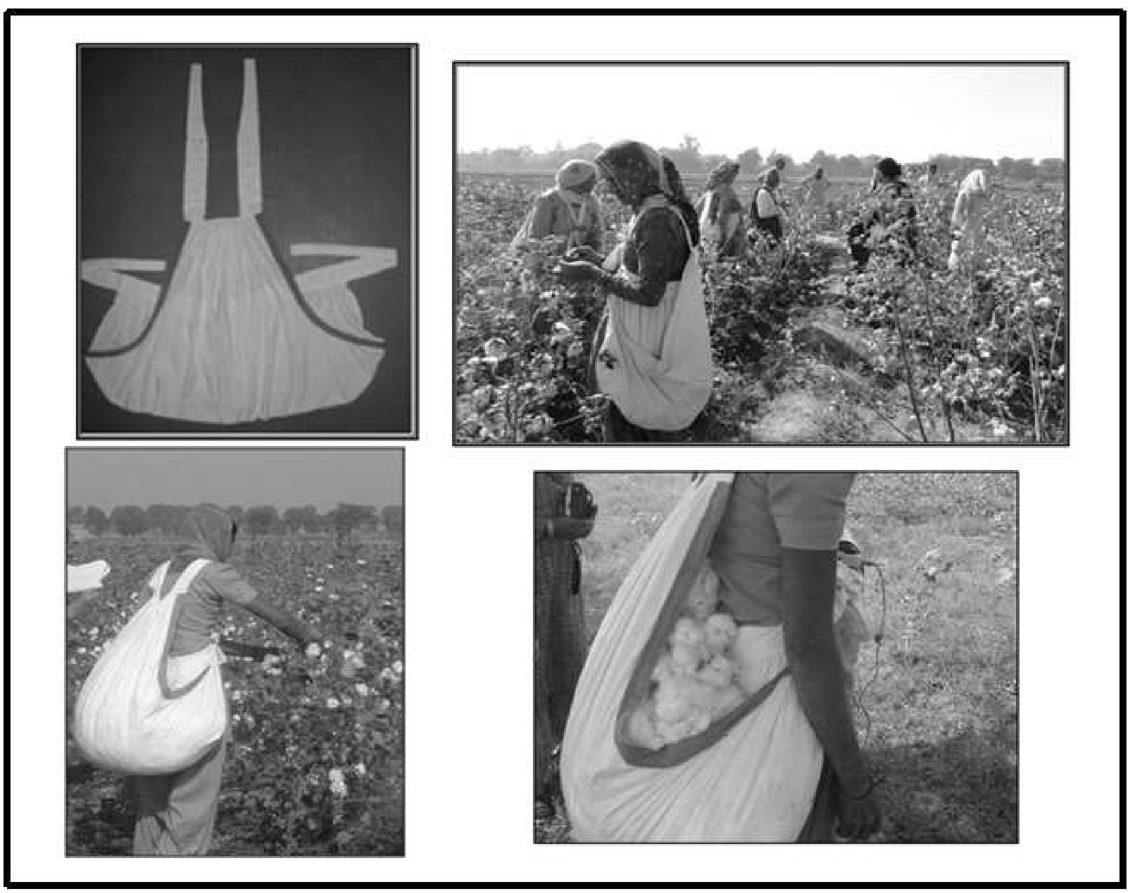
Muscle-skeletal problems faced by the rural women while picking cotton using traditional bag were maximum pain in fingers (ms=4.8), upper back (ms=4.8), shoulders joint (ms=4.8), feet (ms=4.3) and upper arm (ms=4.2). Study reported that maximum reduction in pain was reported in upper back (47.9%), shoulder joints (47.9%), thighs (47.3%), mid back (44.4%), upper arms (33.3%) and wrists (33.3%).(Gandhi *et al.,* 2004, (Gandhi *et al.,* 2012)

Acceptability of cotton picking bag: Assessment of cotton picking bag was done on various levels of acceptability in cotton growing areas of Haryana state. Yadav *et al.,* (2006-2008) conducted experiment on propagation and adoption feasibility of paper pattern of (Cot bag/ Pick bag). Perceived feasibility of paper pattern was high *i.e.* 77.22 per cent. Rural women perceived it highly compatible. Rural women expressed their need for paper pattern of permanent nature to use it in long run. Paper patterns may be prepared on ammonia paper according to widths of available fabrics. Yadav *et al.* (2009) conducted experiment on feasibility of pick bag stitching as entrepreneurial Activity. Majority of the respondents indicated their preferences for purchasing pick bag (74.11%) instead of stitching it at their own level. Thirty four per cent respondents' were of the view that the price of pick bag is higher. The stitching charges are acceptable by 44.44 per cent respondents. Modifications in the design of pick bag suggested by some of the respondents were 'single knotting styles' and with 'head cover'. Yadav and Arya (2011-2012) conducted experiment on standardization of pick bag/cot bag for Male. Developed basic paper pattern of cot bag of male was developed using required measurements. Technical knowhow was imparted to the DESs (Home Science), during training it was found to be very useful as they would be able to utilize the knowledge while imparting training to the target group. Yadav *et al.* (2012) conducted experiment on standardization of pick bag for diversified activities. It was observed that majority of the respondent used fabric sheet (86%) and rest use fertilizer bag converted to a sheet for flower collection. All the respondents recommended cot/pick bag better in terms of ease in collection, comfortable straps, capacity to collect more flowers in one batch with no risk of falling flowers

Specialties of pick bag in Comparison with the traditional bag

Traditional bag (*Jholi*)	Special Designing Features added	Pick bag
Traditional bag has no defined straps. The parts of dupatta/ chuni etc. make the narrow straps which cause pain in shoulders.	**Padded straps**	Pick bag is designed with wide straps padded using foam. These padded strips resist pressure on shoulders.
Traditional bag has long opening at the back that is why one has to twist hands . towards back for putting the cotton in bag. This causes pain in wrists and hands	**Front [pening of bag pocket type**	Pick bag has wide pockets in front making front opening at both the sides which makes the dropping of cotton balls in bag with ease and it avoided the twisting of hands towards back.
Traditional bag does not have straps. Absence of straps reduces the possibility of increasing or decreasing the size of bag.	**Padded shoulder straps with extended straps**	Padded shoulder straps have long extended straps for tying and waist belt. It also has extended straps that provide the bag a possibility of increasing and decreasing the size of the bag.
Traditional bag has no defined waist belt and no bag type shape around the It has no extended straps for tying with waist.the result that the knot is tied on the upper part of stomach which causes pain in the chest. The task of empting the bag is time consuming.	**Waist belt with extended straps**	Waist belt is constructed as per the round waist measurement resulting into pocket openings in front on both the sides. Equal distribution of gathers around the waist of the bag helps in maintaining the balance of bag weight. Bag is tied easily with the extended straps of waist belt with extended straps of shoulders. It protects from the pressure on stomach and chest. This also makes the task of empting of bag easy without consuming extra time.
Traditional bags being smaller in size have to be emptied frequently which in turn causes more exhaustion/ tiredness in women. One can collect/ pick 5-6 kg. of cotton at one time.	**Larger in size**	The size of pick bag is larger and more quantity of cotton may be collected without empting the bag frequently. One can collect/ pick 7 to 10 kg. of cotton at one time without any exhaustion.
No defined back yoke	**Pleated shoulder back yoke**	Designed with defined back yoke. Size of the back yoke is kept as per the shoulder measurement. Back yoke has pleats/gathers in its middle and shoulder straps are attached on both the sides which maintain balance of bag weight by putting equal pressure on the whole body. Shoulders and neck are not stressed.
Traditional bag has both sides open at . the back and no defined shape of the bag is made. It causes dropping of cotton balls during activity; soiling and vegetative impurities mixes with cotton balls. It requires more time and efforts	**Compact design**	It was specially kept in mind that its shape should be like a bag so that balance can be maintained. Compact design makes the activity easier, does not let the cotton fall on the ground, cotton remains free of dust and other vegetative materials. Twenty five per cent more capacity for cotton picking than traditional bag. Being convenient to use, it enhances the efficiency of users, and they earn more in less time.

on the ground and time saving. For pearl millet head collection majority of the respondents used cloth bag (72.0 %) and rest of them (28.0 %) were observed to use the sheet prepared out of fertilizer bag. It was concluded that Pick bag was found highly feasible for flower collection. However, certain modifications were suggested for pearl millet head collection. Yadav and Arya (2012-2013) conducted experiment on field testing of developed pick/cot bag for male. Prepared cot/pick bag in different materials were given to cotton pickers at Cotton Research Farm CCS HAU, Hisar, Cotton Research Station, Sirsa and cotton fields of Fatehabad district for further testing. Suitability of fabrics was done. On the basis of the problems faced by farm women, the designs of the cotton picking bags were developed. Samples were prepared and field trials were conducted. One design was finalized on the basis of suitability in terms of required criteria's. Dahiya and Yadav (2014) conducted a study on acceptability of cotton picking among farm women of Sirsa and Fatehabad districts of Haryana. It was reported that perceived feasibility of cotton picking bag was found 88.91 percent which speaks of high percentage farm women found it advantageous, compatible and triable technology. Impact was assessed after completion of intervention programme which was found 43.65 per cent in terms of skill acquisition, knowledge gain and attitude change. It was acceptable on health parameters and helpful in enhancing working efficiency in cotton picking.



Making of pick bag :

Type of fabric to be used: To make Pick bag different types of fabric like terry cot, polyester, cotton *malasia*,etc.. can be used. On the basis of research studies cotton fabric was found to be the best for use. Discarded old clothes or fabrics like bed sheets, quilt cover, *chunni, dupatta* etc. can also be used for making pick bag at home. Regarding measurement of fabric, fabrics with different widths are available in the market. Purchase the fabric having double width at least 52 inches width. If double width fabric is not available then purchase single width but the fabric requirement in this case will increase also a joint will be formed in middle of the pick bag.

Ready to use paper pattern : Keeping the requirement of rural women in mind, ready to use paper pattern have been prepared for making pick bag easily. Actually, paper pattern is a draft which has all important parts of the bag like main body, waist belt, shoulder strips and facing built on a paper with the accurate measurement and seam allowances. This draft can be directly kept on the fabric for cutting.

Opinion of end users: This pick bag was given to farmers for use and their opinions were also noted. Farmers liked this pick bag very much. According to them, they picked more clean cotton balls in lesser time. The narrow strips of traditional cotton picking bag cause pain in upper stomach. But the strips of pick bag can be easily tied and it does not cause any discomfort. By using this Pick bag, they feel less tiredness and are able to spend happy time with their family. In addition to it, they also say that they will learn the stitching of pick bag and will sell it for supporting their family economically. Men and women accepted pick bag 100 per cent suitable for their cotton picking activity.

CONCLUSION

Cotton pick bag has been developed and designed by scientists of Department of Textile and Apparel Designing, ergonomically tested by Department of Family Resource Management and field tested by Dept. of Extension Education Communication Management of I. C. College of Home Science, CCSHAU Hisar. It was found highly promising and acceptable by the end users. Though pick bag has been developed a decade back but even then its technical knowhow has been disseminated only in few nearby villages of Hisar and Fatehabad district of Haryana through organized trainings. It needs to be disseminated at wider scale to reach masses in the rural areas of India through effective media form. There is a need and demand from different end users/clientele groups for imparting training on pick bag. Through the research experience of number of years it is felt that drafting, cutting and stitching of pick bag is taken very lightly/casually (do by estimate) that hampers the effectiveness of pick bag as the shape and size of its user friendly features (mainly front pockets and padded straps) are changed by the users during stitching. This use of defective pick bag affects its potential use as well as adoption rate. Hence, for effective use of developed bag and to get required results, proper training is required. The technical experts cannot go everywhere that is why media in the form of Print and CDROM is developed to serve as a platform for effective dissemination of the developed pick bag technology. Media package in the form of Print and CD ROM on pick bag technology will include: cutting, stitching of pick bag; modification as per body size; its use for multipurpose activities; use of ready paper patterns; use of discarded material for pick bag preparation. Pick bag designed and developed for diversified activities that is: Cotton picking, vegetable picking, fruit picking, flower collection, pearl millet ear head collection etc.. The thrust of work has also been on imparting technical knowhow to undertake it as an entrepreneurial activity for women empowerment. Being interactive it can be used number of times as per the need, time and learning potential of the user. The developed media (print and CDROM) will be helpful for awareness generation, motivation, knowledge and skill development to the beneficiaries.

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Adoption, returns and initiatives for *Bt* cotton cultivation

D.P.MALIK, K.K.KUNDU, S.K.DHANDA AND PARVEEN KUMAR
Department of Agricultural Economics, CCS Haryana Agricultural University, Hisar-125 004
**Email: dpmalik@hau.ernet.in*

ABSTRACT : Cotton is one of important fibre crop grown around 12 million ha. area in the country. The cotton is grown under both irrigated and rainfed conditions. The present study was focused to analyze trend in area, production and yield of cotton in India and Haryana, ii) to work out costs and returns of *Bt* cotton cultivation and initiatives for enhancing production and yield of cotton in Haryana. The results reveals that production and yield of cotton in the country exhibited CGR of 5.98 and 1.92 per cent, respectively during time period 2005-2016. The share of *Bt* cotton in total cotton area was highest Andhra Pradesh (99%) followed by followed by Punjab (95%), Maharashtra (90%), Haryana (87%), Karnataka, Tamil Nadu and Madhya Pradesh (85%). This indicates that *Bt*-Cotton in India has grown exponentially since introduction in 2002 because of heavy crop loss in cultivation of non *Bt* cotton due to occurrence of American Bollworm, insect-pests and diseases, increased use of plant protection chemicals etc.

The acreage under cotton in Haryana is around 6.0 lakh ha. The area coverage under cotton in Fatehabad, Hisar and Sirsa districts showed negative sign however, it indicated positive trend in Bhiwani and Jind districts. The cotton production was lowest in 2015-2016 due to outbreak of whitefly. Further, the economic analysis of *Bt* cotton cultivation reveals that 32 percent of total expenses were incurred on picking of cotton crop. The expenses on individual item like fertilizers, seed, hoeing and preparatory tillage was around 8 to 12 per cent of total variable cost. The net return worked out over variable expenses was Rs.49187/ha.

Besides various interventions like demonstrations, distribution of quality seed capacity building of cotton growers for sustainability of cotton cultivation, there is urgent need to focus on cost cutting technology (mechanization of farm operations especially picking) to enhance farm income and to reduce dependence on human labour.

Key words : *Bt* cotton, CGR, Cost, return analysis, crop development initiatives

Cotton is an important fibre crop of global significance, which is cultivated in tropical and sub-tropical regions of more than seventy countries in the world. The major producers of cotton are USA, China, India, Pakistan, Uzbekistan, Argentina, Australia, Greece, Brazil, Mexico and Turkey. These countries shared about 85 per cent of global cotton production. India has become the number one global exporter of cotton and second largest in world next to China in term of cotton production (30.15 million bales, 2015-2016). Though productivity of cotton has increased over years in India, but it is still very low in comparison (decadal average 522 kg lint/ha) to cotton growing countries like China, Brazil and USA (Anonymous, 2017).

Cotton is cultivated in three distinct agro-ecological regions *i.e.* north (Punjab, Haryana, Part of Rajasthan and U.P.), central (M.P., Maharashtra and Gujarat) and south (Andhra Pradesh, Karnataka and Tamil Nadu) of the country. The northern zone is almost totally irrigated, while the percentage of irrigated area is much lower in the central (23%) and southern zones (40%). The lowest irrigated area in the central zone which has nearly 60 per cent of cotton area of country. About 60 per cent of cotton in India is cultivated under rainfed conditions and this is regarded as one of the reasons for the low productivity recorded in the country. This is a cause for concern because millions of people depend on cotton cultivation for their economic wellbeing (Ramasundaram and Gajbhiye, 2001)

Cotton provides an excellent example of the interaction between technology and policy, and its effects on the cultivation of a crop. Cotton cultivation in India has witnessed major technological changes over the years and supportive public policy resulted into significant increase in its production and productivity.

***Bt* cotton adoption :** Government of India has approved commercial cultivation of *Bt* cotton hybrid with effect from 2002. *Bt* cotton is the first agricultural biotech crop that has been commercialized in India. The adoption of *Bt* technology revolutionized India's cotton cultivation. *Bt* cotton is cultivated by about 7.7 million smallscale farmers, across different cotton growing areas of the country. The area under *Bt* cotton hybrids was 0.29 lakh ha. in country during 2002-2003 and it increased abruptly and touched to 3.72 million ha. in 2006-2007 and thereafter continuation increase in *Bt* cotton acreage reached to 119.40 lakh ha in 2014-2015 showing more than 93.14 per cent adoption within a span of thirteen years. The continuous increase in area under *Bt* cotton is attained due several advantages like increase in yield, protection from bollworms and reduction in pesticide use, cost of cultivation, environmental pollution etc. Socio economic surveys confirm that *Bt* cotton continues to deliver significant and multiple agronomic, economic, environmental and welfare benefits to Indian farmers and society including halved insecticide requirements and a doubling of yield.

The area coverage under *Bt* cotton in Haryana was 0.09 lakh ha. in 2002-2003 increased to 3.46 lakh ha. In 2008-2009. It reached to 5.72 lakh ha in 2015-2016 sharing 94.85 per cent of total cotton area in the state. As result of fast spread of *Bt* cotton seeds in the state, production touched to 20.41 lakh bales with an yield of 608 kg lint/ha in 2016-2017.

Keeping in view , the present study was undertaken with objectives i) to examine trend in area, production and yield of cotton in India and Haryana, ii) to work out costs and returns of *Bt* cotton cultivation in Haryana and iii) to study various initiatives for enhancing production and yield of cotton in Haryana

MATERIALS AND METHODS

The present study is based on information extracted from published sources. The data pertaining to area, production and yield of cotton crop was scanned from *Agricultural Statistics At A Glance*, Department of Agriculture and Farmers Welfare, Govt of Haryana. The information on cost of cultivation of cotton was based on the data presented in Agricultural Officers Workshop for *kharif* season 2016 held at CCS Haryana Agricultural University, Hisar.The analytical tools like average, percentage, compound growth rate (CGR) etc. were computed to draw valid inferences.

RESULTS AND DISCUSSION

Cotton cultivation scenario in India : Cotton is one of important fibre crop grown around 12 million ha. area in the country. The major cotton growing states are Maharashtra, Gujarat, Andhra Pradesh, Madhya Pradesh, Karnataka and Haryana sharing 97.12 per cent of total cotton area. The cotton is grown under both irrigated and rainfed conditions. It is planted more than 30 per cent in irrigated areas. The area under cotton in last decade showed an increasing trend due to availability of better quality seed of *Bt* cotton. The increase in acreage under cotton was reported @3.99 per cent/annum during time period 2005-2016.

The cotton production increased up to 35.90 million bales in 2013-2014 and then decreased slightly in 2014-2015 and further decreased to 30.15 million bales in year 2015-2016 due to severe incidence of whitefly. However, overall production in last decade exhibited growth rate of 5.98 per cent. The production of cotton also increased substantially in the country due to adoption of better production technologies, use of quality seed and spread of cultivation of *Bt* cotton.

The cotton yield was 362 kg/ha in 2005-2006 and it touched to 510 kg/ha in 2013-2014 indicates an increase of 148 kg/ha within a period of nine years (Appendix 1). The overall increase in cotton yield achieved @1.92 per cent/ annum during time period 2005-2016.The increase in yield is attained due to adoption of better management practices, use of quality seed and planting of *Bt* cotton on large area in the country. The cotton yield declined in two consecutive years *i.e.* 2014-2015 and 2015-2016 due to severe attack of whitefly in northern India (Haryana and Punjab) and incidence of other insect-pests in central cotton growing zone.

State wise cotton cultivation status : The cotton is cultivated in 16 states of country and it is grown in states of Haryana, Rajasthan, Madhya Pradesh, Chhattisgarh, Odisha, Maharashtra, Andhra Pradesh, Telangana, Karnataka, West Bengal, Punjab, Tripura, Assam, Uttar Pradesh, Tamil Nadu. The major cotton growing states like Maharashtra, Gujarat, Andhra Pradesh, Madhya Pradesh, Karnataka, Haryana constituted more than 97 per cent of total cotton area. Maharashtra is leading state for cotton cultivation covering an area of 3.82 million ha. followed by Gujarat (2.72 m.ha), Andhra Pradesh (0.67 m.ha), Karnataka(0.63 m.ha), Haryana(0.60 m.ha) and Madhya Pradesh(0.55 m.ha) during 2015-2016 (Table 2). Maharashtra and Gujarat states shared about 50 per cent of total cotton area in the country. There is tremendous increase in cotton acreage in Andhra Pradesh from 0.31 to 0.67 million ha.during last decade. The cotton area in the states like Haryana and Gujarat increased slightly and in Madhya Pradesh, it decreased marginally during time period 2005-2016. The cotton area has increased substantially in Karnataka from 0.41 million ha in 2005-2006 to 0.88 million ha in 2014-2015.

The growth rates of cotton acreage for Andhra Pradesh, Karnataka, Maharashtra, Gujarat and Haryana was 12.84, 7.27, 3.79, 2.59 and 2.02 per cent, respectively. The cotton acreage showed declining trend in Madhya Pradesh. The area diverted towards cotton in the states of Andhra Pradesh, Karnataka, Maharashtra, Gujarat and Haryana from coarse cereals, pulses and oilseeds .However, cotton area shifted to oilseeds in Madhya Pradesh as farmers prefer to cultivate soyabean crop in rainfed conditions instead of cotton.

Coverage under *Bt* cotton : The *Bt* cotton was introduced in India for commercial cultivation in 2002 and about 0.29 ha area covered in first year (Table 1). Based on performance of *Bt* cotton and continuous heavy incidence of American Bollworm (*Helicoverpa armigera*), acreage under *Bt* cotton had touched to 64.13 lakh ha within a time span of five years. The continuous increase in area under *Bt* cotton was reported in recent decade and it extended to 10.53 million ha in 2013-2014 contributing of 88.09 per cent of total area

Among major cotton growing states, acreage under *Bt* cotton was more than 85 per cent of total cotton area except Rajasthan state (63 %). The share of *Bt* cotton in total cotton area was highest Andhra Pradesh (99%) followed by followed by Punjab (95%), Maharashtra (90%), Haryana (87%), Karnataka, Tamil Nadu and Madhya Pradesh (85%). This indicates that *Bt* cotton in India has grown exponentially since introduction in 2002 because of heavy crop loss in cultivation of non *Bt* cotton due to occurrence of American bollworm, insect pests and diseases, increased use of plant protection chemicals etc.

The cotton production in all major growing states like Andhra Pradesh, Karnataka, Maharashtra, Gujarat and Haryana and Madhya Pradesh along with all India Level showed positive sign. The cotton production increased in Andhra Pradesh (> four times), Karnataka (>six times), Madhya Pradesh (> three times), Maharashtra (> two times) Gujarat and Haryana

Table 1. Area coverage under *Bt* cotton and total cotton in India

State	2002-2003		2007-2008		2013-2014		2015-2016	
	Bt	**Total**	*Bt*	**Total**	*Bt*	**Total**	*Bt*	**Total**
Andhra Pradesh	0.038	**8.03**	10.00	**11.34**	23.65	**23.89**	4.38	**4.49**
Gujarat	0.091	**16.35**	13.00	**24.22**	21.25	**25.19**	19.24	**24.00**
Haryana	0.000	**5.18**	2.79	**4.83**	4.67	**5.36**	3.77	**4.98**
Karnataka	0.021	**3.93**	1.46	**4.03**	5.63	**6.62**	2.85	**4.64**
Madhya Pradesh	0.000	**5.59**	4.71	**6.30**	4.40	**5.14**	5.39	**5.99**
Maharashtra	0.120	**28.00**	25.62	**31.95**	37.72	**41.92**	32.30	**38.06**
Punjab	0.000	**4.49**	5.57	**6.04**	4.24	**4.46**	2.43	**2.56**
Rajasthan	0.000	**3.86**	0.38	**3.69**	2.50	**3.93**	2.87	**4.42**
Tamil Nadu	0.003	**0.75**	0.60	**0.99**	1.30	**1.52**	0.90	**1.50**
Telangana	0.000	**0.00**	0.00	**0.00**	0.00	**0.00**	12.27	**12.50**
Others	0.000	**0.52**	0.00	**0.74**	0.00	**1.57**	0.00	**1.86**
All India	**0.290**	**76.70**	**64.13**	**94.13**	**105.36**	**119.60**	**86.40**	**105.00**

(about 1.5 times) during time period 2005-2015. The cotton production in states of Karnataka, Andhra Pradesh, Madhya Pradesh, Maharashtra, Gujarat, Haryana increased at rate of 15.56, 14.67, 13.56,7.15, 3.70 and 1.83 per cent per annum , respectively during last decade (Table 2).

Table 2. Compound growth rates (CGR) of area, production and yield of cotton in India: 2005-2016 (%)

State	Area	Production	Yield
Andhra Pradesh	12.84	14.67	5.10
Gujarat	2.59	3.70	1.09
Haryana	2.02	1.83	-0.16
Karnataka	7.27	15.56	6.38
Madhya Pradesh	-1.43	13.56	14.39
Maharashtra	3.79	7.15	3.59
All India	**3.99**	**5.98**	**1.92**

The cotton yield (in terms of kg/ha) increased tremendously in states of Andhra Pradesh (280 to 515), Karnataka (228 to 449),Madhya Pradesh (204 to 540),Maharashtra (187 to 316), Haryana (437 to 603) and Gujarat (603 to 644) during time period 2005-2015. The increase in cotton yield in states of like Madhya Pradesh, Karnataka, Andhra Pradesh and Gujarat was attained at rate of 14.39, 6.38, 5.10 and 1.09 per cent, respectively during last decade (Table 2).

The increase in cotton production in all major cotton growing states as well as on all India Level is attained as result of increase in acreage and tremendous increase in yield. The increase in yield of cotton was attributed due to adoption of improved production technologies, timely planting, use of quality seeds, cultivation of *Bt* cotton seeds on large areas, favourbale market conditions.

Cotton cultivation Scenario in Haryana : Haryana state is broadly divided into two agro climatic zones *i.e.* eastern zone and western zone based on soil types, cropping pattern, rainfall etc. Cotton is mainly cultivated in western zone and cotton-wheat is most prevalent cropping system in the state. It is mainly cultivated in districts of Bhiwani, Fatehabad, Hisar, Jind and Sirsa falling in the western zone of the state. The medium staple cotton crop is planted in month of April May and picking starts from last week of September to November. Cotton is one of commercial crops grown in Haryana under semi-arid condition.

The acreage under cotton in the state is about 6.0 lakh ha. The area coverage under cotton in districts of Fatehabad, Hisar and Sirsa decreased slightly during time period 2005-2016, however , it increased in Bhiwani (0.60 to 0.93 lakh ha.) and Jind (0.49 to 0.75 lakh ha.) districts (Appendix 1). The overall cotton area in all major growing districts as well as state as whole declined during the years 2015-2016 and 2016-2017 as result of outbreak of white fly (*Bemisia tabaci*) in the state in 2014-2015. The cotton area diverted towards paddy, coarse cereals, pulses, cluster bean etc. The cotton acreage in state registered positive sign during last decade and indicated increase @ 1.68 per cent per annum (Table 3). The area under cotton again touched to 6.56 lakh ha. in 2017-18 against 5.70 lakh ha.in 2016-2017.

Table 3. Compound growth rates (CGR) of area, production and yield of cotton in Haryana: 2005-2017 (%)

District	Area	Production	Yield
Sirsa	-0.51	2.15	-1.99
Fatehabad	-2.28	-2.60	-4.50
Hisar	-0.22	2.97	-0.63
Bhiwani	7.25	14.61	3.53
Jind	4.41	2.33	-3.16
Haryana	**1.68**	**1.98**	**0.90**

The cotton production in the state increased from 15.02 lakh bales in 2005-2006 to 26.0 lakh bales in 2012-2013 and it decreased slightly to 24.0 lakh bales 2013-2014 and further declined to 19.45 lakh bales in 2014-2015. The worst situation in cotton production was in year 2015-2016 and it was only 9.93 lakh bales. The cotton production again showed increasing trend and it is expected that cotton production in the state will touch to 26 lakh bales in 2017-2018. The overall cotton production in state exhibited increase @ 1.98 per cent per annum during 2005-2017 (Table 3). The major cotton growing districts except Fatehabad also showed positive sign of compound growth rate of production during the same time period.

The cotton yield in state was 372 kg/ha in 2005-2006 increased to 761 kg/ha in 2013-2014 and declined to 508 kg/ha in 2014-2015 and 273 kg/ha in 2015-2016. The cotton yield again recaptured and touched to 609 kg/ha in 2016-2017. The cotton yield in the state as well as all major growing districts augmented during time period 2005-2014. This increase in yield achieved as result of introduction of *Bt* cotton, balanced use of nutrients, timely planting and adoption of improved agronomic practices etc. The decline in cotton yield during two consecutive years *i.e.* 2014-2015 and 2015-2016 as large areas was infested with whitefly, long dry spell, delay in sowing etc.

The increase in yield was again recorded in the year 2016-2017 in almost cotton growing districts. The increase is attained as CCSHAU, Hisar and State Department of Agriculture and Farmers Welfare, Govt of Haryana issued advisory, imparted training, conducted demonstrations, organized awareness campaigns for cultivation of specific hybrids of *Bt* cotton for farmers for management of white fly and other insect pests and diseases in the state. The regular monitoring by joint team of scientists and development officials for monitoring the occurrence of whitefly during crop season and off season, release timely advisory, arrangement of quality seed and plant protection chemicals resulted into substantially increase both in terms of production and yield of cotton.

Cost and return analysis of *Bt* cotton cultivation : The cotton crop is grown as commercial crop in the state. The assessment of inputs used, their costs and income received from cultivation of cotton is of utmost importance. The information pertaining to costs and returns of crops guide farmers to take appropriate decision for area allocation for particular crop , use of resources, adoption of technologies, arrangement of credit etc. Keeping in view various parameters, economic analysis of cotton cultivation was done based on the information collected by District Extension Specialist (Farm Management) posted in different district headquarters of the state. The relevant information was gathered by scientists through

Table 4. Costs and returns of Bt cotton cultivation in Haryana: 2016-2017 (/ha)

S.N.	Particulars	Quantity	Value (Rs.)	Percentage share*
1.	Preparatory tillage including sowing	4.00	5983	12.18
2	Seed treatment (kg)	2.25	4392	8.94
3.	Fertilizers	233.00	6978	14.20
4.	Irrigation	3.61	3970	8.08
5.	Hoeing/weeding (manual)		5747	11.70
6.	Plant protection		3733	7.60
7.	Picking		15895	32.35
8.	Miscellaneous **		2430	4.95
A.	**Total variable cost**		**49128**	**100.00**
9.	Rental value of land		21585	
B.	Total cost		81692	
C.	Production (quintals)			
1.	Main	18.00	95085	
2.	By product		3230	
	Gross return		**98315**	
D.	**Return over variable cost**		**49187**	
E.	**Net return**		**16623**	

* Percentage share to total variable cost, ** includes interest on working capital

interviewing 103 cotton cultivator of four districts namely Bhiwani, Fatehabad, Hisar, Mahendergarh for the year 2016-2017.

The expenses incurred on various operations in cultivation of *Bt* cotton are preparatory tillage, seed, fertilizers, hoeing/ weeding, plant protection and picking. About 32 per cent of total expenses were incurred on picking of cotton crop. The expenses on individual item like fertilizers, seed, hoeing and preparatory tillage were around 8 to 12 per cent of total variable cost.

The gross returns received from the sale of cotton produce was Rs.39328/ha and net return worked out over variable cost and total cost was Rs.19675/ha and Rs.6649/ha, respectively. The analysis of cost and returns reveals that farmers should continue cultivation of cotton crop particularly in limited irrigation conditions. The farm income can be further enhanced by adoption of latest production technologies, use of quality seeds, regular monitoring of crop, use of recommended doses of agro-chemicals, mechanization of farm operations (hoeing/weeding and picking) etc.

Crop development initiatives : Various cotton development programs like ICDP in 1970 to increase cotton area in irrigated area and development of improved hybrid cotton , Technology Mission on Cotton (TMC) in 2000 to improve the yield and quality of cotton, creation of market infrastructure, modernization of existing ginning and pressing mills were initiated in major cotton growing states including Haryana.

Cotton is one component of National Food Security Mission (NFSM) is being implemented in 14 states including Haryana. Under this component, the various activities like

APPENDIX 1

Area, production and yield of cotton in India:2005-2016

States	2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016*
Area (million ha.)											
Andhra Pradesh	0.31	0.24	0.27	0.30	0.30	0.38	0.48	0.58	0.67	0.82	0.67
Gujarat	1.90	2.39	2.42	2.35	2.46	2.63	2.96	2.50	2.52	2.77	2.72
Haryana	0.58	0.53	0.48	0.45	0.50	0.49	0.64	0.61	0.54	0.65	0.60
Karnataka	0.41	0.37	0.40	0.40	0.45	0.54	0.55	0.49	0.66	0.88	0.63
M. Pradesh	0.62	0.63	0.63	0.62	0.61	0.65	0.76	0.61	0.51	0.55	0.55
Maharashtra	2.87	3.19	3.19	3.14	3.39	3.94	4.15	4.14	4.19	4.19	3.82
Other states	1.99	1.79	2.02	2.15	2.42	2.61	2.64	3.05	2.87	2.96	2.88
All India	**8.68**	**9.14**	**9.41**	**9.41**	**10.13**	**11.24**	**12.18**	**11.98**	**11.96**	**12.82**	**11.87**
production (million bales)											
Andhra Pradesh	0.69	0.68	1.00	1.02	0.89	0.85	0.88	1.52	2.17	2.84	2.40
Gujarat	6.77	8.78	8.28	7.01	7.98	10.40	12.0	8.85	10.15	10.50	9.70
Haryana	1.49	1.81	1.88	1.85	1.92	1.75	2.65	2.50	2.30	2.30	1.35
Karnataka	0.41	0.61	0.77	0.86	0.86	1.20	1.20	1.26	1.88	2.31	1.60
M. Pradesh	0.62	0.82	0.86	0.85	0.85	2.00	2.00	2.20	1.73	1.75	2.10
Maharashtra	3.16	5.12	6.20	6.20	6.57	8.77	7.60	8.10	8.40	7.80	7.50
Other states	5.36	4.81	6.89	4.49	4.95	8.03	8.87	9.79	9.27	7.3	5.5
All India	**18.5**	**22.63**	**25.88**	**22.28**	**24.02**	**33**	**35.2**	**34.22**	**35.9**	**34.8**	**30.15**
yield (kg lint/ha)											
A. Pradesh	280.5	353.6	380.8	431.8	413.1	311.1	282.2	426.7	445.4	515.1	612
Gujarat	603.5	625.6	581.4	506.6	550.8	671.5	688.5	603.5	685.1	644.3	605.2
Haryana	436.9	581.4	663	693.6	646	605.2	703.8	691.9	729.3	603.5	380.8
Karnataka	227.8	275.4	328.1	360.4	323	374	367.2	440.3	481.1	448.8	430.1
M. Pradesh	204	219.3	232.9	232.9	238	523.6	482.8	615.4	571.2	544	652.8
Maharashtra	187	250	330	335	319	379	313	332	341	316	333
All India	**362**	**421**	**467**	**403**	**403**	**499**	**491**	**486**	**510**	**462**	**432**

* 4th Advance Estimates.

Area, production and yield of cotton in Haryana: 2005-2017

District	2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017
Area (lakh ha.)												
Sirsa	1.93	1.90	1.82	1.72	1.93	1.89	2.11	1.99	1.48	2.04	1.72	1.79
Fatehabad	0.94	0.91	0.86	0.84	0.86	0.84	0.91	0.86	0.75	0.84	0.71	0.67
Hisar	1.46	1.30	1.18	1.12	1.33	1.24	1.54	1.46	1.23	1.43	1.27	1.14
Bhiwani	0.60	0.49	0.37	0.30	0.33	0.35	0.60	0.63	0.50	0.77	0.93	0.87
Jind	0.49	0.46	0.44	0.45	0.46	0.47	0.63	0.67	0.62	0.70	0.72	0.59
Other districts	0.40	0.25	0.16	0.12	0.17	0.13	0.63	0.55	0.78	0.7	0.80	0.64
State	**5.84**	**5.3**	**4.83**	**4.56**	**5.07**	**4.92**	**6.41**	**6.14**	**5.36**	**6.48**	**6.15**	**5.70**

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Production (lakh bales)												
Sirsa	3.42	4.38	4.32	4.44	4.71	4.15	5.62	5.29	5.00	4.27	2.99	7.31
Fatehabad	1.80	2.19	2.23	2.22	2.20	1.81	2.58	2.11	2.05	1.35	0.87	2.70
Hisar	1.85	2.33	2.74	2.75	2.81	2.54	3.92	3.11	2.95	2.50	2.08	4.17
Bhiwani	0.62	0.61	0.58	0.44	0.52	0.62	1.27	1.36	1.21	1.10	1.83	2.65
Jind	0.76	0.81	0.97	0.90	0.83	0.95	1.50	1.44	0.79	0.60	0.75	1.75
Other dist.	6.57	5.68	4.16	3.25	4.19	6.93	11.10	12.71	12	9.63	1.41	1.83
State	**15.02**	**16**	**15**	**14**	**15.25**	**17**	**26**	**26**	**24**	**19.45**	**9.93**	**20.41**
Yield (kg lint/ha)												
Sirsa	511.7	664.7	686.8	744.6	705.5	635.8	768.4	768.4	775.2	484.5	295.8	693.6
Fatehabad	547.4	697	749.7	761.6	741.2	623.9	822.8	712.3	739.5	375.7	209.1	686.8
Hisar	363.8	518.5	669.8	708.9	610.3	589.9	737.8	617.1	629	518.5	278.8	622.2
Bhiwani	295.8	360.4	450.5	421.6	455.6	516.8	617.1	627.3	642.6	535.5	333.2	518.5
Jind	442	508.3	632.4	578	521.9	579.7	688.5	620.5	615.4	467.5	176.8	503.2
State	**372.3**	**513.4**	**528.7**	**521.9**	**511.7**	**586.5**	**690.2**	**720.8**	**761.6**	**508.3**	**273.7**	**608.6**

demonstrations on ICM IPM, INM, soil/water management practices, intercropping with cotton, high density planting system (HDPS) are being carried at farmers field by state department of agriculture and SAU. Besides, cotton crop is also being promoted as alternate crop to paddy under Crop Diversification Program (CDP) and Rashtriya Krishi Vikas Yojana (RKVY) in Haryana. The financial assistance is provided to cultivators for demonstrations, farm machinery and implements under CDP.

State government has also initiated state Plan Scheme on " Promotion of Cotton Cultivation in Haryana State" in 2011-2012 to increase the area, production and productivity of cotton. The various interventions like distribution of certified seeds, production of certified and foundation seeds, farmers trainings, supply of manually operated and tractor mounted spray pumps.

Besides various interventions like demonstrations, distribution of quality seed capacity building of cotton growers for sustainability of cotton cultivation in the state, there is urgent need to focus on cost cutting technology (mechanization of farm operations especially picking) to enhance farm income and to reduce dependence on human labour.

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Present status and requirement of quality cotton and its by products

P G PATIL, P K MANDHYAN* AND P JAGAJANANTHA
Central Institute for Research on Cotton Technology, Mumbai -
**E-mail :pkmandhyan@gmail.com*

ABSTRACT : Cotton is one of the premier commercial crops of India supporting livelihood of about 60 million people engaged in cotton cultivation, trade and processing. The requirement of quality cotton has always been an issue with the processors. The quality of the cotton fibre is dependent on the pedigree or genetic composition of the variety as well as on the conditions under which the plant is grown. Although fibre quality parse cannot be improved during processing however improper handling or processing can adversely affect the quality. With the globalization and opening of markets major changes have taken place in the cotton processing industry. The pre-cleaning, ginning, lint cleaning and baling are the important processes which the cotton undergoes on its passage from the field to the industry and its ultimate conversion into yarn and fabric for various applications.

The world cotton production has been projected to grow by 8 per cent to 24.9 million tonnes with global area of around 31.7 million hectares under cotton cultivation. The acreage under cotton cultivation in India has increased by around 20 per cent to 121 lakh hectares with an estimated output of about 6 million tons. Bumper crop is expected to put downward pressure on the cotton prices in the beginning of the season.

The international prices represented by the Cotlook A index is likely to hover around 69 cents per pound during the year. In India the price of the Fair and Average Quality cotton is ruling above the minimum support price at present. It is expected that the domestic prices will experience a depressing trend with the increase in the arrivals. The role of Cotton Corporation of India would be crucial to maintain the stable price for cotton through its domestic procurement. The minimum support price for cotton has been fixed at Rs.4020/q for medium staple and Rs.4320/q for long staple cotton.

The production of cotton seed, two-third of cotton by weight, is estimated to be around 12 million tons. The cottonseed processing industry has assumed significance as the production of cotton has attained a substantial growth in the recent past. Presently only around 5 per cent of the cottonseed is scientifically processed for extraction of oil and other value added products *viz.,* linters, hulls and cake, while the remaining seed is processed either through conventional expellers for oil extraction with lesser recovery. Besides cotton stalks to the tune of around 30 million tons are being produced in the country annually and there is a need to commercially exploit the biomass to convert waste into wealth on one hand and enable farmers to get additional remuneration for the cotton stalks.

Table 1. World cotton supply and distribution

	2015-2016	2016-2017	2017-2018
	(Million Tons)		
Production	21.48	23.03	24.89
Consumption	24.18	24.47	25.00
Imports	7.57	7.88	7.80
Exports	7.55	7.88	7.80
Ending stocks	20.33	18.90	18.80
Cotlook A Index*	70	83	69

*The price projection for 2017-2018 is based on the ending stocks to mill use ratio in the world-less-China in 2015-2016 (estimate), 2016-2017 (projection) and 2017-2018 (projection); on the ratio of Chinese net imports to world imports in 2016-2017 (projection) and 2017-2018 (projection); and on the price projection of 2016-2017. The price projection is the mid-point of the 95% confidence interval: 54 cts/lb to 87 cts/lb.

India's Share in World (CCI Ltd.) : India is the largest producer of cotton in the world accounting for about 26 per cent of the world cotton production. It has the distinction of having the largest area under cotton cultivation in the world ranging between 10.9 million hectares to 12.8 million hectares and constituting about 38 per cent to 41 per cent of the world area under cotton cultivation. The yield per hectare (*i.e.*504 kg to 566 kg/ha) is however still lower against the world average of about 701 Kg to 766 kg/ha. Country is expected to make more strides in cotton production in the years to come.

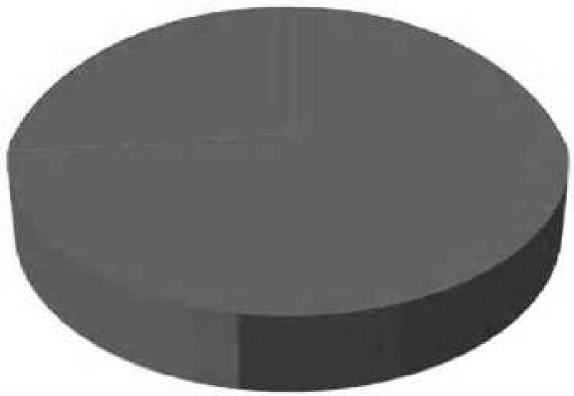
COTTON QUALITY REQUIREMENTS : ICAR-CIRCOT is a premier institute under the ICAR carrying out basic and strategic research in processing cotton and its agro residues, development of value added products and quality assessment. The institute is also providing skill development programme and the agri business incubation services to the stakeholders. CIRCOT is also an NABL accredited laboratory and is a referral laboratory for cotton testing.

The market value of Indian Textile and Apparels was USD 137 billion (2016) and it is expected to grow upto USD 226 billion by 2023. The textile sector has evolved in India from first cotton mill, started in 1854 in Mumbai, to 50 Million Spindles and 0.75 Mn Open-End Rotors, which accounts for about 24 per cent of the world's spindle capacity and 8 per cent of global rotor capacity. India has the highest loom capacity (including hand looms) with 63 per cent of the world's market share, in order to cater to the kind of Industry India needed to produce the raw material of matching magnitude, therefore, with production of 6,106 million kg, India became the largest producer of cotton in 2016-2017. Textile plays a major role in the Indian economy. India's textile market contributes 14 per cent to industrial production and 4 per cent to GDP with over 45 million people employed; the industry is one of the largest sources of employment

Table 2. Production of spun yarn (SSI and Non-SSI) in India

Sr. No.	Year	Production in million kgs	
		Cotton yarn	Blended yarn
1.	2007-2008	2948	677
2.	2008-2009	2896	655
3.	2009-2010	3079	707
4.	2010-2011	3490	796
5.	2011-2012	3126	789
6.	2012-2013	3583	828
7.	2013-2014	3928	896
8.	2014-2015	4054	920
9.	2015-2016	4138	972
10.	2016-2017	4056	1033

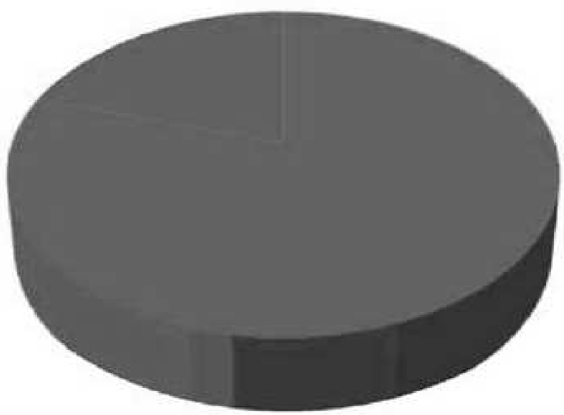
Area in Million Hectares



Crop Year 2016-17 (P)*	World	India
Area in Million Hectares	29.24	10.50

*P-Projected **Source:** CAB & ICAC Cotton: Nov, 2017

Production in Million MT



Crop Year 2016-17 (P)*	World	India
Production in Million MT	22.85	5.88

*P-Projected **Source:** CAB & ICAC Cotton: Nov, 2017

Fig. 1. Status of International and National Cotton Production for 2016-2017

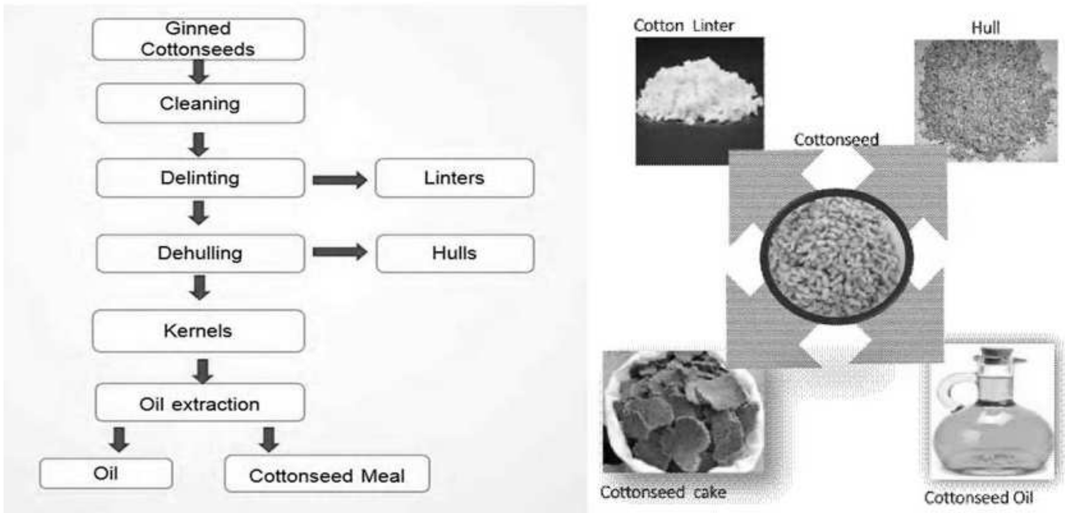


Fig. 2. By-products extraction from Cottonseed

Table 3. Count wise production of cotton yarn during the year 2015-2016

Sr. No.	Count	Production in million kgs.	Requirement of cotton* (lakh bales of 170 kg.)
1.	1s-10s	634.39	47
2.	11s-20s	754.27	55
3.	21s-30s	981.05	72
4.	31s-40s	1209.83	89
5.	41s-60s	378.63	28
6.	61s-80s	127.88	9
7.	Above 80s	51.95	4

**Assuming the average waste percentage at 25 per cent (In the case of carded yarn, we can assume an average waste of 18 per cent (from blow room to winding). In the case of combed yarns, we can assume an average waste of 36 per cent. Of the total quantum of yarn production in Indian mills, combed yarns constitute 35% and carded yarns constitute 65% per cent (roughly)*

generation in the country.

The industry accounts for nearly 15 per cent of total exports. The production of yarn stood at 5664 million Kg. in 2016-2017. Cotton yarn accounted for the largest share in total yarn production in 2016-2017, the segment's share amounted to 71.66 per cent. Cotton yarn accounted for approximately 60 per cent share in fabric production (2016-2017). The mills in India produce yarn ranging from 1s count to 80s and above. Therefore, the availability of raw material with appropriate fibre attributes to produce yarn with such a wide range of fineness has to be ensured. In the present study the requirement of the cotton fibre by the industry vis-à-vis its present availability has been presented with emphasis on fibre quality.

Requirement of the Industry : India became a net exporter from an importer of the

Table 4. The classification from the UHML point of view

Category	Range of UHML (mm)
Short	20 mm and below
Medium	20.5 - 24.5
Medium long	25.0 - 27.0
Long	27.5 - 32.0
Extra long	32.5 mm and above

Figure 3. Scientific Cottonseed processing Plant

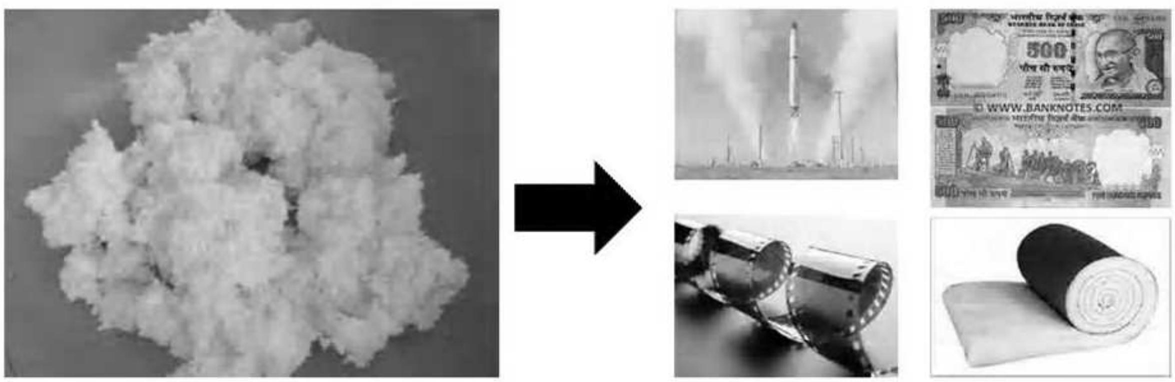


Fig. 4. Products from Cotton Linters

Table 5. The quality of cotton required to produce different counts of yarn

Count Range	Range of UHML (mm)	Minimum value of UI	Minimum tenacity (g/t) (HVI mode)	Micronaire range	Type of cotton
<14s	Below 24 mm	-	-	Above 5.0	Short
14s-18s	24-25	81	27.5	3.9-4.7	Medium
20s-24s	25-26	82	28.0	3.8-4.2	Medium Long
25s-30s	26-27	83	29.1	3.4-4.2	
31s-40s	27-29	84	29.3	3.3-4.1	Long
41s-50s	29-31	84	31.3	3.3-4.0	
51s-60s	31-33	86	33.6	3.2-3.9	
61s-80s	33-34	86	36.6	3.2-3.8	Extra Long
81s-100s	34-36	87	38.3	3.1-3.4	
101s-120s	36>	88	40.0	2.9-3.2	

cotton after 2003-2004. The increased production after meeting domestic consumption opened the opportunities of export of raw cotton by India. The improvement in quality has been a major achievement in recent years and the textile industry has expressed their satisfaction. Today, Indian yarn is widely accepted in International markets as the exporters here regularly meet the needs of importers with unmatched efficiency and economy in countries like USA, Italy, Spain, Japan, China, South Korea, Taiwan, Bangladesh, Vietnam etc.

The Production of cotton yarn in India rose from 2949 million kgs to 4138 million kgs in 2015-2016. It comprises count range from 1s to above 80s. The quality requirements of cotton differ for different count range of yarn.

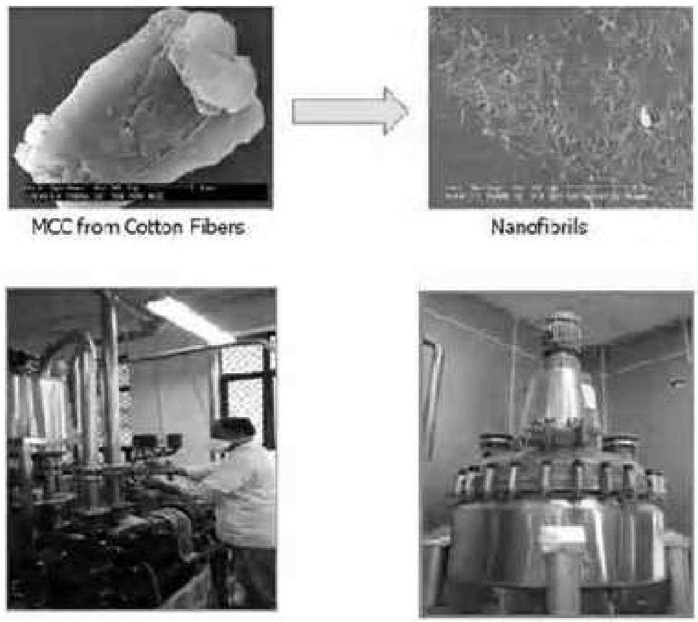


Fig. 5. ICAR-CIRCOT pilot plant with capacity of 10kg/day

The country is divided into three parts so far as cotton production is concerned. The northern region produces short and medium staple cotton; the southern region normally produces long staples cotton, while the central region produces long and medium staples.

Despite a bumper crop, the mills were forced to go in for some imports, particularly of extra long staple cotton (ELS) as there has been a quantitative and qualitative gap in this category. Since the indigenous ELS cottons do not combine all the fibre parameters to yield world class yarn in the superfine count group. Mills have been continuing to import such cotton from Egypt, USA etc. The highest import of cotton was 20.00 lakh bales and minimum was 02.38 lakh bales in 2015-16 and 2010-2011 respectively.

After the introduction of Bt hybrids for commercial cultivation in the year 2002-2003, the composition of cultivation of species drastically changed. Presently, all the cotton in

Table 6. Requirement of the Cotton and its Availability

Sr.No.	Count	Requirement of cotton* (lakh bales of 170 kg.)	Type of cotton required	Requirement (%)	Production (%)
1.	1s-10s	47	Short	15	1
2.	11s-20s	55	Medium	42	32
3.	21s-30s	72	Medium long		
4.	31s-40s	89	Long	38	65
5.	41s-60s	28			
6.	61s-80s	9	Extra long	5	2
7.	Above 80s	4			

India is under hirsutum group (>95%, 2012) leaving only <5% under arboreum and harbaceum and negligible area under barbadense group (Fig. 5). As a result, in recent years, shortage of short staple and ELS cotton has been realized by the textile Industries.

COTTON BY-PRODUCTS : Cotton Seed is the by-product of cotton that obtain from ginning. From the cotton seed, the four major products that can be obtained are linters, hulls, meal and oil. Generally 5 per cent of the cotton seeds were scientifically processed and the remaining 95 per cent were mechanically expelled.

Scientific processing of cottonseed gives

- linters (6%),
- Hulls (27%),
- Oil (18%),
- Meal (45%)

The following table provides the availability of by-products and their values after processing.

Cotton seed cake : Presently, in India, whole seeds are crushed and oil is extracted in which case the oil recovery is only 11-12 per cent. The cake thus obtained is fed to cattle. The crude protein in the cake is about 25-27 per cent. When kernels are used for extraction of oil, the recovery of oil is much better and cake fetches a better price due to high protein and good colour.

Cottonseed meal : Availability: 5.75 million tonnes annually

? Oiled Cake: 5.4 m tonnes and De-oiled cake: 0.35 m tonnes

? Uses: Mostly used for ruminates feeding

? Total gossypol content: 0.6 - 1.15% (0.05 – 0.7% free gossypol)

? Gossypol: Limitation to non-ruminants like

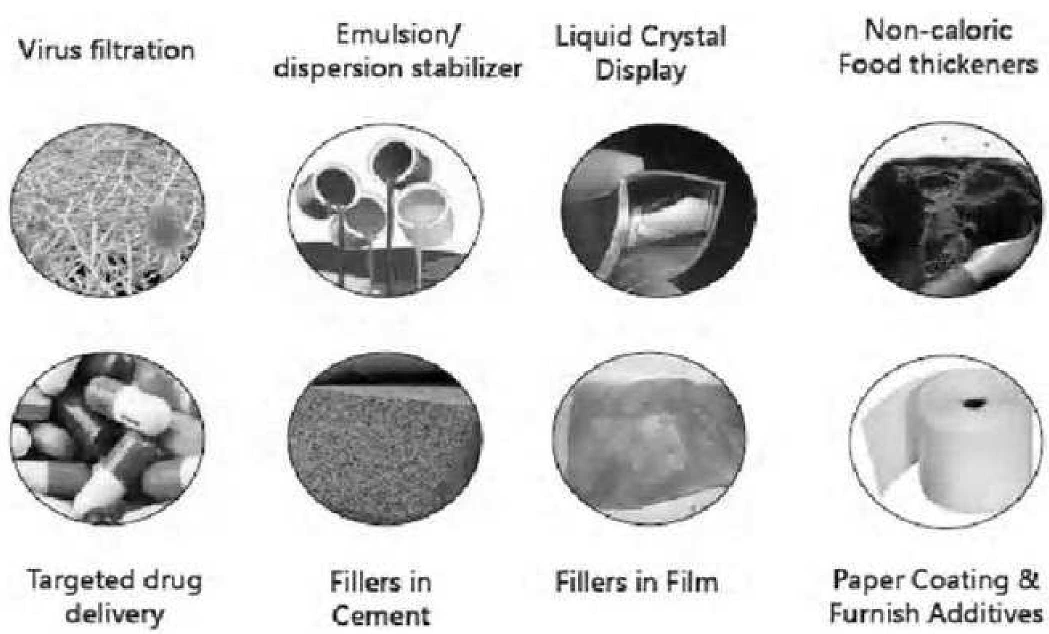


Figure 6. Applications of Nanocellulose

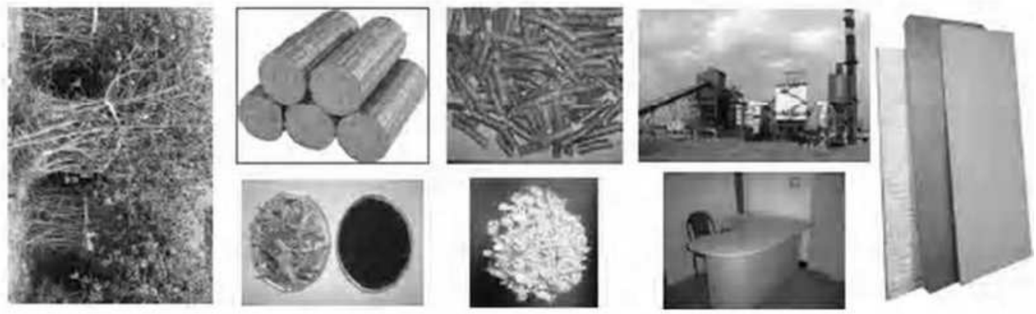


Fig. 7. Applications of cotton stalk

Table 7. Cotton Seed By-Products and their Value

Products(Mn. Kg)	Availability* (Qty)	Value (Rs Mn.)	Potential (Q)	Value (Rs. Mn.)	Additional Benefit (Rs. Mn.)
Cotton Linter	39.6	871	7920	174240	17336
Cottonseed oil	1400	926124	2.25	1451498	52537
Cottonseed hull	178	2492	35640	498960	49646
		929487		2124698	Rs.1195 Billion

fish and Poultry

? Large scale production of degossypolised meal under trials

? Small scale production of degossypolised meal for poultry and fish feeding, etc. using CIRCOT technology

Cotton seed oil : It is well known that as much as 60-70 per cent of seed is available from seed cotton during ginning. The cottonseed despite being rich in edible oil and protein, it has not received as much attention as it deserves. The seeds are stored in open and there could be chances of infection by fungi elaborating aflatoxins. Such seeds become unfit for feeding to cattle and even the meal cannot be exported. Efforts have to be made to utilize cottonseed more scientifically to realise good returns.

Preparation of pulp and paper from cotton linters : It is short fuzzy fibres from cottonseed. The linter sample was mechanically cleaned using shirley trash separator. Cleaned linter samples were kiered with various concentrations of alkali (2%, 4% and 6%) in a rotary bomb digester at 160p C for 2 hours. The kiered samples were washed thoroughly and then converted into pulp by beating in a valley beater to desired freeness. Pulp samples were bleached in plastic containers using hypochlorite at 40p C for 2 h. Standard paper sheets were prepared from all the pulps and evaluated for various strength properties. The test results indicated that the quality of paper was quite satisfactory.

Uses : Cellulose Nitrate (explosives), Cellulose acetate (film, membranes etc.), High grade paper (currency, security), Medical grade cotton (Absorbent), Micro Crystalline cellulose (Filler in Tablets) Food Casings, Felts etc.

Cotton seed hulls : Bio-enriched Cattle Feed: Cottonseed hull is a conventional feed for cattle and is a by-product of seed crushing industry. Cottonseed hulls are available in abundance and are rich in cellulose content but poor in digestibility. The presence of lignocellulosic bonds makes the material difficult to digest by ruminants. It is well known that microorganisms attack lignocellulosic bonds of these materials resulting in improved digestibility of the materials. The digestibility of cottonseed hulls could be improved by subjecting to an inexpensive anaerobic treatment with mixed microbial consortium for 7 days at room temperature.

Nanocellulose from cotton linters : The Nano-cellulose produced at ICAR-CIRCOT's piolet plant with the capacity of 10 kg/day. The nano-cellulose particle size is usually less than 100 nanometer. Nanocellulose Crystalline Cellulose (NCC) could be produced from cotton linters.

Generally the nano-cellulose will have the following properties

ü High mechanical strength (1 to 10GPa)

ü High young modulus (100-130GPa)

ü High surface area (50-200 m^2/g)

ü Bio degradable

ü Novel optical properties

Cotton stalks : Availability : 26 million tonnes annually

- Utilization: About 5-6 per cent commercially utilized
- Properties: about 60 per cent holocellulose, 27 per cent lignin and 6 per cent ash, Gross calorific value: 4000 kcal/kg
- Commercial Uses: Briquettes, Pellets, Compost, Power generation
- Under Trials: Particle Board, Pulp And Paper, Hard Boards, etc.

On farm utilization of cotton stalks : CIRCOT accelerated process for compost preparation. Compost is enriched with nutrients, plant growth microorganisms. This is stable for the period up to one year. In mushroom production, oyster mushroom (edible) were grown from cotton stalks. This mushroom yields up to 500 g/kg of cotton stalks.

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INVITED PAPERS

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Synonymous codon usage bias in chloroplast genome of *Gossypium thurberi* and *Gossypium arboreum*

FARSHID TALAT*, SAMANEH HASANI NEJAD, MEHDI BADRI ANARJAN
Seed and Plant Improvement Research Department, West Azarbaijan Agricultural and Natural Resources Research and Education Center, AREEO, Urmia, Iran
**E-mail: f.talat@areeo.ac.ir*

ABSTRACT : Analysis of codon usage is very important to optimize the production of proteins in gene expression system. Chloroplast has special importance due to its small size and high copy number of genome. *Gossypium* spp. is the most important fiber crop in the modern world. In this research, the complete nucleotide sequence of the chloroplast genomes of two wild cotton species was studied, and analyzed using Codon W software. Synonymous codon usage of 57 protein coding genes in chloroplast genome of *Gossypium thurberi* and *Gossypium arboreum* was analyzed to find out the possible factors contributing codon bias. All preferred synonymous codons were found to use A/T ending codons as chloroplast genomes are rich in AT. Correspondence analysis and method of effective number of codon as Nc-plot were conducted to analyze synonymous codon usage. ENC Vs GC3 plot grouped majority of the analyzed genes on or just below the left side of the expected GC3 curve indicating the influence of base compositional constraints in regulating codon usage. According to the corresponding analysis, codon bias in the chloroplast genome of *Gossypium thurberi* and *Gossypium arboreum* are related to their gene length, mutation bias, gene hydropathic level of each protein, gene function and selection or gene expression only subtly affect codon usage. This study provided insights into the molecular evolution studies.

Key words : Codon adaptation index, correspondence analysis, *G. arboreum*, *G. thurberi,* synonymous codon usage, ENC Vs GC3 plot,

Cotton (*Gossypium* spp), belongs to family Malvaceae and is grown almost all over the world from time immemorial. It is one of the most important cash crops in many countries and is being grown in warmer regions of the countries. In addition to the lint, cotton seed is used for oil extraction which makes about 80 per cent of the national oil production. Cotton is mainly grown for fiber which is an economic component and plays a vital role for uplifting country's economy (Riaz *et al.*, 2013). Generally, the alternative codons for any amino acid are not randomly used (Ghosh, 2000). Studies of the synonymous codon usage reveal information on molecular evolution of individual genes, which provides data to improve gene recognition algorithms, are utilized to design DNA primers, and detects horizontal transfer events. Most plastidic genomes have four regions, namely large single copy region (LSC, 80 Kb), small single copy region

(SSC, 20 kb) and two inverted repeat regions (IR, 25 kb). The single copy region is separated by two IRs. This structural conservation however breaks in some plants such as *Vicia faba* (Kim, and Lee, 2004), and *Cryptomeria japonica* (Hirao *et al.*, 2008 and Saski *et al.*, 2005) by loss of an IR, and in *Euglena gracilis* that has three tandem repeats (Hallick *et al.*, 1993). Variations among different species provide large information for the phylogenetic studies. Chloroplasts have low mutation rate with great deal of conservation in their genome size and structure, gene content and organization. Few differences have been reported in the same species, but significant differences could be detected between the different species in genome size and gene orientation (Young-Kyu *et al.*, 2009). Transplastomics have proved to be a powerful tool to improve the plant genetic architecture with high expression of the foreign protein, low risk of the pollen pollution (Talat, 2014 and Ruf *et al.*, 2007) and no gene silencing. Therefore and In addition to phylogenetic analysis based on plastidic genomes, it is imperative to understand the chloroplast genome in order to logically design our next generation transplastomics. Accordingly, chloroplast genomes of many species have been sequenced (Talat, 2015 and Diekmann *et al.*, 2009). Following a long period of evolution, codons are used in a species-specific manner, a phenomenon known as codon usage bias. In recent years, an ever-increasing body of studies on codon usage bias has been reported for plant breeding (Kawabe *et al.*, 2003 and Ravi *et al.*, 2008 and Lei *et al.*, 2013). Liu and Xue (2005) reported that the chloroplast genome might display particular characteristics of codon usage that are different from its host nuclear genome. Ruhfel *et al.,* (2014) put forward that their analyses of the plastid sequence data recovered a strongly supported framework of relationships for green plants. Several articles have also reported the codon usage pattern, and the factors that shape codon usage, for *Zea mays* (Liu *et al.*, 2010), Silene latifolia (Qiu *et al.*, 2011), seven different citrus species (Xu *et al.*, 2013), and the *Asteraceae* family (Nie *et al.*, 2013). However, the exact codon usage characteristics for single genes of higher plants have not been well explored to date.

MATERIALS AND METHODS

Softwares : Complete chloroplast genome sequence of *G. thurberi*, *G. arboreum*, *G. barbadense* and *G. hirsutum* in FASTA format, with respectively accession number and length (NC_015204.1 and 160.264), (HQ_325740.1 and 160.230), (NC_008641.1 and 160.317), (NC_007944.1 and 160,301) downloaded from NCBI //http:www.ncbi.nlm.nih.gov/nuccore/term. To identify the position of genes in four chloroplast genomes, according to the gene database information for each genome at the NCBI site, a montage of the sequences of each genome with the genes highlighted in the sequence was obtained by word office 2013. After determining the position of all genes on the corresponding genome sequence, information about each gene from the NCBI site and from the gene bank page for each genome was obtained and written alongside with the corresponding gene. The introns are distinguished by separated color that this caused till position of the genes, the IGS regions as well as the genes that are shared have also been identified. Additionally, the length of the coding regions (CDS, tRNA, rRNA) and non-coding regions (intron and IGS) for each of the three genomes was obtained separately from this file. Genome structure map and gene distribution drew with giving information about the access number of each genome in OGDRAW V1.1 software (http://ogdraw.mpimpgolm.mpg.de). The REPuter software online version (http://bibiserv.techfak.uni-bielfeld.de/reputer) was used to identify duplicate sequences and their position. RSCU of different codon were counted for each gene sample by CodonW in the Mobyle software at the address (http://mobyle.pasteur.fr/cgibin/portal.py). To calculating of the per centage of A, T, C and G nucleotides, as well as AT and GC in genomes in order to making CG table was used Visual Bioanformatics (V 2.1.0) software. SPSS V.22 and minitabV.16 were used for plotting the usage of codon and adaptive analysis charts.

RESULTS AND DISCUSSION

GC content : The content of GC is an important feature of the chloroplasts genome. The GC content for chloroplast genome of four species are presented in Tables 1- 4. The results of this study showed that per centage of GC in

Table 1. GC contents for chloroplast genome of *G. thurberi*

- -	Coding protein	region trna	- rrna	**Total**	Non IGS	coding intron	**Region total**	- Complete genome	- LSC	- SSC	- IR
Length	79740	2775	8970	**91485**	49915	20436	**70351**	160264	88737	20.271	25628
proportion	49.76	1.73	5.60	**57.08**	31.15	12.75	**43.90**	100.00	55.37	12.65	15.99
T(%)	31.05	23.14	22.32	**30.34**	34.32	32.28	**33.73**	31.83	33.15	34.46	28.52
A(%)	29.85	24.58	22.17	**29.31**	34.10	30.97	**33.19**	30.95	31.67	33.92	28.54
C(%)	19.28	26.13	27.79	**20.56**	15.99	19.12	**16.90**	18.99	18.11	16.54	20.66
G(%)	18.42	26.16	27.71	**19.79**	15.58	17.63	**16.18**	18.23	17.08	15.09	22.29
A+T(%)	60.90	47.71	44.49	**59.65**	68.42	63.25	**66.92**	62.78	64.81	68.38	57.05
C+G(%)	37.69	52.29	55.51	**40.35**	31.58	36.75	**33.08**	37.22	35.19	31.62	42.95

Table 2. GC contents for chloroplast genome of *G. arboreum*

- -	Coding protein	region trna	- rrna	- **Total**	Non IGS	coding intron	**Region total**	- Complete genome	- LSC	- SSC	- IR
Length	79253	2769	8349	**90371**	493330	20526	**69859**	160230	88721	20287	25611
proportion	49.46	1.53	5.21	**56.4**	30.8	12.8	**43.60**	100.00	55.37	12.66	15.98
T(%)	31.4	22.8	22.3	**30.2**	34.4	32.0	**33.7**	31.8	33.2	33.9	28.5
A(%)	30.3	24.0	22.3	**29.4**	34.0	31.1	**33.2**	31.0	31.6	34.4	28.5
C(%)	19.3	27.2	27.7	**20.4**	16.0	19.0	**16.8**	18.8	18.1	15.1	21.5
G(%)	19.0	26.0	27.7	**20.1**	15.6	17.9	**16.3**	18.4	17.1	16.6	21.5
A+T(%)	61.7	46.8	44.5	**59.6**	68.4	63.1	**66.9**	62.8	64.8	68.2	57.0
C+G(%)	38.3	53.2	55.5	**40.4**	31.6	36.9	**33.1**	37.3	35.2	31.7	43.0

Table 3. GC contents for chloroplast genome of *G. barbadense*

-	Coding	region	**-**	-	Non	coding	**Region**	-	-	-	-
-	protein	trna	rrna	**Total**	IGS	intron	**total**	Complete genome	LSC	SSC	IR
Length	78675	2791	9050	**90516**	48556	21245	**69801**	160317	88897	20036	25692
Proportion	49.07	1.74	5.64	**56.46**	30.28	13.27	**43.53**	100.00	55.45	12.49	16.03
T(%)	31.5	23.3	22.3	**30.4**	34.3	32.0	**33.7**	31.8	33.1	34.4	28.5
A(%)	30.2	23.9	22.3	**29.3**	34.1	31.2	**33.2**	30.9	31.7	33.8	28.5
C(%)	19.6	26.7	27.7	**20.6**	16.0	19.0	**16.8**	19.0	18.1	16.6	21.5
G(%)	18.7	26.1	27.7	**19.7**	15.6	17.8	**16.2**	18.2	17.1	15.3	21.6
A+T(%)	61.7	47.2	44.**6**	**59.7**	68.4	63.2	**66.9**	62.8	64.8	68.1	56.9
C+G(%)	38.3	52.8	55.4	**40.3**	31.6	36.8	**33.1**	37.2	35.2	31.9	43.1

Table 4. GC contents for chloroplast genome of *G. hirsutum*

-		Coding	region	-	Non	coding	**Region**	-	-	-	-
-	protein	trna	rrna	**Total**	IGS	intron	**total**	Complete genome	LSC	SSC	IR
Length	78531	2801	9048	**90380**	48798	21123	**69921**	160301	88862	20509	25465
Proportion	48.98	1.74	5.64	**56.38**	30.44	13.20	**43.61**	100.00	55.43	12.79	15.88
T(%)	31.4	22.8	22.3	**30.2**	34.4	31.9	**33.7**	31.7	33.2	33.9	28.5
A(%)	30.4	23.9	22.3	**29.4**	33.9	31.3	**33.2**	31.0	31.6	34.4	28.5
C(%)	19.3	27.1	27.7	**20.3**	16.0	18.9	**16.9**	18.8	18.1	15.1	21.5
G(%)	19.0	26.2	27.7	**20.1**	15.6	17.9	**16.3**	18.4	17.1	16.5	21.5
A+T(%)	61.8	46.7	44.5	**59.6**	68.4	63.2	**66.8**	62.8	64.8	68.3	57.0
C+G(%)	38.2	53.3	55.5	**40.4**	31.6	36.8	**33.2**	37.2	35.2	31.7	43.5

the *G. thurberi, G. arboreum, G. barbadense and G. hirsutum* genomes are similar and equal 37.2 per cent. Coding and non coding regions in each of the four genomes had a little GC content and were 40.4 per cent, 33.1 per cent, respectively. IR region was richest based on GC, Its rate for species was approximately 43 per cent, while GC in SSC and LSC was 31 per cent and 35 per cent, respectively. The rRNA genes had the highest GC content about 55.5 per cent, and the protein coding sequences had the lowest GC that amount was about 37.3 per cent. In the non coding region, the GC content for IGS and introns was 31.58 per cent and 36.75 per cent.

NC graph : The NC graph for each four genomes was drawn and was showed with Fig. 1, 2, 3 and 4, and the results for it were almost similar for all species, so describe based on one of them. Fig. 1.4 shows that a significant number of points are located on the graph and to a region that is poor from GC, which it is result of a strong nucleotide composition. Most points with low NC values are below the expected graph with high distances. These results show that some genes in *G. thurberi* have a codon application independent of the nucleotide combination (created by mutagenic pressure and other factors), and the combined constraints. Wright, (1990) suggested that graph of NC values column to GC3s could be useful for finding the diversity of codon usage among genes. Duret and

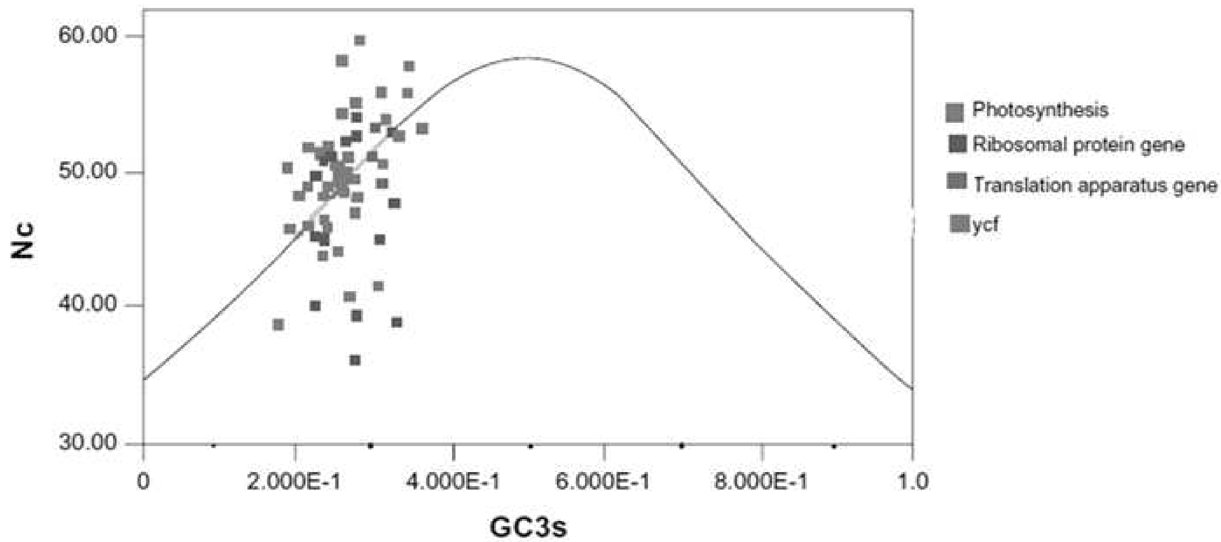

Figure 1. NC graph of *G. thurberi*

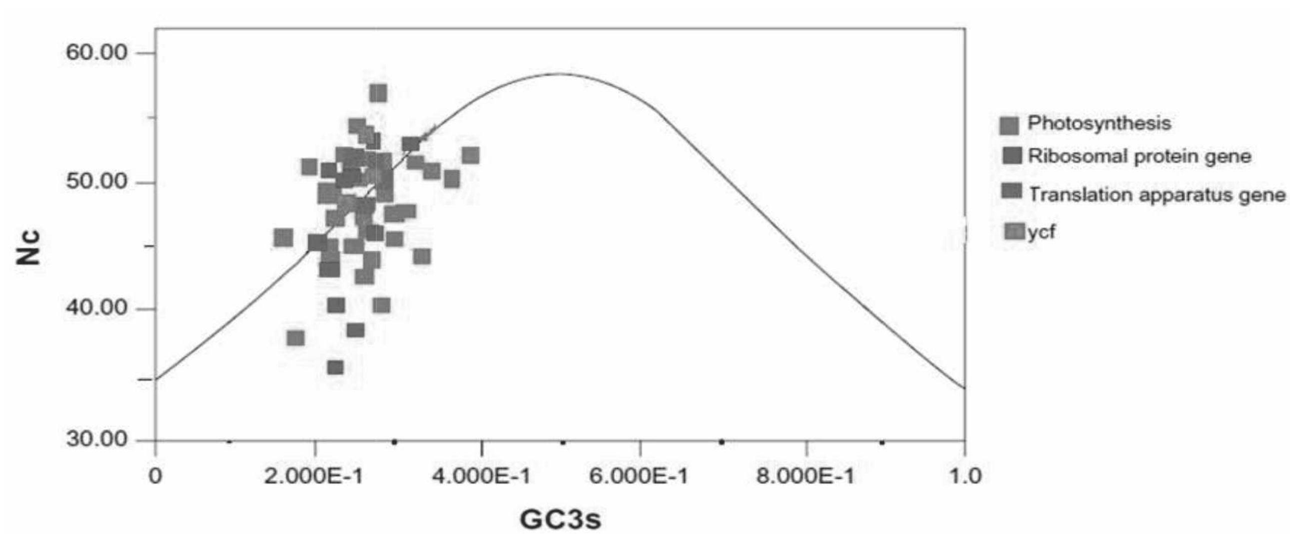

Figure 2. NC graph of *G. arboreum*

Mouchiroud (2000), argued that comparing the actual distribution of genes with the expected distribution would indicate that the tendency of codon preference to be influenced by factors other than combined constraints.

Correspondence analysis (COA) : Correspondence analysis for species in this study was conducted to calculate the factors responsible for the distribution of genes in the adaptive analysis chart (COA plot), by determining the correlation between axis4 axis1 with codon preference indices for 57 coding genes with a length of more than 100 codons. The results of

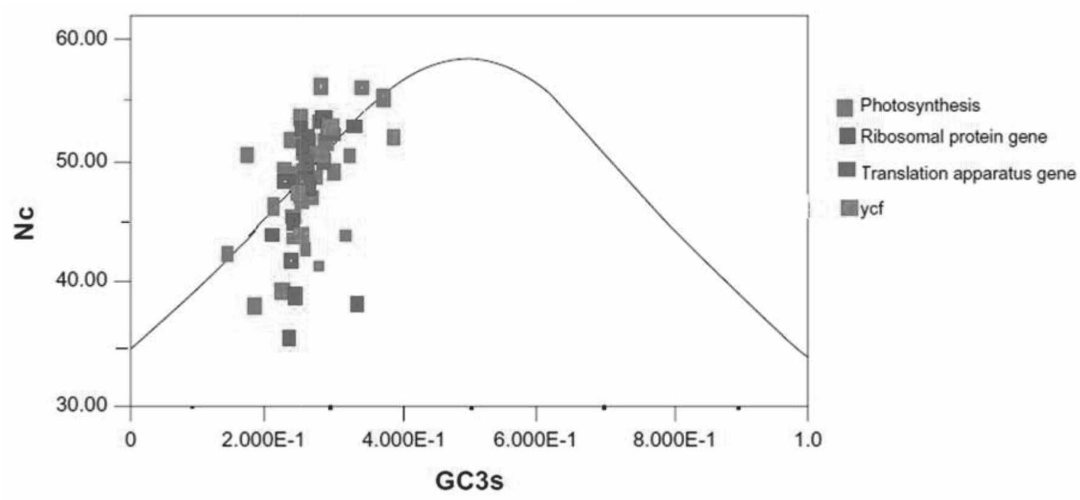

Figure 3. NC graph of *G. barbadens*

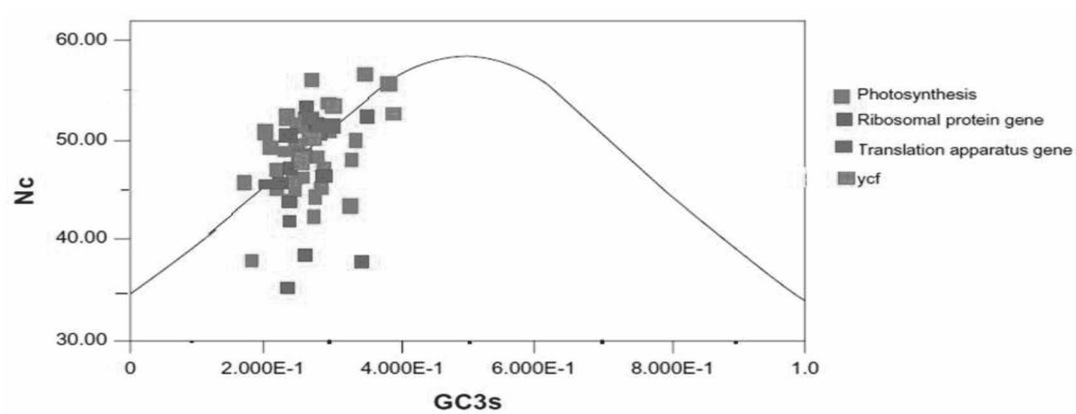

Figure 4. NC graph of *G. hirsutum0*

Table 5. Correlations of codon preference indices with gene distribution in *G. thurberi*

	ENc	CAI	Fop	$T3_s$	$C3_s$	$A3_s$	$G3_s$	$GC3_s$	GC	L sym	GRAVY
Axis1	-0.049	-0.070	0.112	-0.131	0.203	-0.050	-0.087	0.105	0.108	0.092	0.012
Axis2	-0.294*	0.223	0.380**	-0.169	0.374**	-0.085	-0.124	0.252	0.294*	-0.070	-0.261
Axis3	-0.260	0.289*	0.132	0.177	0.007	-0.137	-0.344**	-0.201	0.099	-0.095	0.214
Axis4	-0.001	0.474**	0.299*	0.164	0.227	-0.228	-0.198	0.020	0.180	0.020	0.348**

Table 6. Correlations of codon preference indices with gene distribution in *G. arboreum*

	ENc	CAI	Fop	$T3_s$	$C3_s$	$A3_s$	$G3_s$	$GC3_s$	GC	L sym	GRAVY
Axis1	0.209	0.358**	-0.372**	-0.010	-0.252	0.112	0.268*	-0.059	-0.264*	0.060	0.141
Axis2	0.189	0.169	0.143	0.370**	-0.314**	0.139	-0.248	-0.559**	-0.28*	-0.143	-0.300
Axis3	0.033	0.526**	0.436**	0.149	0.341*	-0.057	-0.392**	-0.021	0.245	-0.013	0.368**
Axis4	0.552*	0.217	0.335	0.001	0.116	-0.057	-0.290*	-0.085	0.089	-0.161	0.039

Table 7. Correlations of codon preference indices with gene distribution in *G. barbadense*

	ENc	CAI	Fop	$T3_s$	$C3_s$	$A3_s$	$G3_s$	$GC3_s$	GC	L sym	GRAVY
Axis1	-0.241	-0.078	-0.252	0.036	-0.408**	0.220	0.036	-0.277*	-0.213	-0.106	0.023
Axis2	0.085	-0.457**	-0.519**	0.043	-0.426**	0.232	0.203	-0.237	-0.399**	0.014	0.109
Axis3	0.463**	-0.253	-0.109	-0.214	0.100	-0.030	0.475**	0.406**	0.046	0.220	-0.194
Axis4	0.078	0.442**	0.304	0.159	0.092	-0.067	0.277*	-0.138	0.123	-0.021	0.364*

Table 8. Correlations of codon preference indices with gene distribution in *G. hirsutum*

	ENc	CAI	Fop	$T3_s$	$C3_s$	$A3_s$	$G3_s$	$GC3_s$	GC	L sym	GRAVY
Axis1	-0.185	0.097	-0.033	0.009	-0.240	0.180	-0.030	-0.188	-0.052	-0.093	-0.059
Axis2	0.131	-0.212*	-0.450**	0.083	-0.458**	0.226	0.206	-0.275*	-0.379**	0.005	0.186
Axis3	-0.442**	0.430**	0.229	0.335*	-0.032	-0.084	-0.529**	-0.422**	-0.030	-0.214	0.325*
Axis4	-0.121	-0.431**	-0.377**	-0.105	-0.305*	0.190	0.256	-0.049	-0.243	-0.019	-0.288

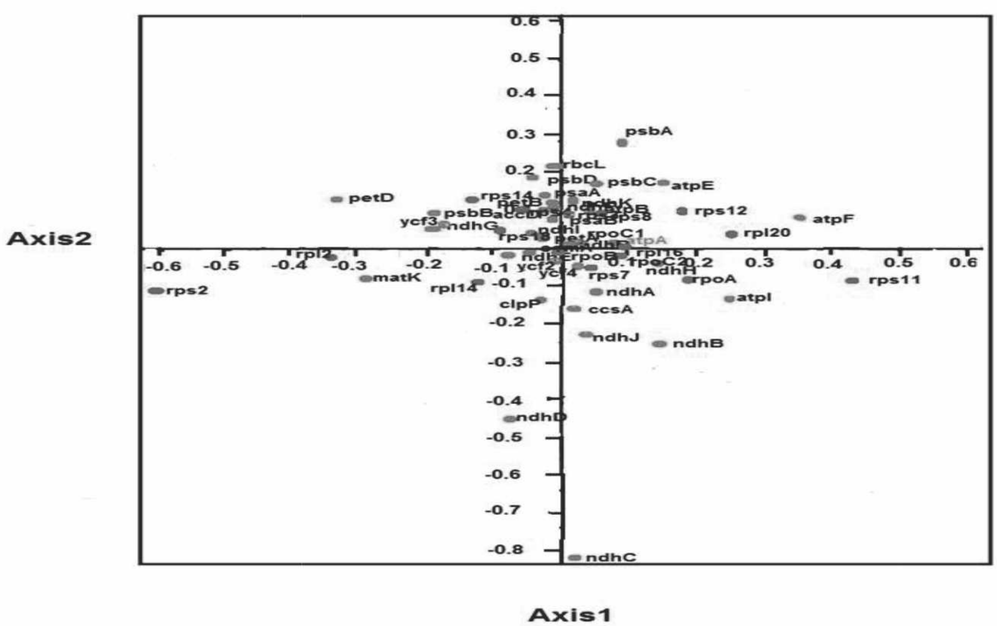

Fig. 5. COA graph of *G. thurber*

analysis for all four genomes were very similar, so, to prevent from repetition of the material, explanations were made based on the table and graph of the *G. thurberi* chloroplast genome. The first axis, 10.3 per cent, and the next three axes expresses 9 per cent, 7.93 per cent and 7.16 per cent of the codon preference variations. The results showed that the second axis had a positive correlation with C3 ($r = 0.374$, $p < 0.01$), GC ($r = 0.294$, $p < 0.05$) and Fop ($r = 0.380$, $p < 0.01$), the third axis with G3 ($r = -0.344$, $p < 0.01$) had a positive correlation, but with CAI ($r = 0.289$, $p < 0.05$) had a negative correlation and at the end, the fourth axis had a positive correlation with CAI ($r = 0.474$, $p < 0.01$) and Fop ($r = 0.299$, $p < 0.05$), the being of a significant relationship between

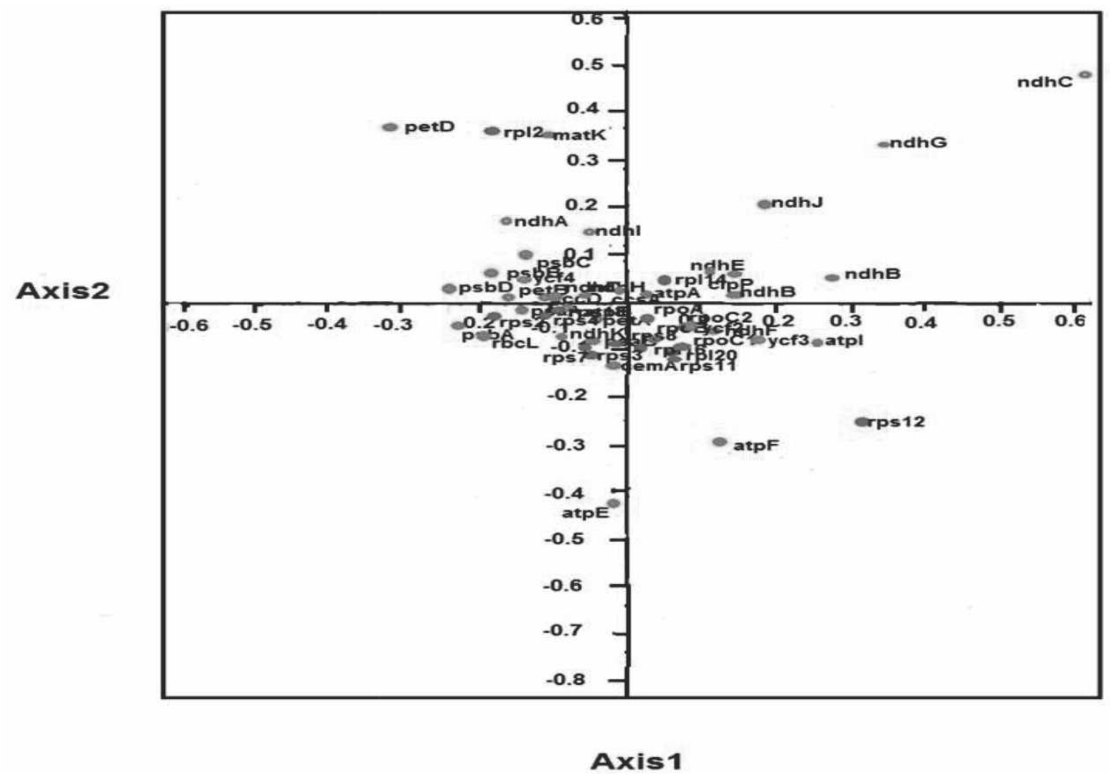

Figure 6. COA graph of *G. arboreum*

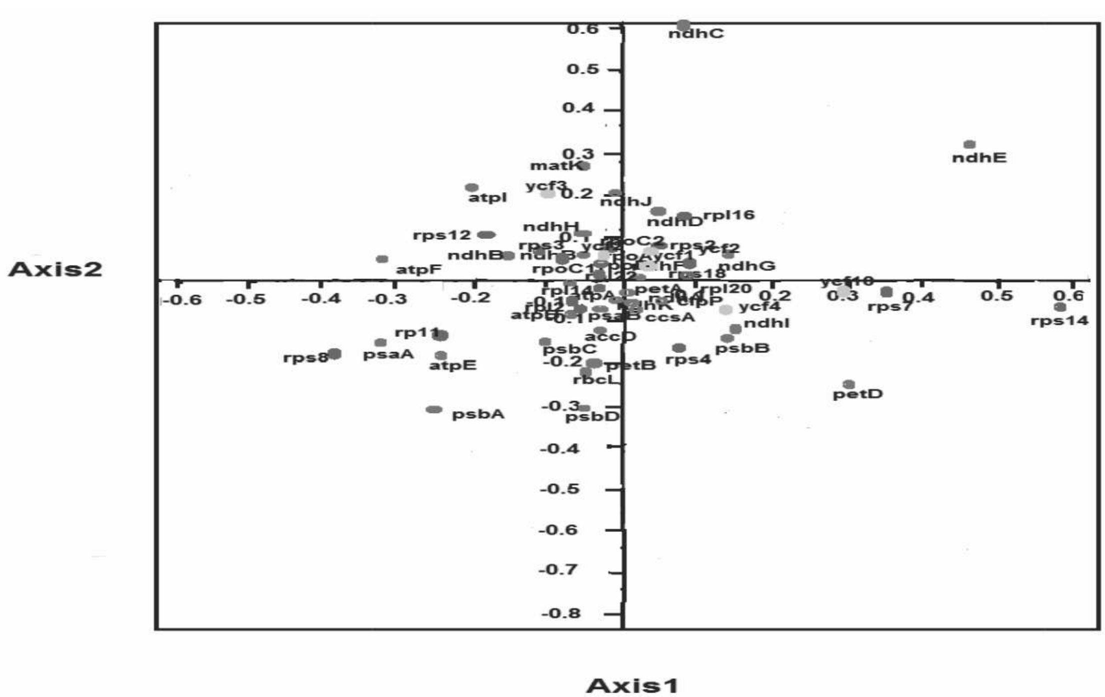

Figure 7. COA graph of G. *barbadense*

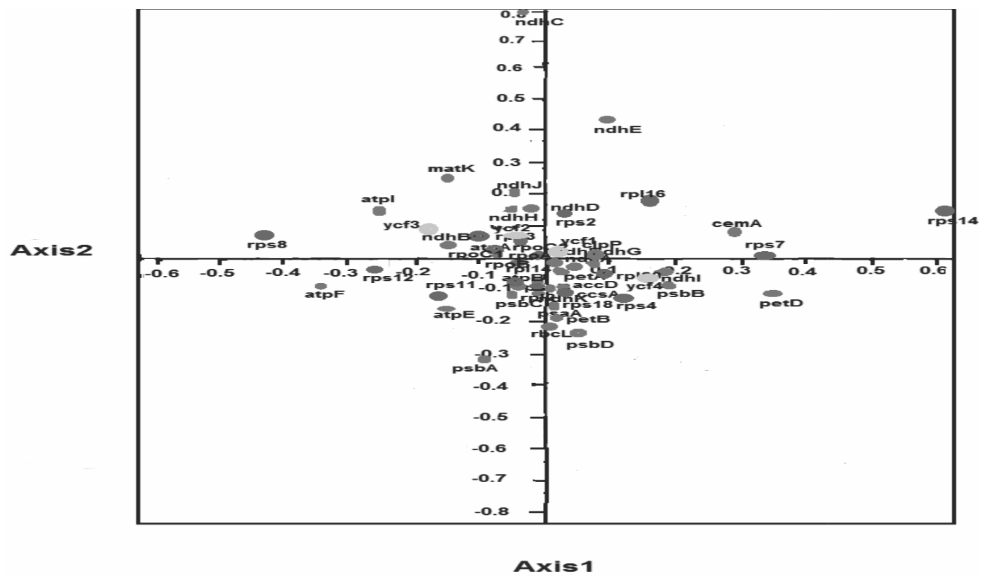

Figure 8. COA graph of *G. hirsutum*

each nucleotide axes and nucleus shows the probabilistic effect of the nucleotide combination on the formation of codon preference. Considering that in all four species, the number of two axes had a significant relationship with CAI and Fop, it was predicted that the levels of gene expression slightly affected by the patterns of codon preference (poor selection), and also because of Gravy which was significant in only one of the axis in the species *G. barbadense* and *G. hirsutum*, the selection pressure which affects the codon is poor.

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Exploring emerging genomics tools in enhancement of cotton fiber productivity and quality under water limited environments : Personal perceptions on achievements, obstacles and alternatives

N. MANIKANDA BOOPATHI*

Department of Fruit Crops, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Periyakulam - 625 604

**E_mail : nmboopathi@tnau.ac.in*

ABSTRACT : Cotton fiber productivity and quality are severely affected by water stress. Breeding cotton cultivars with enhanced drought tolerance has long been a key objective in cotton south zone region of India. Owing to complex network of drought tolerance and lack of understanding on genetics of drought tolerant component traits and cognate governing genes, there has been a slow progress in achieving this goal. To fasten the progress, recent developments in genomics were employed at this institute. Initial screening of available germplasm at molecular and physiological level identified extreme cotton germplasm accessions. They have been used to develop different kinds of mapping populations that can be utilized in quantitative trait loci (QTL) mapping of yield and fiber quality traits under water stress. Though this progress has helped to identify consistent QTLs across the mapping populations and environments, the markers that flank these QTLs were not tightly linked since there were poor polymorphisms between the parents. Consequently, the differential drought tolerant trait expression in these parents was analyzed using transcriptomics and miRNomics strategies. Besides identifying large numbers of novel miRNAs, several abiotic stress responsive conserved mRNAs and miRNAs were also noticed. Of particular interest were water stress responsive genes and miR750, miR2, miR14, miR276, miR279, miR-bantam and miR5176 that were highly down regulated in drought tolerant parent, KC3, under water stress conditions. Such efforts unveils unusual insights in molecular mechanisms of drought tolerance in cotton and it is proposed that integration of these information in the future breeding program would lead to develop resilient cotton cultivars with enhanced drought tolerance. However, amalgamation of such results in routine cotton breeding program need a cautious optimistic approach since it has several difficulties during realization of the benefits of genomics in a breeding program. There are appropriate alternatives to overcome these obstacles and the details of those potential other ways will be discussed during presentation.

Key words : Drought stress, marker assisted selection, micro RNAs, molecular markers, QTL mapping, tools of ‘omics

Impact of drought on cotton productivity: Molecular, Physiological and Agronomical considerations : Cotton, the top most preferred fiber commodity, faces several production constraints and among them ever-changing climatic conditions project to considerably affect cotton yield. Particularly, the impact of water scarcity during critical cotton growing stages such as flowering and boll forming phases is very large.

Deficit irrigation and dry land cotton production is a key feature of many Indian production systems. Stomatal closure minimizes water loss through transpiration but also lowers intercellular CO_2, thereby limiting photosynthesis (Carmo-Silva *et al.,* 2012). Baker *et al.,* (2007) demonstrated that stomatal conductance was very sensitive to initial soil water deficit, whereas photosynthesis decreased under more severe deficits. Down regulation or inhibition of metabolic processes may occur under more severe drought conditions (Flexas and Medrano 2002). Prolonged water stress also reduces growth and productivity through reduced biomass, loss of boll setting and decreased lint yield and quality (Hearn 1980). Water deficits reduced the vegetative growth of cotton by 32 per cent, and water stressed plants were 16 per cent shorter than irrigated cotton (Pettigrew 2004). Therefore, water deficits reduce leaf expansion and stem elongation with even greater impacts on reproductive growth (Baker 1965) and thus to the extent of > 90 per cent yield loss has been recorded. Hence it is imperative to evolve climate resilient cotton cultivars.

Plants have evolved complex molecular, cellular and physiological mechanisms to respond to environmental stresses including drought. Studies in cotton have demonstrated that several physiological processes in cotton may be more susceptible to long, dry periods in projected warmer environments (Broughton *et al.*, 2017). In response to drought stress several modifications at the transcriptional, translational, and posttranslational levels were reported (Boopathi *et al.*, 2017). It has also been shown that there was a change in specific genes related to photosynthesis, carbohydrate, amino acid and phytohormone metabolism and it was further revealed the importance of posttranslational regulation mechanisms in drought tolerance in cotton. Owing to these inherent complexities of the response, genetic manipulation to substantially improve water deficit tolerance in cotton has been largely unsuccessful.

Unlocking the potentials of cotton germplasm : Though, the improved cotton cultivars developed during the last few decades led to spectacular increases in fiber yields, recent planting with a mix of traditional varieties, as insurance against adverse conditions such as drought, is missing. For example, in India, trends in cotton cultivation clearly show that less than 20 hybrids will soon cover more than 80 per cent of the total cotton area, replacing thousands of different cotton cultivars that were once grown there.

As urban development destroys habitats and farmers abandon traditional varieties in favour of modern uniform types, the resulting loss of diversity has serious implications for long-term fiber production under changing climatic conditions. Further, because of deployment of few cultivars, cotton cultivation now is more vulnerable to attacks from pests and diseases and more prominently to climate changes such as drought coupled with elevated temperature stresses.

Thus, during the last few decades it is increasingly believed that meeting the natural fiber needs of the world's growing population depends, to a large extent, on the conservation and use of the world's remaining cotton genetic resources (Boopathi and Hoffmann, 2016). All the studies that were intended to estimate the genetic diversity exist in the currently cultivating cotton cultivars and the germplasm accessions used in cotton breeding program evidently revealed that there was very narrow genetic diversity in the investigated materials (Lacape *et al.,* 2007; Boopathi *et al.,* 2008; Thiyagu *et al.,* 2011; Ravikesavan *et al.,* 2014).

If the adoption and use of improved cultivar and hybrids and other farming technology brings significant benefits to cotton farmers, why should we be concerned with the loss of landraces and the preservation of cotton genetic diversity? There are several important reasons. Genetic diversity is the elementary factor of evolution in *Gossypium* species. It is the foundation of sustainability because it provides raw material for adaptation, evolution and survival of species and individuals, especially under changed environmental, disease and social conditions and it will allow them to respond to the challenges of the next century. Therefore, the future of global fiber supply depends on the exploitation of genetic recombination and allelic diversity that exists in the cotton germplasm resources.

Genetic diversity of cotton traditional varieties is the most immediately useful and economically valuable part of cotton germplasm. Subsistence cotton farmers use landraces as a key component of their cropping systems. Landraces are a complex and continually evolving collection of local cotton varieties that reflect interactions with wild species, adaptations to changing farming conditions and responses to the economic and cultural factors that shape farmers priorities. In addition, landraces are the basic raw materials used by cotton breeders for developing modern varieties.

In addition, the preservation and utilisation of cotton genetic diversity is of particular importance to the more marginal, diverse agricultural environments where modern plant breeding tools and technologies has had much less success. These areas are often centres of diversity for many *Gossypium* species (for example, *karunganni* cotton in south Tamil Nadu, India), but increasing poverty is forcing many of these farmers to place more dependence on non farm sources of income, with consequent reduction in their capacity to grow and maintain the range of cotton local varieties they have been adapted to manage. Therefore, decisions must be made in designing cotton germplasm conservation projects.

The challenges of cotton genetic resource conservation also highlight the dilemma of balancing between development and conservation in the light of policy implications. Much more effort is required to develop adequate analytical tools to enable policy makers to clearly address the trade offs and consequences of particular decisions. It also requires clear policy decisions about the appropriate mix of public, commercial and voluntary contributions. Such efforts require increasing collaboration between researchers and the members of grassroots development initiatives.

Importance of evolving new breeding materials through novel approaches : Discovery and utilization of new *Gossypium* diversity is important for sustainable cotton production because of its narrow gene pool. The natural 'genetic bottleneck' imposed by polyploid formation has been aggravated by repeatedly crossing relatively few closely related genotypes to one another to breed new cultivars and using only a few cultivars to deploy transgenes (Paterson *et al.*, 2010). For example, a looming worldwide water crisis makes it important to identify adaptations that permitted wild cottons to endure periodic drought and temperature extremes, restoring such valuable alleles that may have been "left behind" during domestication to create cultivars that produce more with less water (Paterson *et al.*, 2010).

The genetic bases of many traits have been conventionally dissected by linkage analysis in segregating mapping populations (*e.g.* Double Haploids (DHs), Recombinant Inbreed lines RILs) or using nearly isogenic lines (NILs) developed using several back crosses. Nevertheless, the estimated effects are specific to the same or genetically related populations and are often not transferable to other genetic backgrounds, thus limiting their practical application for breeding purposes. In the last decade, the availability of high resolution and cost effective genotyping platforms have opened the way to genome wide association studies (GWAS). By exploiting linkage disequilibrium (LD) between markers and traits across all chromosomes, GWAS aims at genetically scrutinizing complex phenotypes in natural or *ad hoc* generated populations, and it has been widely adopted in different plant species to overcome some of the constraints inherent to bi-parental linkage mapping, such as the limited genetic diversity explored. Moreover, the long history of recombination events captured in large germplasm collections, when combined with dense marker coverage, permit increased genetic resolution, sometimes to a level that allows a causative sequence variant to be identified.

Nevertheless, some drawbacks have to be considered: i) LD levels, and hence the mapping resolution, can vary not only among species (*e.g.* selfing *v/s* outcrossing), but also among populations within one species and among different regions within a given genome ii) population structure may lead to false associations and iii) the effect of rare alleles (even if large) might not be detectable by GWAS analysis. The power of detecting significant marker trait associations depends on the quality of the phenotypic data, sample size, the genetic architecture and heritability of the trait (Boopathi, 2013).

New crossing schemes and types of experimental populations have been suggested to overcome some of the limitations (e.g. population structure) that are encountered when GWAS is run with panels of natural germplasm, breeding lines or varieties, and to increase the statistical power and mapping resolution with respect to bi parental populations, hence the ability to identify genes underlying phenotypic variation. Multi parent Advanced Generation Intercross (MAGIC) populations are created by intercrossing multiple parental lines and self crossing the progeny to generate RILs. Multiple founders capture more allelic diversity (including rare alleles) whereas the multiple cycles of intercrossing give greater opportunities for recombination and hence, greater precision in QTL location.

Alternatively, in Nested Association Mapping (NAM) population development is proposed in which a number of founder lines are crossed with the same reference line to develop sets of related (half-sib) mapping progenies. The advantage of this population derives from the ability to incorporate a large number of alleles from the gene pool. Besides, advanced backcross QTL (AB-QTL) mapping population is also considered as an effective method of combining molecular dissection of the traits and their introgression into elite line. Further, use of chemical and irradiation mutagenesis and their uses in targeted local lesions in genome (TILLING) analysis also found helpful in genetic dissection of drought tolerance traits in other crops. However, efforts on utilizing population that focus on MAGIC, NAM, TILLING or AB-QTL is very scarce in cotton.

High throughput genomics resource development : Overviews on various strategies and advances in next generation sequencing (NGS) and genotyping technologies have enabled generation of large scale genomic resources in cotton and they are described hereunder.

Molecular markers : Even though molecular markers have been available for more than 25 years in cotton, the advent of NGS represented a break through in this field. Before NGS, a typical linkage map was based on few hundred markers. In the age of NGS, thousands of markers can be easily included in any map, including in species with little a priori genome information available. With NGS technologies the DNA marker identification has shifted from fragment based (RFLPs, AFLPs, microsatellites) to sequence based polymorphisms (SNPs).

TaqMan™ (http://www.appliedbiosystems.com) and competitive allele specific PCR (KASP™, http://www.lgcgenomics.com) are among the most popular techniques on the market. Multiplexed SNP analysis can be run on middle throughput platforms with a capacity of a few hundred SNPs/run (*e.g.* Illumina Bead Xpress, Fluidigm EP1) or with high throughput array-based technologies capable of generating between a few thousand to over one million SNPs per run (*e.g.* Illumina BeadArray™, Affymetrix GeneChip™ technology). The advent of high density SNP arrays coupled with powerful computational pipelines has allowed the fast and easy scoring of large set of markers across many genotypes. Medium or high density arrays are available for many crop species, *e.g.* grapevine, maize, tomato, peach, soybean, barley, rice, wheat and apple. However, still it is in infant stage in cotton.

There are two main strategies to assist breeding with molecular selection: to use molecular markers that map near or within specific loci with known phenotypic effects (marker assisted selection, MAS) or to exploit all available markers as predictors of breeding value (genomic selection, GS).

NGS technologies offer the possibility of shifting from array based genotyping assays with pre defined SNP panels to the direct sequencing of the populations of interest, producing a genome wide and unbiased set of markers. These techniques employ a reduced genome representation achieved through restriction enzyme digestion and subsequent adaptor-mediated PCR amplification, and require no prior knowledge of the SNPs being interrogated, making them useful for genetic analysis in species where no reference sequence is available. Among them, restriction-site associated DNA sequencing (RAD) and genotyping by sequencing (GBS) have been adopted in plants. Furthermore, a strategy based on low coverage genome sequencing of all genotypes from a barley segregating population (called as, POPSEQ) was recently employed for the development of high density genetic maps. Such efforts should be accelerated in cotton, too.

Genome sequencing : Cotton genome sequencing promises to reveal the spectrum of diversity in the *Gossypium* genus. A high degree of conservation of gene order and sequence suggests that the vast majority of data from diploids will extrapolate to tetraploids (Paterson *et al.,* 2010). Rapid low cost re-sequencing is sufficient to reveal diversity in the remaining six genomes (B, C, E, F, G, K) that permitted *Gossypium* species to adapt to a wide range of ecosystems in warmer, arid regions of the world (Paterson *et al.,* 2010).

Reference genome sequences have been published for many crop species and many more genome sequencing projects are in progress (http://www.ncbi.nlm.nih.gov/genomes/leuks.cgi; http://plants.ensembl.org/index.html; http://phytozome.jgi.doe.gov/pz/portal.html). The sequences of crop genomes provide a useful starting point to explore genome organization and evolution and provide insight into genetic variation through partial or complete re-sequencing of different accessions.

Though high-quality assembly of allopolyploid plant genomes is a formidable task because the genomes are large and have highly homeologous subgenomes, Li *et al.*, (2015) sequenced and assembled the allotetraploid genome of *Gossypium hirsutum* TM 1 and compared the *G. hirsutum* assembly to the putative ancestral species, *G. raimondii* and *G. arboreum*, to investigate subgenome evolution and gene function including genes related to fiber biology.

Such information offers new opportunities and has a number of practical consequences for cotton breeding: i) the analysis of cotton genetic diversity can be based on genome re sequencing ii) genome wide association studies (GWAS) and quantitative trait loci (QTLs) mapping would be more pronounced since broad genetic resources can be scanned for marker trait association without any limitation of marker availability and iv) the genome sequences allow the targeted modification of specific genes through genome editing technologies or identification of suitable mutations within mutagenized populations, resulting in the introduction of new allelic variants in the genome of cultivated varieties.

Beside the description of allele diversity, genome re sequencing coupled with *de novo* assembly of the sequences not matching the reference genome offers the possibility of harnessing the gene repertoire from wild relatives of cotton leading to the description of their pan genomes. Pan genome refers to the full complement of genes in a group of individuals (*e.g.* species) and consists of a core genome containing DNA sequences shared by all the genotypes and of a dispensable genome composed of partially shared genomic features (*i.e.* present in only some genotypes). For instance, the re-sequencing of seven accessions of *Glycine soja* led to the identification in the dispensable genome of many genes that had structural variant involved in the adaptation to the environment (R genes, flowering time-related genes, genes involved in oil and fatty acid content), and which were therefore potentially useful in crop breeding (Li *et al.*, 2014).

Despite the high number of GWAS done in crop plants, only in few cases has the effect of an underlying candidate gene been verified. In fact, several independent information pieces of evidence are often necessary to definitively assign SNP association signals to genes and identify the causal mutation. These pieces of evidence can include loss of function mutants, over-expression lines, expression data, proteome or metabolome data, sequencing of candidate genes in diverse germplasm collections, including crop wild relatives, and linkage mapping and map-based cloning in experimental

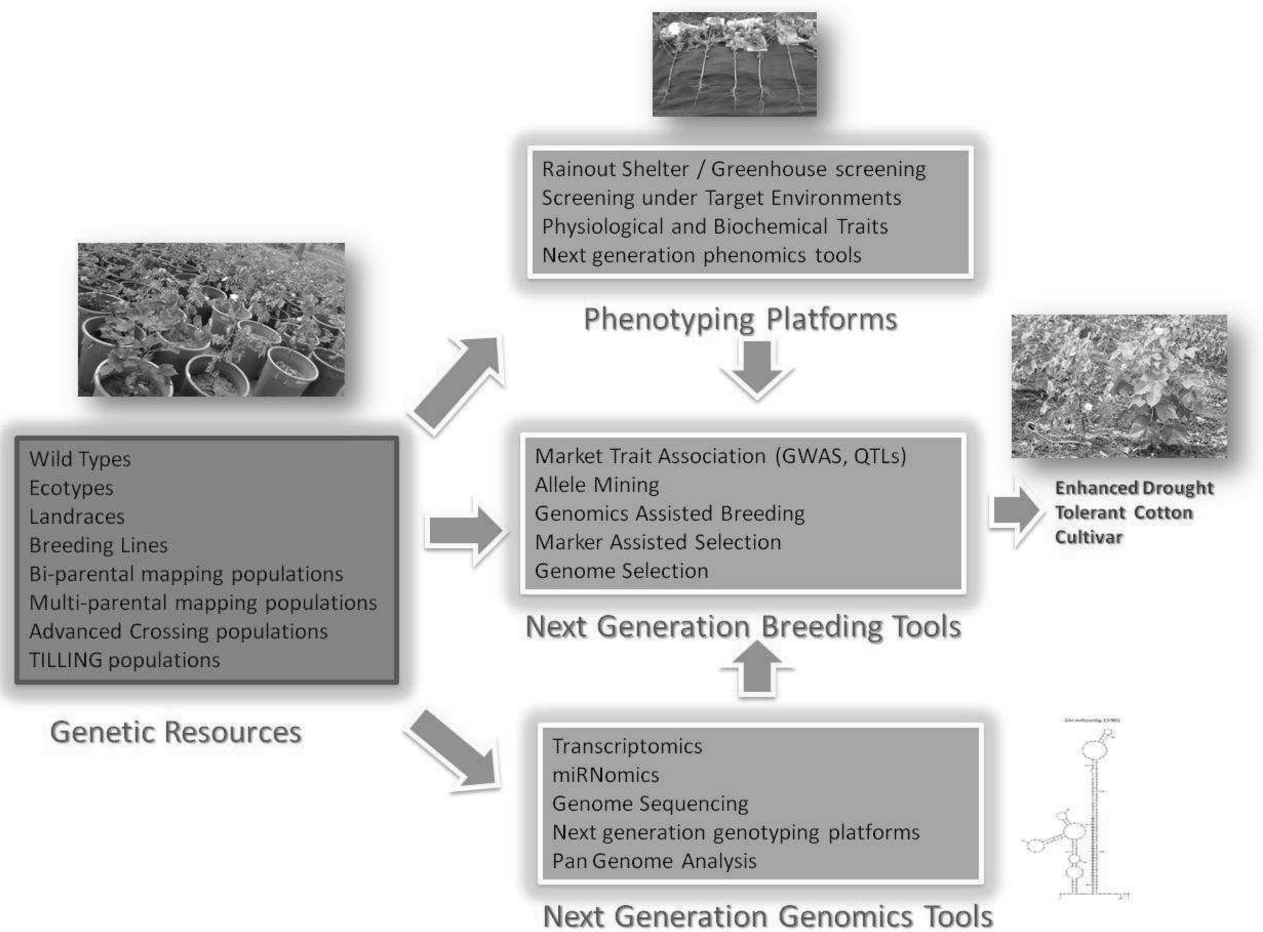

Fig. 1. Integrating advanced approaches for evolving novel drought tolerant cotton cultivar

populations.

Integrated strategy to genetically improve cotton for water limited environments : Therefore, in order to harness the full potential, current breeding programs should rely on integrating high throughput, advanced phenotypic selection in standard breeding schemes (*e.g.* pedigree, backcross, progeny test for combinatory efficiency) with molecular inputs (e.g. genomics and MAS). The availability of NGS, bioinformatics resources and phenotyping platforms is moving plant breeding a step forward and a next generation breeding strategies resulting from combining of genetic resources with advanced technologies can be foreseen for the near future (Fig. 1).

Once genes and alleles responsible for traits are identified, molecular and computational tools can be applied to potentially gain an understanding of the evolutionary processes that have shaped their current diversity in the cotton gene pool. The exploitable value of this genes/allele from unadapted germplasm for prebreeding purposes could also be determined. For example, knowledge of haplotype of favourable alleles present in elite cultivars will help to identify other (including superior) alleles from diverse landraces and wild relatives. With the help of agronomists and crop physiologists, the optimal combinations of traits, referred as ideotype, therefore can now be defined by gene network modelling. Thus, the approach of molecular crop design has the opportunity to improve the speed and efficiency of breeding programs for in cotton.

Although genetic resources, from elite cultivars to landraces and wild relatives, will remain the foundation of any breeding program, it is expected that in the near future the application of NGS technologies, bioinformatics and automatic phenotyping tools for the characterization and subsequent exploitation of genetic diversity will revolutionize breeding strategies to achieve more efficient genetic improvement of cotton for water limited environment.

Progress made and outlook : To this end, significant progresses has made in this direction. In our laboratory, simple selection of accessions from the breeding population and cotton germplasm were used to identify drought tolerant cotton accessions under water stressed conditions. The selected lines were used for different kinds of mapping populations and evaluated in multiple environments and seasons to identify consistent QTLs linked to cotton productivity traits under drought (Boopathi *et al.*, 2015).

In another study, differentially expressed drought responsive miRNAs and their targets were identified under natural field conditions through high throughput small RNA sequencing by comparing leaf samples of drought tolerant *Gossypium hirsutum* cv. KC3 and drought susceptible *G. barbadense* cv. Suvin. In KC3, there were 5,138 unique miRNA reads that were differentially expressed with at least two folds under water stressed conditions. In contrast, Suvin have shown 8,469 unique miRNA reads that were differentially expressed with minimum of two folds under water stressed conditions. Comparison of miRNAs expressed under water stressed conditions between KC3 and Suvin, have resulted 7,494 miRNA reads and interestingly majority of them were down regulated with at least two folds. Besides identifying large numbers of novel miRNAs, several abiotic stress responsive conserved miRNAs were also noticed. Of particular interest weremiR750, miR2, miR14, miR276, miR279, miR bantam and miR5176 that were highly down regulated in KC3 under water stress conditions. Strikingly, miR2 and miR bantam were previously shown to target pre-apoptotic genes in biological systems. Further, the identified miRNAs were also targeting different classes of dehydrogenases, protein kinases and transcription factors (Boopathi *et al.*, 2016). Our results revealed for the first time that there were large numbers ofwater stress related miRNAs that might be sequentially and/or complexly involved in gene regulation that confers drought tolerance in cotton under field conditions and they have enormous potential in elucidating the molecular mechanism of miRNA based gene regulation and more importantly in genetic improvement of drought tolerance in cotton. Further, this is the first report on experimentally identifying miRNAs in *G. barbadense*. Besides, whole transcriptome analysis of drought stressed *G. barbadense* cv. Suvin identified 51,458 validated unigens that were involved in several cellular process including environmental information processing such as signal perception, signaling molecule interaction and signal transduction (Boopathi *et al.* in preparation).

Thus the combination of conventional breeding and molecular breeding strategies promises on development of improved drought tolerant cotton cultivars which will be available to the farmers thereby boosting fiber production and productivity in south zone region of India which is highly affected by water stress.

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Flowering behavior and boll setting in different varieties of *Gossypium arboreum* under different environmental conditions

R.S.SANGWAN*, SUNAYANA, PINKI AND S.NIMBAL
CCS Haryana Agricultural University, Hisar-125004
**E-mail : rssangwan@gmail.com*

ABSTRACT : Cotton plant is of indeterminate growth habit and it starts flowering nearly 55-65 days after sowing depending upon the sowing time, varietal duration and environmental factors. This process may continue even in the month of December if moisture and nutrition supply is continued. Under such situation to obtain good seed cotton yield, it is very essential to find out the optimum period of flowering, boll setting and factors influencing them. In the present study effective boll setting per cent ranged from 43.2 to 73.5 per cent. Early sown conditions of the variety HD 123 produced 52 per cent higher flowers compared to late sown condition whereas boll setting per cent under both the conditions was 59.5 and 62.1. The varieties HD 324 and HD 432 produced 14 and 33 per cent more flowers in early sown condition compared to late sown condition respectively. The period from July 25 to August 14 was observed most ideal time for flowering and boll formation in all the varieties irrespective of sowing period indicated that utmost care is required during this period for higher yield. During the experimental period a total of 22277 flowers in the variety HD 432, 20453 in HD 123 and 19554 in HD 324 were opened and tagged for taking observations and boll setting was 60.4, 58.7 and 59.7 per cent, respectively in different varieties over different sowing conditions. During the experimental period a total of 62284 flowers were tagged and boll setting per cent was 59.6 of all varieties in all sowing conditions.

Key words : *G. arboreum*, effective boll setting, flowering behavior, sowing time

Cotton is the most important commercial crop of Haryana. It is grown in an area about 6 lakh ha. Two species *i.e.* American cotton and *desi* cotton are grown in Haryana and major acreage is under American cotton. During the year 1975 the area under American cotton was 1.07 lakh ha and *desi* cotton was 1.47 lakh ha. After that farmers inclination towards American cotton increased and its area in 1980 increased to 2.14 lakh ha compared to 1.06 lakh ha of *desi* cotton. The main reason for preference towards American cotton was small boll size, more shedding of fruiting bodies and kapas in *desi* cotton. The flowers of *desi* cotton are small sized, solitary, more delicate and prone to shedding mainly due to fluctuation in environmental conditions. Area under *desi* cotton is decreasing continuously for the past many years, in spite of its advantages like inherently resistance to sucking pests and cotton leaf curl virus disease (CLCuD). In Haryana there was a tremendous jump in area under this species from 12000 ha in the year 2015 to 38000 ha during the year 2016 mainly due to farmer's disillusion with American cotton mainly due to heavy incidence of white fly and cotton leaf curl virus disease from 2013 to 2015 which adversely affected the seed cotton yield. Sizable area under *desi* cotton is very essential to sustain cotton crop, as it serves as a barrier for white fly as well as CLCuD spread. To sustain the advantages of Bt cotton it also serves as refugia crop. But it could be possible without addressing its weaknesses and increasing its productivity. Cotton crop had indeterminate growth habit and its flowering starts from II fortnight of June to end of September under normal conditions. There is heavy shedding of floral bodies during this period. This experiment was conducted to study the pattern of flowering and boll setting under different sowing periods and to identify suitable period for obtaining higher seed cotton yield.

MATERIALS AND METHODS

The present study was conducted during *kharif*, 2016 at research farm of CCS Haryana Agricultural University, Hisar. It consists of three varieties of *desi* cotton namely HD 123, HD 324 and HD 432 grown in three replications at recommended spacing of 67.5 cm between rows and plants were kept 30 cm apart under three different sowing conditions (early, normal and late sown). There were 8 rows of 6 m length of each variety in each replication. Plant stand was good under all the sowing conditions in all the varieties. Observations were recorded as and when sizable number of flower opening started *i.e.* from July 4 and it remained continued up to September 12. Uniformity was kept in tagging of flowers and efforts were made to tag all the flowers on weekly basis under normal situation except on rainy days and irrigation conditions. The numbers of opened flowers in a particular week were tagged with a colored woolen thread in different weeks for their identification and how many of them produced the bolls were counted at boll opening time. Recommended agronomic and plant protection measures were adopted during the crop season. In early sown condition tagging of flowers flowering started in first week of July while in normal and late sown conditions it started second fortnight of July and continued by mid September in all the three varieties. Data was recorded on weekly basis. Hence early sown condition had data of 10 weeks whereas normal and late sown conditions had data of 8 weeks for number flowers produced and boll produced by these flowers were counted.

RESULTS AND DISCUSSION

In cotton once fruiting begins, fruiting branches tend to be produced at each successive main-stem node. The first fruiting branch is often produced at the sixth or seventh node on the main stem. The time interval for the development of two successive fruiting forms on the same sympodial branch is approximately six days. Squaring is followed about three weeks later by flowering and the start of boll development. The time requirement for a square to develop into a flower is not influenced significantly by external conditions or plant stress. Cotton plant due to its indeterminate growth habit will continue adding vegetative growth simultaneously with reproductive development throughout the crop season as it

Table 1. Varietal differences in flowering and boll setting under early sown condition

Week*	HD 123			HD 324			HD 432		
	Flower tagged	Boll set	**(%) boll setting**	Flower tagged	Boll set	**(%) boll setting**	Flower tagged	Boll set	**(%) boll setting**
1	996	535	**53.7**	278	161	**57.9**	529	389	**73.5**
2	1253	704	**56.2**	462	295	**63.9**	722	508	**70.4**
3	1197	726	**60.7**	331	230	**69.5**	923	596	**64.6**
4	1253	757	**60.4**	1171	592	**50.6**	1191	605	**50.8**
5	1217	737	**60.6**	1103	649	**58.8**	1168	647	**55.4**
6	1120	710	**63.4**	1195	702	**58.7**	1217	723	**59.4**
7	919	561	**61.0**	874	527	**60.3**	917	551	**60.1**
8	615	380	**61.8**	846	521	**61.6**	837	470	**56.2**
9	538	326	**60.6**	445	245	**55.1**	692	406	**58.7**
10	527	301	**57.1**	491	212	**43.2**	506	314	**62.1**
Total	**9635**	**5737**	**59.5**	**7196**	**4134**	**57.4**	**8702**	**5209**	**59.9**

Table 2. Varietal differences in flowering and boll setting under normal sown condition

Week*	HD 123			HD 324			HD 432		
	Flower tagged	Boll set	**(%) boll setting**	Flower tagged	Boll set	**(%) boll setting**	Flower tagged	Boll set	**(%) boll setting**
3	938	579	**61.7**	621	403	**64.9**	715	488	**68.3**
4	1094	671	**61.3**	1167	756	**64.8**	1129	563	**49.9**
5	1021	675	**66.1**	980	526	**53.7**	1205	604	**50.1**
6	794	464	**58.4**	1036	598	**57.7**	897	452	**50.4**
7	732	435	**59.4**	792	506	**63.9**	704	413	**58.7**
8	642	400	**62.3**	664	388	**58.4**	616	381	**61.9**
9	544	248	**45.6**	494	358	**72.5**	484	311	**64.3**
10	427	273	**63.9**	419	294	**70.2**	435	309	**71.0**
Total	**6192**	**3745**	**60.5**	**6173**	**3829**	**62.0**	**6185**	**3521**	**56.9**

Table 3. Varietal differences in flowering and boll setting under late sown condition

Week*	HD 123			HD 324			HD 432		
	Flower tagged	Boll set	**(%) boll setting**	Flower tagged	Boll set	**(%) boll setting**	Flower tagged	Boll set	**(%) boll setting**
3	656	391	**59.6**	715	488	**68.3**	840	528	**62.9**
4	751	451	**60.1**	1129	563	**49.9**	1006	531	**52.8**
5	657	447	**68.0**	1205	604	**50.1**	1147	686	**59.8**
6	653	409	**62.6**	897	452	**50.4**	1103	650	**58.9**
7	619	380	**61.4**	704	413	**58.7**	752	407	**54.1**
8	536	334	**62.3**	616	381	**61.9**	699	374	**53.5**
9	432	268	**62.0**	484	311	**64.3**	520	343	**66.0**
10	322	195	**60.6**	435	309	**71.0**	475	338	**71.2**
Total	**4626**	**2875**	**62.1**	**6185**	**3521**	**56.9**	**6542**	**3857**	**59.0**

* Week **1**:July 4-10, **2**: July 11-17, **3**: July 18-24, **4**: July 25-31, **5**: Aug. 1-7, **6**: Aug. 8-14, **7**: Aug. 15-21, **8**: Aug 22-28, **9**:Aug. 28- Sept.5 and **10**: Sept. 6-12

gets proper environmental conditions for vegetative growth. However, under North Indian conditions effective flowering in cotton generally starts in the beginning of July and continued up to September. Afterwards flowers do not result into the effective boll because their opening time coincides with the low day and night temperatures and such bolls remained unopened with poor fibre quality. Identification of optimum period for flowering and effective boll setting is of great relevance. In the present study under early sown condition the variety HD 123 had produced the maximum number of flowers and effective boll and these were 25.3 and 28.0 % higher than HD 324 and effective boll setting per cent was 59.5, 57.4 and 59.9 in the varieties HD 123, HD 324 and HD 432, respectively (Table 1) and effective boll setting per cent ranged from 43.2 (HD 324) to 73.5 per cent (HD 432). In normal sown condition perusal of table 2 revealed that the number of flowers produced were almost similar in different varieties and effective boll setting per cent was 60.5, 62.0 and 56.9 in the varieties HD 123, HD 324 and HD 432, respectively. Late sown condition (Table 3) reveled that effective boll setting per cent was 62.1, 56.9 and 59.0 in the varieties HD 123, HD 324 and HD 432, respectively. Tables 1 to 3 revealed that early sown condition produced higher number of flowers and effective bolls compared to normal and late sown condition. Observations of tables 4 to 6 indicated that July 25 to August 14 was most critical period as it had produced the maximum flower and effective bolls in all the varieties under all sowing conditions. From these observations it can be concluded that utmost care is required during this period for higher yield. These results are in broad agreement with earlier findings of Sangwan *et al.,* 2010 regarding crossed boll setting in *desi* cotton. The variation in flowering and boll setting during a particular period may due to variation in climatic conditions *i.e.* temperature, relative humidity, wind direction, wind speed, clear or cloudy sky etc. Hake *et al.,* 1992 observed effect of environmental factors on square and boll development and suggested the means for their mitigation.

Early sown conditions of the variety HD 123 produced 52 per cent higher flowers compared to late sown condition whereas boll setting per cent under both the condition were 59.5 and 62.1. The varieties HD 324 and HD 432 which produced 14 and 33 per cent more flowers in early sown condition compared to late sown condition respectively and boll setting per cent were almost same indicated the advantages of early sown conditions compared to normal and late sown conditions. The period from July 25 to August 14 was observed most ideal time for flowering and effective boll formation in all the varieties under irrespective of sowing period needs utmost care like proper maintenance of moisture and plant protection during this period for obtaining higher yield. During the experimental period a total of 22277 flowers in the variety HD 432, 20453 in the variety HD 123 and 19554 in the variety HD 324 were tagged for recording observations and effective boll setting was 59.7, 60.4 and 58.7 per cent, respectively in different varieties in all three sowing periods. A total of 62284flower were tagged in three varieties in three different sowing periods and 37151 bolls were picked from these tagged flowers and thus the overall boll setting per cent was 59.6 and boll setting of different sowing was 59.1,

Table 4. Critical period of flowering and boll setting under early sown condition

Week	Number of flower tagged				Number of boll set				(%) boll setting
	HD 123	HD 324	HD 432	**Total**	HD 123	HD 324	HD 432	**Total**	
1	996	278	529	**1803**	535	161	389	**1085**	**60.2**
2	1253	462	722	**2437**	704	295	508	**1507**	**61.8**
3	1197	331	923	**2451**	726	230	596	**1552**	**63.3**
4	1253	1171	1191	**3615**	757	592	605	**1954**	**54.1**
5	1217	1103	1168	**3488**	737	649	647	**2033**	**58.3**
6	1120	1195	1217	**3532**	710	702	723	**2135**	**60.4**
7	919	874	917	**2710**	561	527	551	**1639**	**60.5**
8	615	846	837	**2298**	380	521	470	**1371**	**59.7**
9	538	445	692	**1675**	326	245	406	**977**	**58.3**
10	527	491	506	**1524**	301	212	314	**827**	**54.3**
Total	**9635**	**7196**	**8702**	**25533**	**5737**	**4134**	**5209**	**15080**	**59.1**

Table 5. Critical period of flowering and boll setting under normal sown condition

Week	Number of flower tagged				Number of boll set				(%) boll setting
	HD 123	HD 324	HD 432	**Total**	HD 123	HD 324	HD 432	**Total**	
3	938	621	885	**2444**	579	403	567	**1549**	**63.4**
4	1094	1167	1190	**3451**	671	756	738	**2165**	**62.7**
5	1021	980	1162	**3163**	675	526	712	**1913**	**60.5**
6	794	1036	1132	**2962**	464	598	747	**1809**	**61.1**
7	732	792	846	**2370**	435	506	427	**1368**	**57.7**
8	642	664	755	**2061**	400	388	430	**1218**	**59.1**
9	544	494	593	**1631**	248	358	347	**953**	**58.4**
10	427	419	470	**1316**	273	294	276	**843**	**64.1**
Total	**6192**	**6173**	**7033**	**19398**	**3745**	**3829**	**4244**	**11818**	**60.9**

Table 6. Critical period of flowering and boll setting under late sown condition

Week	Number of flower tagged				Number of boll set				(%) boll setting
	HD 123	HD 324	HD 432	**Total**	HD 123	HD 324	HD 432	**Total**	
3	656	715	840	**2211**	391	488	528	**1407**	**63.6**
4	751	1129	1006	**2886**	451	563	531	**1545**	**53.5**
5	657	1205	1147	**3009**	447	604	686	**1737**	**57.7**
6	653	897	1103	**2653**	409	452	650	**1511**	**57.0**
7	619	704	752	**2075**	380	413	407	**1200**	**57.8**
8	536	616	699	**1851**	334	381	374	**1089**	**58.8**
9	432	484	520	**1436**	268	311	343	**922**	**64.2**
10	322	435	475	**1232**	195	309	338	**842**	**68.3**
Total	**4626**	**6185**	**6542**	**17353**	**2875**	**3521**	**3857**	**10253**	**59.1**

Table 7. Effect of sowing period on flowering and boll setting in variety HD 123

Week	Number of flower tagged				Number of boll set				(%) boll setting
	Early	Normal	Late	**Total**	Early	Normal	Late	**Total**	
1	996		-	**996**	535	-	-	**535**	**53.7**
2	1253		-	**1253**	704	-	-	**704**	**56.2**
3	1197	938	656	**2791**	726	579	391	**1696**	**60.8**
4	1253	1094	751	**3098**	757	671	451	**1879**	**60.7**
5	1217	1021	657	**2895**	737	675	447	**1859**	**64.2**
6	1120	794	653	**2567**	710	464	409	**1583**	**61.7**
7	919	732	619	**2270**	561	435	380	**1376**	**60.6**
8	615	642	536	**1793**	380	400	334	**1114**	**62.1**
9	538	544	432	**1514**	326	248	268	**842**	**55.6**
10	527	427	322	**1276**	301	273	195	**769**	**60.3**
Total	**9635**	**6192**	**4626**	**20453**	**5737**	**3745**	**2875**	**12357**	**60.4**

Table 8. Effect of sowing period on flowering and boll setting in variety HD 324

Week	Number of flower tagged				Number of boll set				(%) boll setting
	Early	Normal	Late	**Total**	Early	Normal	Late	**Total**	
1	278	-	-	**278**	161	-	-	**161**	**57.9**
2	462	-	-	**462**	295	-	-	**295**	**63.9**
3	331	621	715	**1667**	230	403	488	**1121**	**67.2**
4	1171	1167	1129	**3467**	592	756	563	**1911**	**55.1**
5	1103	980	1205	**3288**	649	526	604	**1779**	**54.1**
6	1195	1036	897	**3128**	702	598	452	**1752**	**56.0**
7	874	792	704	**2370**	527	506	413	**1446**	**61.0**
8	846	664	616	**2126**	521	388	381	**1290**	**60.7**
9	445	494	484	**1423**	245	358	311	**914**	**64.2**
10	491	419	435	**1345**	212	294	309	**815**	**60.6**
Total	**7196**	**6173**	**6185**	**19554**	**4134**	**3829**	**3521**	**11484**	**58.7**

Table 9. Effect of sowing period on flowering and boll setting in variety HD 432

Week	Number of flower tagged				Number of boll set				(%) boll setting
	Early	Normal	Late	**Total**	Early	Normal	Late	**Total**	
1	529	-	-	**529**	389	-	-	**389**	**73.5**
2	722	-	-	**722**	508	-	-	**508**	**70.4**
3	923	885	840	**2648**	596	567	528	**1691**	**63.9**
4	1191	1190	1006	**3387**	605	738	531	**1874**	**55.3**
5	1168	1162	1147	**3477**	647	712	686	**2045**	**58.8**
6	1217	1132	1103	**3452**	723	747	650	**2120**	**61.4**
7	917	846	752	**2515**	551	427	407	**1385**	**55.1**
8	837	755	699	**2291**	470	430	374	**1274**	**55.6**
9	692	593	520	**1805**	406	347	343	**1096**	**60.7**
10	506	470	475	**1451**	314	276	338	**928**	**64.0**
Total	**8702**	**7033**	**6542**	**22277**	**5209**	**4244**	**3857**	**13310**	**59.7**

Table 10. Flowering and boll setting in different varieties under various sowing periods

Sowing period/ Variety	Number of flower tagged				Number of boll set				(%) boll setting
	HD 123	HD 324	HD 432	**Total**	HD 123	HD 324	HD 432	**Total**	
Early	9635	7196	8702	**25533**	5737	4134	5209	**15080**	**59.1**
Normal	6192	6173	7033	**19398**	3745	3829	4244	**11818**	**60.9**
Late	4626	6185	6542	**17353**	2875	3521	3857	**10253**	**59.1**
Total	**20453**	**19554**	**22277**	**62284**	**12357**	**11484**	**13310**	**37151**	**59.6**

60.9 and 59.1 of all the varieties. It can be concluded from this table that boll setting per cent is least influenced by different sowing period. However, early sowing had significant advantage over late sown condition through number of flower production.

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Organic cotton : Status, production practice and future prospectus

DEVENDRA PAL SAINI*
AICRP on Cotton, Agricultural Reasearch Station, Banswara - 327 001
**E-mail : dsaini1590@gmail.com*

With the world getting sensitive towards the environment, there has been a quick response from the textile industry, and are becoming involved in the re thinking process. Today, clothing must not only be fashionable but also be produced in an environmentally conscious, socially acceptable and efficient way. It means that a product with a modern brand must not cause harm, firstly to the consumers, secondly, to the persons who participate in the production process and most of all the mother nature.

Table 1. World scenario of organic cotton

World production	1,38,813mt
No. of countries growing Organic cotton	18
Largest producer	(74%) from India
Total area under organic Production	3,16,907 ha
Total number of certified Organic cotton farmers	2,14,905

Source: Textile Exchange, 2013

Key findings of organic cotton across the world : With rapid increase in the production from 2006 to 2010, there had been a significant drop in the year 2010-2011. However, the production seemed stabilizing in the year 2011-2012, with relative increase in the global production of organic cotton to 1,38,813 Mt.

India is consistently being the largest producer, since last five years. It has experienced a 1 per cent increase in production, expanding from 102,452 Mt last year to 103,004 Mt fibers in the year 2011-2012.

In the USA, Texas organic cotton farmers suffered severe drought. Despite an increase in planting by 36 per cent the actual area harvested plunged – with nearly two thirds of the planted crop abandoned to drought. As a result the USA saw a 45 per cent reduction in the overall harvest (from 2,893 Mt to 1,580 Mt fibers) Africa achieved a record growth of 103per cent increase in the production for the year 2011-2012 from last year. Also, there was a dramatic increase from Tanzania which is of 153per cent. Due to favorable rains, Tanzania's production leapt from 2,723 Mt fibers to 6,891 Mt on similar land area.

The top five countries *viz.,* India, China, Turkey, Tanzania, and the United States produce nearly 97per cent of total global organic cotton fiber. India continues to be the biggest producer, growing approximately 74per cent of the world's organic cotton. Global growth was

Table 2. Global profile of organic cotton sector, 2011-2012

Region	Producer groups	Farmers	Women farmers
Africa	9	25,584	6,625
China	5	1,993	952
CA	25	1,273	261
Latin America	13	1,186	219
South Asia (India)	100	1,84,029	No data
USA	6	40	No data

Source: Textile Exchange, 2013

expected to experience a 15 to 25per cent increase during 2014-2015.

Organic cotton in India : Indian organic cotton continues to make its presence felt. Initial heady growth took a sharp dip for the first time in three years since India overtook Turkey the year 2006 - 2007 to emerge as the global leader. Growth from 2007 to 2010 was fuelled by a combination of reasons and brought with it several challenges supply/demand, price, profile of stakeholders and regulatory issues. However, the year 2010-2011 had been a defining year for organic cotton in India.

Table 3. Area under organic agriculture in the world and in top five countries

Top five countries in agriculture production	Percentage of agriculture land under organic agriculture
China	0.36
India	0.28
USA	0.64
Indonesia	0.16
Brazil	0.27
World	0.86

Source: The world of organic agriculture, 2014

It is clear from the data that **"Globally less than 1 per cent land is under organic agriculture"**

Table 4. List of world organic cotton producing countries

S. No.	Country (mt)	Fiber production (% of total)	Fiber production
1	India	103,003.52	74.20
2	Turkey	15,802.00	11.38
3	China	8,105.53	5.84
4	Tanzania	6,890.90	4.96
5	USA	1,580.00	1.14
6	Mali	860.00	0.62
7	Peru	478.50	0.34
8	Uganda	455.70	0.33
9	Egypt	420.00	0.30
10	Burkina Faso	370.00	0.27

Source:Textile Exchange,2013

India remained the biggest producer for five years running, by the year 2011-2012. It produced 103,004 Mt of organic cotton, with an area of 253,161 ha, which was 75 per cent of world's organic cotton and roughly two per cent of India's cotton acreage. Production grew by 1per cent over last year, 2010-2011.

However, there has been no dramatic difference in the acreage. Madhya Pradesh, despite a small drop, continued to have the highest acreage. Maharashtra follows, though with a fairly significant rise mostly on account of the 2010-2011 addition of conversion acreage. Rajasthan has emerged the third largest producer with a significant increase, followed by Odisha. Maharashtra and Madhya Pradesh together constitute 78.7 per cent of India's organic cotton.

Scope for organic cotton cultivation : The preamble of organic farming has been aimed at conservation and optimized utilization of all natural resources for a reasonable profitability under the guiding factors of sustainability of the farm. In order to keep a certain threshold of profit from the farms, all the farming practices have to be redesigned to undo the ill effects that have crept in the current agricultural scenario while attempting to increase cotton production in the prevalent cropping systems. A sense of balancing act to moderate the resource utilization with anticipation for suspected damage to mother earth is the essence of organic farming. The organic protocols of farming could accentuate and aid in imparting improved

Table 5. Organic cotton production in India, 2011-2012

States	Area (ha)	Seed cotton production (Mt)	Fiber cotton production (Mt)
Andhra Pradesh	3,625	4,469	1,475
Gujarat	4,690	5,783	8,760
Madhya Pradesh	126,165	155,553	51,333
Maharashtra	73,124	90,157	29,752
Odisha	16,540	20,392	6,729
Rajasthan	27,594	34,022	11,227
Others	423	522	172
Total	**253,161**	**312,131**	**103,004**

Source: Textile Exchange, 2013

Table 6. India organic cotton profile, 2011-2012

States	Number of producer groups	Number of farmers	Farmer distributio n (%)
Andhra Pradesh	3	5,500	3
Gujarat	10	18,350	10
Haryana	2	1,820	1
Karnataka	4	1,840	1
Madhya Pradesh	44	90,500	49
Maharashtra	21	38,000	21
Odisha	9	16,500	9
Rajasthan	3	3,500	2
Tamilnadu	4	8,019	4
Total	**100**	**184,029**	

Source: Textile Exchange, 2013

momentum to the bio dynamism of crop fields. Lesser stable and poor bio dynamism that has caused less productive farms has alerted farmers on the question of long term sustenance.

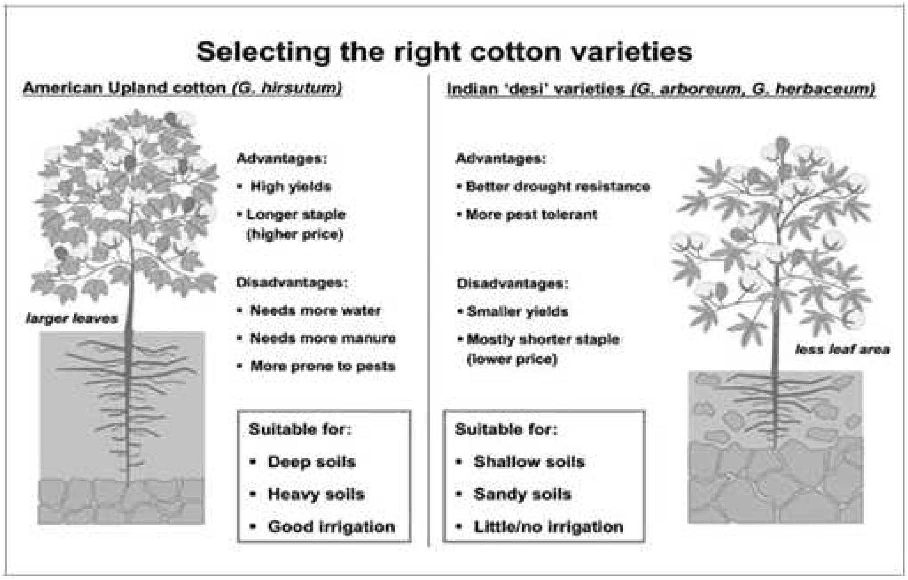
At the end of this decade, it is quite satisfying to find that the above thoughts paved the way for increased adoption of non chemical farming options. The happy marriage of conventional wisdom and rationalized modern agricultural technology has instilled sense optimism and hope to growers, especially in rain grown crops. The balancing act seems to be quite deft, but could have considerable impact on developing a better cause of modern Indian agriculture.

Five to seven decades ago, most of the cotton cultivated in the country was 'eco-friendly' with little or no use of toxic chemicals in its production. Even today, there are many pockets in India, where it is produced without the use of agrochemicals, *e.g.,* areas growing Wagad cotton in Gujarat, Y 1 *desi* cotton of Khandesh region of Maharashtra, Maljari in Madhya Pradesh, part of areas growing Jayadhar and Suyodhar in Karnataka, Nandicum in Andhra Pradesh and parts of cotton areas in north eastern hill region.

In the rainfed tract of central India, cotton is grown on three million hectare (*i.e.,* 43% of total area) of marginal lands where production is low due to poorly distributed rainfall, and eroded undulating nature of lands and low resources investment by farmers. Such soils require low-cost and low external input production systems to minimize cost on fertilizer and pesticides for imparting stability in production. Cultivation of cotton with organic methods has helped farmers to improve sustainable productivity. The message on non-chemical and sustainable agriculture has pervaded to many parts of India and is hopefully making inroads into some of the southern cotton growing Indian states.

MERITS OF ORGANIC COTTON CULTIVATION

Environmentally friendly technology : Due to excessive use of fertilisers and insecticides, all the elements of the agro eco



system gets polluted by the conventional method. Organic cotton production relies on non-chemical inputs and will decrease pollution hazards.

Pesticides residues in fiber may cause carcinogenic damage to users. The use of bio-rational products and biocontrol agents for pest management in organic farming will cause no such effects.

Large scale discharge of untreated and unprocessed effluents by textile industry and dyeing units has not only caused health problems to man, cattle and fish in the rivers and canals, but yields of cotton are reported to be affected due to polluted water that is used for irrigation.

Destruction of beneficial soil organisms may cause damage to soil health creating imbalance in the natural population of predators/parasitoids of cotton pests. Organic farming helps to restore or preserve the natural equilibrium between different components of the ecosystem.

Reduction in cost of cultivation : Modern production technology has lowered the cost-benefit ratio of cotton production. Farmers in Andhra Pradesh, Punjab, Maharashtra etc. are reported to have committed suicide due to escalation of production cost without occurring commensurate profit from cotton cultivation. On the other hand, organic farming creates rural employments and uses of on farm resources to make it more cost effective.

Management of insecticide resistance : Due to indiscriminate use of hazardous insecticides for controlling cotton pests, the resistance of insects against the insecticide hiked up and in turn compelled the use of more number of sprays, and thus a vicious cycle is created, escalating cost of cultivation. Organic farming will help in reversing this trend. Evidences on poorer choice of multiplication rate of pests on organically grown cotton are encouraging factors to pursue this protocol.

Approaches for farming of organic cotton : Since organic cotton production warrants the cultivation in the absence of agro chemicals, it involves a careful selection of components of farming system keeping the local resources, agro climatic features and socio economic structure for the formation of a suitable package as follows:

Selection of site : Fields with high degree of soil erosion and heavily infested with perennial weeds should not be put under organic farming. Organic farming is not a farming by neglect or arm chair cultivation and so, fertility levels of less fertile soils should be improved through organic means before opting for this type of cultivation.

Varietal selection

Selecting the right cotton varieties : By far the most widely grown cotton species is *Gossypium hirsutum*, often called American Upland cotton, which is available in a large number of hybrid varieties. Some countries grow *Gossypium barbadense* (Sea Island cotton), spinning its long fibers into extra fine garments. In India and

Pakistan, a number of local 'desi' varieties of *G. herbaceum* and *G. arboreum* are grown besides the 'American hybrids'. They are usually more resistant to pests and to drought, but most have a shorter staple length and thus fetch lower prices in the market.

There are a large number of different cotton varieties available on the seed market, and research stations and seed companies continually release new varieties. Most of them are bred for producing high yields under high-input conditions: fertilizers, pesticides, and irrigation. Organic farmers, however, are more interested in robust varieties that are resistant to or tolerant of pests and produce satisfying yields with medium manure supply. Some varieties, however, combine the advantages of the 'desi' varieties (hardy, drought resistant) with those of the *hirsutum* varieties (high yield, long fibers). These varieties could be of great interest, especially for organic farmers with less irrigation.

To select the most suitable varieties, farmers should consider the site conditions (soil quality, rainfall, availability of irrigation water, *etc.*) as well as the conditions of the farm (availability of manure, possibility for pest management, *etc.*). Where irrigation is a constraint and rainfall is erratic, it is preferable to use varieties that require less water (*e.g.* those with less leaf area). In addition, farmers need to consider the buyers' requirements concerning staple length and other fiber quality aspects.

Identifying suitable cotton varieties for a particular field requires a great deal of observation and experimentation. It can also be useful to talk to extension workers or other farmers about their experience with a certain variety and its expected yields, water requirements, resistance to pests, and fiber quality. In some countries, however, the government authorities regulate which cotton varieties can be grown. The cotton varieties that are most popular among organic cotton farmers in the Nimar region of Madhya Pradesh, India, and their properties are listed in Table 7.

High yielding varieties, which respond

Table 7. Cotton varieties grown by organic farmers in the Nimar region, Madhya Pradesh

Variety	Suitable sites	Staple length	Remarks
H 8	Medium soils, little to Medium irrigation available.	25–26 mm	Most popular variety; good yields in organic farming; suitable for monsoon sowing; drought tolerant.
H 10	Deep, heavy soils.	26–27 mm	Ideal for summer sowing; not suitable for light soils.
JK 4	Medium soils	27–28 mm	Resistant to diseases and bollworm; susceptible to sucking pests; requires less water.
JKH 1	Deep, heavy soils; irrigation.	27–28 mm	Good yields in organic farming; ideal for heavy soil; susceptibleto droughts.
Ankoor 09	Medium soils, not for heavy soils.	26–27 mm	A short duration crop suitable where a Rabi crop is grown; not suitable for summer sowing; susceptible to waterlogging.
Ankoor 651	Heavy to medium soils.	27–28 mm	Ideal for late summer sowing and monsoon sowing; suitable for heavy soils.
New research varieties:			
Jawahar Tapti	Dry areas, little irrigation.	24–25 mm	Hardy; requires less water; resistant to bollworm, but short fibers.
Surabhi	Medium to dry areas.	28–32 mm	A non hybrid with long fibers.
Devi Raj	Dry areas, little irrigation.	27–28 mm	A variety grown in Gujarat.

well to chemical inputs, may not always be suitable for organic farming. Instead, varieties which are hardy and capable of giving acceptable farming especially in the early phase of conversion are ideal. Varieties, which are jassid-tolerant, can be preferred over susceptible ones. Early maturing varieties are less exhaustive and will also help the crop to escape heavy bollworm damage.

Seed rate and sowing : Acid delinted seeds cannot be used according to international norms [*e.g.*IFOAM] for organic cultivation for the purpose of certification of the fiber. However, those farmers who pursue organic farming for reducing the cost of cultivation and to increase the profitability could use acid delinted seeds in order to avoid seed borne pathogenic infections and achieve optimum plant stand. If fuzzy seeds are used, however, higher seed rate is to be used in order to achieve the same goal. About 25 kg/ha of seeds at 75x15 cm spacing ensures a final plant population of 85-90 thousand plants/ha. One row of fodder cowpea (*Vigna unguiculata*) should be drilled between two rows of cotton. This crop could be ploughed down and buried in soil just before its flowering.

Manuring : To realise economical production, soil fertility has to be maintained and gradually improved. Improvement and maintenance of organic matter of the soil is important in organic cotton production, as this would increase physical parameters of soil, improve soil structure and enhance nutrient supply. Since huge amounts of FYM to meet nutrient requirement of the cotton crop is not generally available, a combination of sources with different biological properties should be preferably used. Organic manures (FYM, compost, Vermicompost), *in situ* green manuring, cowpea and biofertilisers along with fertility restoring crop rotations form the components for maintaining soil fertility.

Farm yard manuring [FYM] : FYM @ 15 t/ha must be added before preparatory tillage and mixed thoroughly. FYM should be well decomposed and should be preferably treated with composting organisms such as *Trichoderma viride*. The rate may gradually be brought down 5-10 t/ ha, once the farm yield stabilises over a few years.

Fodder cowpea : In situ green manuring with fodder cowpea and its burying at 40 days after sowing [DAS] will ensure a steady N supply during the grand growth phase and flowering period, when the N demand peaks up in the crop. It hastens microbial activity in soil, reduces weed growth and enhances natural enemy build up.

This provides around 400-500 kg dry matter/ha with (2.5%) N and contributes 10-12 kg N/ha during squaring. Its additional benefits include smothering of weeds, controlling seasonal soil erosion and nurturing natural enemies of cotton pests.

Dhaincha (*Sesbania aculeata*) : Dense stand of this legume can be raised around cotton field at a width of 2 m; its lopping cut and spread between cotton rows at 65-70 DAS. Its fast decomposing leaves provide N during early boll development period and stalks act as temporary mulch, preventing soil moisture evaporation.

Vermicompost : Vermicompost @ 1-2 t/ ha should be added supplementing FYM on the furrow lines on which sowing is done. Its nutrient composition varies with substrate that is verrmicomposted, but generally contains several diverse microflora that aid in good plant growth. It offers good scope for recycling of farm waste.

Biofertilisers : Seed inoculation of *Azatobactor* or *Azospirillum* @ 200 g/seed required for sowing one acre is recommended.

Technology for composting

Vermicompost: Reliance on green biomass and farmyard manure is a sure method of increasing soil organic content. However, under the existing conditions, these requirements are not fully met with. Enormous quantity of farm wastes and organic residues are simply burnt. In order to utilise farm wastes and organic residue for being recycled into compost, the modern thoughts are for utilising earthworms and fungus that are habituated to such conversion. Promising Indian species, *Eisenia foetida* can convert organic wastes into vermicompost in about one month's time and convert anything except plastic into compost.

Since preparation of vermicompost utilising any of the above species can be a very promising endeavour in rural areas, in addition to meeting the compost requirement of one's own farm, it is desirable to take this up as part of organic farming. The brief details regarding vermicomposting techniques is as follows.

Vermicompost can be made in raised beds of 15-25 cm height. The length and width can vary according to the quantum of wastes available for composing. Beds of 6x2 m are ideal. These beds should be made slightly raised at the centre and sloping towards the sides (to facilitate effective drainage), preferably under shade. As earthworms do not relish light, it is advisable to keep the pits covered. Darkness also reduces the composting time.

A soft bedding material with wheat/ soybean straw is added as the first layer. This should be followed by a thin layer of cow dung slurry. Earthworm culture @ 1 kg/10m length of bed (2m wide) is then added. Earthworm cocoons or starter inoculant worms from vermi compost can also be used. Weeds, leaves chopping, farm wastes, household wastes and other degradable materials can be continuously added on the top. Water should be sprinkled periodically to keep the beds slightly moist, but neverwet. Under ideal moist and temperature conditions (27-33° C) the composting time would be 40-50 days. Earthworm castings contain approximately 2.0-2.5per cent N, 2.5-2.9 per cent P2O5 and 1.2- 1.4per cent K2O, the exact composition varies according to the substrate and composting conditions. The excreta of organisms contain more N content over their level of consumption of N as in vermi castings too.

Composting of cotton stalks through *Trichoderma viride* : Cotton stalks are burnt as fuel after picking of seed cotton is over. This residue together with farm wastes from other crops and weeds can effectively be utilised for preparing compost, through the use of beneficial fungi like *Trichoderma viride*. The technique, as developed at CICR, Nagpur is briefly described.

In a pit of 10 x 2 x 1m in size, dried cotton stalks from 2 ha area are filled in four layers interspersed with other soft farm waste, such as sorghum stubble, linseed straw and soybean pod haulms (to fill the gaps in between cotton stalks) and 50 kg of cow dung (to provide a soft substrate for initial multiplication of the fungus). Each layer was sprinkle inoculated with 2.5 kg *T.viride* wettable powder in 60 litre water mixed with half-kilogram jaggery and 15 g yeast. The pit is finally covered with one foot layer of sunhemp stalks for checking water loss. Periodic watering is made to maintain sufficient moisture in the pit and turning of the top layer at least once during the decomposition process.

In the span of four months, most of the cotton stalks are converted into compost, the rest (20%) being black, brittle, semi-decomposed stalks. This compost is comparable to well-decomposed vermicompost. It could be used for nutrient recycling, antagonistic fungus against certain soil borne pathogens, *viz., Fusarium* spp., *Rhizoctonia* spp. etc.

Weed management : Fields not infested with perennial weeds such as *Cyperus* sp. (Motha), *Cyanodon dactylon* (Doob) and *Sachharum* sp. (Kans) are preferred for organic farming as these are difficult to control. However, if such weeds occur in patches, their underground propagatory structures (stolons, rhizomes etc.) must be exposed by summer cultivation and manually removed. Mechanical/manual weeding as per existing practice may be adopted. Composting can recycle the weeds removed. It must be ensured that the FYM, compost added is completely decomposed, otherwise many seeds of annual weeds, introduced through FYM, will germinate and aggravate the weed problem.

Growing a crop of cowpea between 2 rows of cotton will also suppress the early emerging weeds.

Selection of rotations : Crop rotations play a very important role in restoring soil fertility and minimising damage due to insect pests and weeds. High nutrient exhaustive rotations must be avoided and instead rotations with a legume that is recommended for the locality may be adopted.

IPM strategies for crop protection : The crop protection to reduce the damage due to insect pests to organically cultivated cotton revolves around the use of bioagents such as predators such as *Chrysoperla* sp or *Apertochrysa* spp, egg parasitoids such as *Trichogramma*, larval parasitoids such as *Habrobracon* spp or insect pathogens such as *Helicoverpa armigera* Nuclear Polyhydrosis Virus [NPV] and a bacterium, *Bacillus thuringuiensis* var. *kurstaki* (B.t.k.) formulations along with utilization of bird perches and botanical insecticides like *neem* products.

Avoidance of pesticide application by introducing bio control agents, either by natural augmentation processes or by artificial releases increased the stability of cotton cultivation. The basic concept of conserving natural mortality agents of pests can be achieved in organic cotton cultivation, primarily by reducing insecticide application. These toxicants destroy both, pests and their natural enemies, and so, are not desirable for common use. To sum up, the following pest suppression strategies are recommended for organic cotton cultivation.

- Select a reasonably jassid tolerant cultivator.
- Release of *Chrysoperla* spp. @ 500-1000/ ha according to the intensity of jassid damage between 20-25 days of crop growth once. For jassid susceptible cultivator, this may be released after 35 days.
- Release Trichocards @ 5/ha once at 45-50 days and then after 10-12 days, twice more in order to kill bollworm eggs.
- Spray H-NPV @ 250 larval equivalent (LE) [1LE= 200 crore (10^9) Poly Inclusion Bodies [PIBs] or Poly Occlusion Bodies [POBs] when very young larvae of American bollworm are spotted. This could be repeated after every 15 days for retaining good inoculum of the pathogen. This could be alternated with any commercial *Bt* formulation @ 1.5 l/ha.
- Release of *Habrobracon hebator* is also useful for controlling growing bollworm larvae and other caterpillars damaging leaves and flowers.
- Placement of bird perches @ 5-6/ha would help in increasing the predatory bird visit in cotton fields.
- The need based botanical insecticides, seed kernel extract is used at (5%) v/v or (1%) oil are very useful to deter pest activity in the crop.
- Monitoring of bollworm using the respective pheromone traps would give a clue regarding their first occurrence in a season in order to initiate adequate and suitable crop protection measures.
- One of the important cultural practices that is desirable is to depot the crop that has grown beyond 80 days. This would

reduce the egg laying of *H.armigera*.

From the studies conducted at Central institute for Cotton Research, Nagpur on the technology generation for sustainable organic cotton production and its evaluation with conventional farming with use of chemicals (fertilisers and insecticides), the following facts has emerged for careful consideration.

- In a span of 3-4 years, there was gradual build up in soil productivity and seed cotton yield in organic farming was *at par* to non organic farming .
- In the initial year, the yield realization through organic system was about 40per cent of that of conventional (non organic) system, with comparable or slightly higher (7-10%) production costs. This situation improves in subsequent years
- There was also a gradual improvement in soil fertility parameters such as organic carbon content and available P. The organic carbon content stabilized at 0.50-0.55per cent after 4-5 years.
- One interesting observation was that even jassid susceptible cultivator such as LRA. 5166 showed good tolerance to jassid infestation under organic environment.

There was a good build up of natural enemies, such as egg, larval and pupal parasitoids, and also of various predators of cotton pests. Under continuous cultivation of cotton in organic environment, its stability situation for better performance was achieved over a period of time. Capability of cotton plant to withstand pest infestation was found to be highly remarkable.

Awareness for growing organic cotton, however, is growing. Many voluntary organizations, like VOFA (VIDARBHA ORGANIC FARMERS ASSOCIATION), MOFA (MAHARASHTRA ORGANIC FARMERS ASSOCIATION), SHRIDA-BIORE *etc.* have been formed either by farmers groups interested in organic cotton cultivation or to assist such groups by offering technical assistance. Around 1200 hectares of land was cultivated under organically grown cotton by 135 farmers in Vidarbha region of Maharashtra alone through voluntary association VOFA with average yield level of 500-750 kg/ha. The technological properties of various cultivators grown under the organic cultivation such as micronaire (3.8-5.0), span length (25.5-29.9 mm) and fiber maturity parameters were similar to fibers produced by conventional methods.

A voluntary Organization - INTERNATIONAL FEDERATION FOR ORGANIC AGRICULTURE MOVEMENT [IFOAM] has formulated standards and guidelines for organic cotton cultivation and are followed by many labelling agencies to certify organic cotton and other farm produce.

Technology for growing organic cotton for different regions of the country is being developed for its higher profitable and sustainable production so that marketing agencies can market organic cotton to potential buyers. Efforts are needed to identify and tap such buyers of organic cotton and yarn. It is necessary to contact and tap some leading international buyers from Japan, Korea, Thailand etc. to explore the marketing of organic cotton. Premium prospects of organic cotton trade will have to be fully explored.

Road ahead for organic cotton in India

(opportunities) : A new fabric fashion is reinforced by the impression for high quality and elegance. A new social awareness is setting in, which encounters the natural fibre and eco - trend. Many collections are changing towards the modern naturalness. Wool and cotton are mixed with linen, silk, cashmere, bamboo and more recently with the hollow fibre kapok, to make the fabrics lighter and furnish them with a sophisticated sheen.

Finally, the fashion industry has realised that there is money in this new "Green market". The market for apparel products obtained with "Ethical" raw materials will remain a niche area, but is likely to grow. Although the organic cotton is still only a niche within the global cotton market, it has gained an extremely high profile with retailers and consumers. According to Harkirat Singh, Managing Director Woodland, "Despite being a niche market, the market for organic clothing is growing in India as people are getting aware and more conscious about what they are purchasing. Though the consumer is willing to pay more for eco friendly products, they also like transparency in knowing that the product is actually eco friendly".

The market for organic goods in India is at a nascent stage and has great potential especially for the apparel segment. Currently accounting for less than 1per cent of the Rs. 32,000 crore organized branded apparel market, the organic clothing segment has a potential to grow to about 5per cent of the total market in the next five years, according to experts.

Indian organic cotton continues to depend heavily on the overseas markets. The existing value chains typically extend from farmers engaged through a contracting system, through to gins, mills and finally to brands and retailers. Traders are also involved. However, given the current international market demand constraints, Indian producers and mills engaged with organic cotton would benefit hugely from expanding their markets within India. This would help them reduce their dependence on international markets, minimize their vulnerability, create more self-reliance and also help enhance their image within national boundaries. The domestic market holds great promise and remains relatively untapped. According to recent estimates, the Indian market for apparel is currently valued at USD 40 billion and is estimated to go up to USD 124 billion in 2020.

India would thus emerge as a country with one of the fastest growing markets for apparel, up from four per cent of global share to seven per cent. Currently the market consists of both branded and unbranded apparel but all indications are that the preference for branded apparel will grow considerably in the future. Even a casual visitor to India can see clear evidence of this. There is growing consumerism and urbanization, a larger segment of people with bigger incomes, young people with higher discretionary incomes, preference for easy and wider access to a greater variety of clothing, more organized retail through shopping malls, and both Indian and International brands.

Interest in organic cotton clothing is primarily driven by the following reasons: A small group of people's demand is based on necessity. This segment includes individuals with chemical skin sensitivities and allergies strong enough to warrant special products with few or no chemical residues. Toxic chemical residue remains in industrially treated fibres; in clothing in contact with the skin can aggravate a variety of allergies and allergic symptoms such as asthma and multiple chemical sensitivities.

Another group of people can be characterised as those whose demand is based on choice rather than necessity. This is a much more substantial segment of the market as these are consumers who are changing their buying pattern to emphasise and encourage products that are perceived to be less damaging to the environment and health and safety of their families. The environmentally aware customer has gained promise in the marketplace so that the range of business-determining parameters has been extended by a new one: Ecology. Now there are more and more consumers with enough income to purchase products that are in alignment with their values.

CONCLUSION

Cotton is an important agricultural commodity, heavily traded in more than 150 countries. Prior to 2008, the world cotton industry had been experiencing robust demand growth and rising yields. Over the last 60 years, cotton production once almost quadrupled, from 7 million tons in 1950/51 to 27 million tons in 2006-2007, but declined thereafter to 22 million in 2009-2010. Indian organic cotton continues to make its presence felt. Initial heady growth took a sharp dip for the first time in three years since India overtook Turkey the year 2006 - 2007 to emerge as the global leader. Growth from 2007 to 2010 was fuelled by a combination of reasons and brought with it several challenges supply/ demand, price, profileof stakeholders and regulatory issues. However, the year 2010-2011 had been a defining year for organic cotton in India.

As in previous years, the prices of organic cotton were based on the prices of conventional cotton. Some of the more committed producer have offered an increase of 8 to 12 per cent over conventional cotton prices for organic and an increase of about 5per cent for in conversion fiber, especially where there were written contractual agreements. However, the global economic situation resulted in a modest demand situation from the market, with a resulting reluctance from buyers to pay any more than a marginal increase for organic over conventional.

At yarn level, organic was perhaps slightly more profitable at about a 7per cent increase over conventional, but the majority of producer groups reportedly received only about 3 – 5per cent at fiber level. Finally, the fashion industry has realised that there is money in this new "Green market". The market for apparel products obtained with "Ethical" raw materials will remain a niche area, but is likely to grow. Although the organic cotton is still only a niche within the global cotton market, it has gained an extremely high profile with retailers and consumers. According to Harkirat Singh, Managing Director Woodland, "Despite being a niche market, the market for organic clothing is growing in India as people are getting aware and more conscious about what they are purchasing. Though the consumer is willing to pay more for eco friendly products, they also like transparency in knowing that the product is actually eco- friendly". India would thus emerge as a country with one of the fastest growing markets for apparel, up from four per cent of global share to seven per cent. Currently the market consists of both branded and unbranded apparel but all indications are that the preference for branded apparel will grow considerably in the future. Even a casual visitor to India can see clear evidence of this. There is growing consumerism and urbanization, a larger segment of people with bigger incomes, young people with higher discretionary incomes, preference for easy and wider access to a greater variety of clothing, more organized retail through shopping malls, and both Indian and International brands.

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Pre breeding through various methods and its implications in cotton

O. P. TUTEJA*
ICAR-Central Institute for Cotton Research, Regional Station, Sirsa-125 055
**E-mail:optuteja2001@yahoo.co.in*

Pre breeding or genetic improvement is necessary and useful, but it is still not recognized as such. This is evident because there is no group of scientists or professionals who call themselves "Genetic Enhancers", or "Pre breeders. Only three methods of breeding have been employed for cotton throughout the world, i.e. introduction, selection and hybridization. Varieties have been imported from other countries and directly adopted for commercial cultivation. This is probably the most obvious and easiest way to improve production based on improving the genetic background of cultivation material. The material from where selections were made often comprised adopted/ commercially grown varieties. The major limitation to the selection method of developing varieties has been a lack of sufficient variability, as selection had to rely either on existing variability in the population resulting from natural out-crossing or natural mutations. But with the advent of molecular genetics and cell biology, a new kind of biotechnology assisted genetic enhancement is possible. Therefore, unavailable genes for insect resistance or other characters like abiotic stresses may be transferred from alien species into elite genotypes.

The genetic enhancement refers to the transfer of gene or gene combinations from wild or cultivated sources into breeding materials (FAO, 1996). The concept emphasizing the use of plant genetic resources only concerns the improvement of genetic material. Enhanced germplasm lines can easily be used in breeding programs for varietal development. Therefore, pre-breeding does not differ significantly from the general framework of plant breeding and is considered a pre requisite step in the sustainable breeding programme. In pre breeding a useful character is identified, capturing genetic diversity and putting those genes in to useful form. Then the question arises why we need genetic enhancement or pre breeding?

Need for pre breeding : It is strongly believed that the wide genetic variability within the cotton (*Gossypium* spp.,) increases their chance for adaptation to changing harmful environments, and thus upsurge the likelihood of long-term survival of important cash crop in the world. To meet the ever increasing market demand, plant breeders have to develop cultivars, by using the diverse germplasm lines or elite breeding material. Future progress in the improvement of cotton largely depends on discovery, collection, and immediate conservation of genetic resources such as wild progenitors and landraces of *Gossypium* for their effective and sustainable utilization in the cotton breeding program. In the past most of the cotton cultivars have been developed through selection and adaptation rather than through creating variability. This has resulted in narrowing down of genetic base resulting in slow progress in plant breeding and increased risk of genetic vulnerability. The best example in cotton is that several resistant/ tolerant varieties of upland cotton in north zone like RS 875, RS 810, RS 2013, F 1861, H1117, H1226 and hybrids like LHH 144, CSHH 198, CSHH 238 and CSHH 243 were developed in North zone by SAU's and ICAR institutes (Ajmera *et al.,* 2004., Anonymous, 2005, 2006, Tuteja *et al.,* 2005, 2006 and 2007), however, these cultivars have become susceptible over the years due to new strains of begomovirus causing CLCuD . In order to break these bottlenecks and to create the genetic variability for different characters pre breeding is required to improve the cotton germplasm lines that can be used for improving the following characters:

1. In improving the level of resistance to biotic stress especially the resistance against sucking pests and CLCuD
2. Improving the quality characters specially the strength keeping in view the present requirement.
3. Improving the level of resistance to abiotic stress especially the resistance against drought for central India.
4. In developing early maturing genotypes which can fit well for High Density Population System (HDPS).
5. In developing plant types having synchronous boll bursting suitable for machine picking.
6. In developing male sterile and restorer lines to be used in heterosis breeding programme.
7. Use of germplasm will help in broadening the genetic base of cultivars as well as in creating vast genetic variability.
8. It will also help in value addition of different genotypes through genetic enhancement.

Methods of Pre breeding

Introgression: It is a transfer of one or more genes from exotic/un adapted/wild stocks to the adapted breeding population. This is achieved by crossing donor and recurrent parent. This concept of transfer of character through back cross was given by Edgar Anderson. The important part played by hybridization and introgression in the evolution of new world cotton has been brought out by Hutchinson (1959). The various aspects of gene transfer through introgression in *Gossypium* like disease and pest resistance (Mehetre *et al.*, 2002a), fibre quality parameters (Mehetre *et al.*, 2004), problems of wide hybridization (Mehetre *et al.*, 2002b), and embryo rescue as tool to achieve interspecific hybridization (Mehetre and Aher, 2004) have been reviewed critically.

Back cross method : The parent from which desirable genes are to be incorporated is used as donor parent and the parent which is to be further improved is used as the recurrent parent. Six generations of conventional recurrent backcrossing are levels required to transform a genetic stock. Various type of back crossing methods are given below:

(i) **Recurrent backcross**: This method involves successive backcrossing of the cross made between donor and the recurrent parent with the recurrent parent with or without selection. With this method, the monogenic or oligogenic traits with high heritability can be easily transferred.

(ii**) Inbred backcross:** This method involves a limited number of backcrosses (usually one to three). This is followed by several generations of selfing. This method was first given by Wehrhahn and Allard, 1965. This method results in the development of a population of more than 50 per cent of lines that are homozygous and have a common genetic background similar to the recurrent parent

(iii) **Congruity backcross**: This method was originally proposed by Haghighi and Ascher, in 1988. In this method, backcrossing is done to both donor and recurrent parent in alternate generations. It is possible to obtain progenies with intermediate morphologies rather than morphologies resembling one or the other parent. This led to effective recombination through the increased of heterozygosity.

(iv) **Marker assisted backcross method (MAS)** :This method is used to transfer specific elite allele at a target locus from a donor line to a recipient line. The number of target genes involved in the selection and the expected level of line conversion must be defined.

Use of different germplasm lines and genepool in [re-breeding

(i) Use of exotic germplasm : It refers to all the germplasm that do not have immediate usefulness without selection or adaptation in a given environment. (Haullauer and Miranda, 1981). Exotic germplasm has to go under pre-breeding to find its usefulness in breeding programme. Because most of the plant breeders fear using exotic material due to its detrimental effects on elite breeding material (Kannenberg and Falk, 1995). The major constraints in direct use of exotic germplasm lines are:

- Linkage of undesirable genes with desirable traits is a major constraint to increase utilization of exotic germplasm.
- Crosses with exotic material can result in the concurrent introduction of inferior alleles and disruption of co adapted alleles in elite breeding material.
- Exotic germplasm can negatively affect adaptedness when introduced into locally adapted gene base.

Therefore exotic germplasm has to undergo conversion or pre-breeding to find its best use in breeding program.

(ii) Use of wild species of *Gossypium* genome : The genus *Gossypium* contains about 50 species, including diploids (2n=2x=26; genomes A-G and K) and tetraploids (2n=4x=52; genomes AD1-AD5). The wide geographical distribution of the diploid cottons under primitive or traditional cultivation has provided opportunity for the development of extensive diversity in biotic resistance (Stewart and Robbins, 1994). Tetraploid cottons have been the major source of new genes that breeders use, but future improvements in environmental resistance, agronomic fitness, and quality of cotton depend on diversity within the genetic resources from which new traits can be selected (Stewart, 1995). *Gossypium* species and their interspecific hybrids provide an array of plants that display novel chemistries and resistance characteristics that are relevant to protecting cotton from pests (Stipanovic *et al.*.1994).

The A genome species are known as Asiatic cottons (*G.arboreum* and *G. herbaceum*) and tetraploid species of AD genome referred as New World cottons (*G. hirsutum* and *G. barbadense).* These are only four cultivated species of cotton in India and other countries in the world. The *G. hirsutum and G. barbadense* originated in the new world from interspecific hybridization between species of closely related to *G. herbaceum* or *G. arboreum* and American diploid *G raimondii* or *G. gossypoides* (Beasley, 1940). Unfortunately, most of these plants cannot be crossed directly to cotton to make fertile hybrids, but must be genetically enhanced before breeders can use them directly. To make interspecific crosses (1) between diploid A- F- and D- genome species that are compatible with upland cotton (*G. hirsutum*) and (2) between synthetic tetraploids and upland cotton in order to produce advanced germplasm material that can be used by plant breeders as a source of new diversity.

Gene pools of *Gossypium* : Three types of germplasm namely, primary, secondary and tertiary based on the fact that the ease with which genes can be transferred from the donor source to the recent parent/species (Harlan and Dewet, 1971). The germplasm pools that are centered on cultivated tetraploid and diploid cotton and various *Gossypium* genetic resources available for improvement are assigned according to biological affinity is given in Table 1. Stewart (1995) assigned the *Gossypium* genome groups to primary, secondary and tertiary based on the criteria:

(a) The ability to generate fertile hybrids between the donor and recipient species. This also refers to utilization of bridge species that transfer trait to recipient parent.

(b) The frequency of genetic recombination between donor and recipient chromosomes.

(c) The ability to produce stable synthesized allopolyploids its segregation gamete formation and viable progenies.

In the past primary gene pool has been extensively used for genetic improvement of different crops with a view to create vast genetic variability for various traits in cotton. By crossing the *G. hirsutum*, *G. barbadense* and three wild species *G. tomentosum, G. musterlinum* and *G. darwinii* vast genetic variability has been created for morphological and disease resistance traits such as blight resistance, boll worm resistance, Fusarium and wilt resistance , cleistogamy and nectriless leaves (Endrizzi *et al.*,1985 Meredith1991, Stewart, 1995).

Recently, the work on use of secondary and tertiary gene pool in cotton has been intensified and as a result vast genetic variability has been created for various economic characters. Because the secondary gene pool species are diploids, the initial interspecific F_1 from a direct hybridization with a tetraploid cotton is sterile triploid with a few exceptions (Meyer, 1974). Successful cases for introgression are fibre strength, disease resistance and cytoplasmic male sterility(CMS) and restorer lines (Stewart, 1995). Similarly, the tertiary gene pool represents the most difficult group of species which include E, C, G and K genomes. The only successful gene transfer from this gene pool is the introgression of dominant gene controlling terpenoid aldehyde methylation from *G sturtianum* to *G hirsutum* (Bell *et al.,* 1994) which imparts natural resistance against insects and microbial attack.

Keeping the above mentioned points into consideration various conventional and genetic engineering methods can be used for genetic enhancement of germplasm lines. There are two major approaches for genetic enhancement of pre breeding

Introgression in *Gossypium* species : The wild species of *Gossypium* has a number of desirable characters which can lead to improvement in productivity, earliness, ginning percentage, fibre quality traits and insects-pests resistance in the cultivars. The potentialities of wild species are given in Table 1.The role of wild species of *Gossypium* as sources of new characters for genetic enhancement has been carried out by several workers. Fibre quality improvement especially for high strength has been achieved through genetic enhancement by transferring the gene from *G. thurberi, G.raimondii* and form *G. barbadense* to *G. hirsutum. High* ginning out turn has been transferred from *G. arboreum to G. herbaceum.* eg MCU 2 and MCU 5 were obtained from *G. hirsutum x G. barbadense* cross derivatives.

Improvement in yield: In cotton improvement in yield has been achieved by developing high yielding varieties and interspecific hybrids. In *G. hirsutum* cotton, varieties Arogya, PKV 081, Rajat, Gujarat 67, MCU2, MCU5, Deviraj, Devitej, Khandwa 1, Khandwa2and Badnawar are derivatives of interspecific hybridization. Commercially cultivated hybrids have been developed both at tetraploid and diploid levels. Varieties like PKV 081 and Rajat have been developed from a cross between *G. hirsutum* x *G. anomalum* (Narayanan *et al.,* 2004.)

Fibre quality traits: The extra long staple (ELS) cottons (*G. barbadense*) are known for their superior quality fibres. But they account for only a small fraction of the cotton production because of their low yield and limited adaptation to most cotton growing areas. Besides the ELS cottons, some of wild germplasm also acted as potential source for improving the fibre properties. In Texas, hybridization work involving *G. thurberi* gave successful results in the transfer of high lint strength to upland cotton (Guany, 1952). Kalyanaraman and Santhanam (1955) reported the potentialities of utilizing *G. anomalum* in the transference of low fibre weight with fibre maturity to cultivated *arboreum* varieties. Attempts were also made to utilize *G. anomalum* in the hybridization programme for transference of lint fineness to the cultivated *arboreum* by the above workers. Though they succeeded in isolating some useful types, it was recognized that the expected improvement in lint fineness was not fully realized due to restricted selection made in a limited number of plants in the early generation. Marappan (1960) also reported the transference of fineness from *G. anomalum* to the background of *G. arboreum*. A fairly large number of BC_1 F_1 plants indicated the wider scope for recombination and selection of fine linted plants. Similarly Muramata (1969)

Table 1. Potential characters of wild species of Gossypium for cotton improvement through introgression .

No.	Potential characters	*Gossypium* spp (Genome)
A.	**Insect pest resistance**	
1.	Jassids	*G. anomalum(B), G.armourianum(D)*
2.	Thrips	*G. raimondii* (D_5), *G. tomentosum(AD)*
3.	Whitefly	*G. raimondii*(D_5), *G. tomentosum(AD)*
4.	Aphids	*G. armourianum(D)*
5.	Bollworms	*G. davidsonii (D)G. raimondii* (D_5), *G. anomalum(B), G. thurberi,(D)*
6.	*Heliothis*	*G. armourianum(D)*
7.	Mites	*G. somalense(E)*
8.	Nematodes	*G. anomalum(B), G. darwinii(AD)*
9.	Bacterial blight	*G.anamalum(B), G.armourianum(D), G. davidsonii (D)*
10.	*Verticillium* wilt	*G. harknessi (D)*
11.	*Fusarium* wilt	*G. harknessi (D)*
12.	Gummosis	*G.armourianum(D)*
13.	Rust	*G. sturtianum(C) G.thurberi(D), G. harknessi(D)* *G. armouroanu(D),, G. anomalum(B)*
B.	**Fibre properties**	
1.	Lint yield	*G. australe* (C)
2.	Staple length	*G. anomalum(B), G. sturtianum(C), G. australe(C), G. stocksii* (E_1)
3.	Fibre strength	*G. anomalum(B), G. stocksii*(E_1)
4.	Fibre fineness	*G. langicalyx(F), stocksii*(E_1), *G. thurberi(D)*
C.	Male sterility through cytoplasm	*G. anomalum(B), G. harknessi (D), G. aridum* (D_4)
D	Drought resistance	*G. harknessi(D), G. tomentosum(AD), G. longicalyx(F),* *G. stocksii,*(E_1) *G. aridum*(D_4)
	Primitive races	
1	Hardiness, resistance to drought, jassid, bacterial blight, *Vertcillium* wilt, high lint, strength, fineness, less gossypol	Punctatum
2.	Sucking pests resistance	Palmeri, Brasiliense
3.	Stem weevil resistance	Marie-galante
4.	Pink boll worm resistance and high oil content	Taxonomic races of *G. hirsutum*
5	Boll weevil, *Cercospora* and *Verticillium* wilt resistance	Wild accessions of *G. hirsutum*
6	Wilt tolerance, high fibre length and fineness	Sinense
7.	High GOT, big boll, long staple, wilt resistance	Cernuuman
8.	High fibre length and fineness	Burmanicum
9.	High ginning, bacterial blight resistance	Bengalense
10	Root rot and bollworms tolerance	Rozi
11	Resistance to drought and weevil	Nadam

synthesized hexaploid cotton by crossing *G. hirsutum* and *G. sturtianum* and showed the possibilities of producing spinnable yarn with very high yarn length. Arutyunova and Pulatov (1989) attempted the tri species hybrids by crossing G*. hirsutum* x *G. herbaceum* x *G. harknessi* and recorded very high ginning segregants with 42-43 per cent.

Tuteja *et al.,* (2006) used Introgressed lines as sources for improvement of upland cotton (*Gossypium hirsutum* L.) genotypes for yield and fibre quality traits. The introgressed lines were analyzed for ginning outturn (%) and different quality traits *viz.,* 2.5 per cent span length, uniformity ratio, micronaire value and bundle strength and 4 introgressed lines TCH 1648, TCH 1652, TCH 1653 and IH 35 were selected for making crosses with 12 genotypes of upland cotton to explore the possibilities of improving cultivars for seed cotton yield and fibre traits. The cross combinations namely CSH 146 x TCH 1648, CSH 146 x TCH 1652, followed by F 505' x 'TCH 1653', RS 2013 x TCH 1648, RS 2013' x 'TCH 1652' LRA 5166 x TCH 1653, LRA 5166 x IH 35 and F 505 x TCH 1653 showed significantly better performance for seed cotton yield, bolls/plant, 2.5 per cent span length and bundle strength. The choice of cross combination for fibre quality traits was greater than that of seed cotton yield. As many as 11 cross combinations showed superiority for 2.5 % span length and bundle strength

Male sterility: Cytoplasmic male sterility (CMS) is a maternally inherited trait conferring the inability to produced functional pollen because of interaction between cytoplasm and nuclear genes. CGMS does not affect female fertility and the male sterile plants are able to set seeds as long as viable pollens are provided. The presence of certain nuclear genes, Rf (restoring fertility), can effectively suppress the male sterile cytoplasm and restore pollen fertility can set seed. The application of CGMS/ Rf system has proved to be an effective means to produce commercial F_1 hybrid seed for many crops (William 1992).Number of various species imparting male sterility has been reported by several workers. Out of four types of cytoplasmic sources *i.e. G. arboreum, G. anomalum, G. harknessii* and *G. trilobum*, only *G.harknessii* based cytoplasmic male sterility has been more widely accepted and utilized in cotton hybrid program across the world. The first F_1 line of commercial cotton was introduced by crossing an upland cotton (*G. hirsutum*) as a male parent to a wild species *G. harknessii,* (Meyer, 1973). *Gossypium harknessii* Brandagee (D2-2) which is a diploid (2n = 26) was used as female by Meyer (1971) to transfer *G. hirsutum* genome in the cytoplasm of *G. harknessii.* The resultant triploid was made hexaploid (2n=78) using colchicine. Male sterile tetraploid plants were recovered from cross between hexaploid and tetraploids. Tuteja *et al.,* (2004 a) used G*. harknessii* based CMS system in breeding programme and reported that *G. harknessii* cytoplasm source suppresses the yield, ginning, fibre fineness etc. On the other hand, some other reports by Davis (1979) who studied the A x R and R x B combinations to clearly determine the effect of *G. harknessii* cytoplasm upon the performance of hybrid found no obvious difference between the performance of hybrids carrying either *G. hirsutum* or *G. harknessii* cytoplasm. Therefore, the scope of CGMS system will be greater if divergent and stable restorer lines are developed through genetic enhancement or pre breeding.

At Central Institute for Cotton Research, Regional Station, Sirsa, 4 cytoplasmic genic male sterile alloplasmic lines (CGMS) lines viz., CMS SPC 1, CMS SPC 5, CMS SPC 9, CMS SPC 11, were developed using IH 76 carrying *G. harknessii* cytoplasm by back cross breeding. These CMS alloplasmic lines were crossed with restorer euplasmic lines (Cotton Institute Restorers) CIR 7, CIR 9, CIR 20, CIR 26 and CIR 69. The resulting F_1 were selfed to produce F_2. From F_2 onwards the material was handled using Pedigree Breeding approach. The outstanding fertile plants from the segregating generations were selected and selfed and was followed up to F_7 generations. In this way 25 fertility restorer lines namely CIR 97 $P_{1-1,}$ CIR 97 $P_{1-3,}$ CIR 97 $P_{1-4,}$ CIR 97 $P_{2,}$ CIR 97 P_{1-4}, CIR 97 $P_{2,}$ CIR 97 $P_{3-1,}$ CIR 97 $P_{3-2,}$ CIR 97 $P_{3-3,}$ CIR 97 $P_{3-4,}$ CIR 97 $P_{3-5,}$ CIR 119 $P_{1-1,}$ CIR 119 $P_{1-2,}$ CIR 119 $P_{1-3,}$ CIR119 $P_{2-1,}$ CIR 126 $P_{1-2,}$ CIR 126 $P_{2-2,}$ CIR 126 $P_{3,}$ CIR 526 $P_{1,}$ CIR 526 $P_{2,}$ CIR 526 $P_{3,}$ CIR 920 $P_{1-2,}$ CIR 920 $P_{1-3,}$ CIR 926 P_{2-1} and CIR 926 P_{2-3}, were developed which have alien cytoplasm of *G. harknessii* and have the ability of fertility restoration. These fertility restorer lines were evaluated and characterized on the basis of pollen dehiscence plants were classified as male fertile or male sterile (Tuteja *et al.,* 2006).

Another instance of cytoplasmic male sterility was recorded in the diploid Asiatic species (Tayyab, 1982) using the wild species *G. anomalum* as a source for male sterility. It has been reported by Narayanan *et al.,* (2004) that *G. harknessii*, *G. anomalum* and *G. aridum* are the

Table 2. Cotton genotypes genetically enhanced through transformation/genetic engineering for various characters in cotton

S. No.	Introduced gene	Introduced gene	Method of transformation	Reference
1	Insect resistance	Cry 1Ab	*Agrobacterium*	Gould and Magallanes-cedano 1998
		Cry 1Ac	*Agrobacterium*	Thomas *et al.,* 1995
		Proteinase inhi bitor	*Agrobacterium*	
		Bromoxynil tolerance	*Agrobacterium*	
2.	Herbicide tolerance	2,4-D monooxygenase for 2,4-D resistance	*Agrobacterium*	Bayley *et al.*,1992 Lyon *et al.*,1993 Nida *et al.*,1996
		CP4(CP4 EPSPS) for glyphosate tolerance		
		Mutant AHAS for sulfonylurea and imidazolinone tolerance	*Agrobacterium*	Rajasekaran *et al.,* 1996b
		Mutant AHAS for sulfonylurea and imidazolinone tolerance		
		Bialaphos resistance	Particle bombardment	Keller *et al.*, 1997
3	Stress tolerance	Mn superoxide dismutase	*Agrobacterium*	Payton *et al.*, 1997
4	Fibre genes	E6 antisense RNA	Particlebombardment	John, 1996
		E-6 promoter+pha	Particlebombardment	John and Keller, 1996
		Fbl 2A promoter+pha	Particlebombardment	Reinhardt *et al.*, 1996

important sources of sterile cytoplasm.

Pest resistance: Cotton crop is attacked by more than 230 species of insects all over the world. In nine major cotton growing countries 10-15 insects are considered important and six species cause major yield losses (Ridgway *et al.,*1994). Therefore the primary objective of Genetic enhancement is improving of germplasm lines or pre breeding material for resistance against insects by utilizing exotic germplasm. The work of transferring bollworm resistance from *G. thurberi* and *G. armourianum* to Sakel cotton was reported by Knight *et al.,* (1953). Besides that, Knight (1950) also attempted to transfer genes for bacterial blight resistance from a *G. barbadense* to upland cotton, Jassid resistance from *G. tomentosum* and boll weevil resistance from *G. armourianum* were transferred to *G. hirsutum.* Sherif and Islam (1970) derived a hexaploid (F_1 *G. hirsutum* x *G. anomalum* doubled) and backcrossed that to *G. hirsutum.* Backcross derivatives were utilized as promising breeding material for jassid resistance. Introgressive breeding proved its potential for developing disease resistant types as well. Black arm resistance has been transferred from *G. arboreum* to *G. barbadense* and rust resistance from *G. raimondii* to *G. hirsutum.* In USSR, an upland variety namely C 4537 resistant to *Verticillium* wilt was isolated from a trispecific cross.

In India Thombre and Mehetre (1981) reported successful transfer of bollworm resistance from *G. thurberi* to *G. hirsutum.* Viroh Bi *et al.,* (1998) introgressed the 'glandless – seed and glanded-plant' trait from *G. sturtianum* into *G. hirsutum* using *G. raimondii* as bridging species. Konan *et al.,* (2003) reported the introgession of genes for resistance to renifrom nematode into *G. hirsutum* using *G. longicalyx* as the donor parent and *G. thurberi* as the bridging species. Badnawar 1, B 1007 and Cambodia-*tomentosum* types such as SRT 1, Khandwa 1 and Khandwa 2 are the resultant progenies from *G. hirsutum* and *G. tomentosum* crosses. These varieties are highly resistant to jassid and have velvet type of hairiness (Narayanan *et al.,* 2004).

Drought tolerance: In upland cotton, resistance to drought has been improved through genetic enhancement of germplasm lines by utilizing *desi* cottons**.** In India drought resistant breeding programmes utilizing the Asiatic cottons were also attempted by many workers which resulted in the infusing of drought resistant genes in hirsutum cotton and the release of varieties like Deviraj (170 CO2), Devitej (130 Co 2 M) and G 67 with wide adaptability (Singh and Singh, 1996). Transferring drought tolerance from *Hibiscus panduraeformis* to *hirsutum* cotton is possible.

Uses of biotechnology in pre breeding of cotton : There are two main approaches in biotechnology which are used in pre breeding *viz.,* (i) genetic transformation and (ii) cell culture techniques.

Genetic transformation in cotton: Genetic engineering offers a directed method of pre-breeding that selectively target one or few traits for introduction into the crop plants. The development and commercial released of transgenic cotton plants that have been genetically modified relies exclusively on two basic aspects. The first being the ability to "transform" plant by introducing a gene or genes into cotton genome that are stable transmitted and express in the progeny of subsequent generation.

Second-gene delivery system for achieving this end is the wildly used *Agrobacterium* mediated transformation method and particle gun bombardment. The second requirement is a need to regenerate fertile plants derived from individual cells.

Cell culture and plant regeneration for genetic transformation : In vitro culture involves intact tissue and organs and, therefore, requires that structural integrity of the tissue is maintained. In the first instance, the objective is usually to induce the structure to develop as good as it would be on the plant. In order to achieve this, individual cells or cell clusters are cultured on nutrient media containing growth regulators. The undifferentiated mass of cells is called callus. A piece of callus is submerged in liquid medium. The cell dissociates from each other and from suspension, which can be used for somatic embryogenesis and plant regeneration. Not only have this development has enabled cotton to be genetically enhanced for desirable traits but has allowed the use of cell and organ culture for understanding basic studies on cotton genetics and physiology also.

Due to genotype- specificity of regeneration by somatic embryogenesis, two different regeneration protocols have been standardized. They are (i) direct shoot organogenesis and (ii) induction of multiple shoots. These two protocols have helped to overcome genotype specific limitation of regeneration and secondly majority of the plants are true to the types. Unlike in case of somatic embryogenesis derived plants where cultures induce genetic damage (Stelly *et al.,* 1989), limited analysis of plants regenerated by callus based sometic embryogenesis revealed extensive phenotypic abnormalities and cytogenetic changes. (Li *et al.*, 1989).

Development of transgenic cotton: The era of transgenic cotton began in 1990 with introduction of Cry I A (b) and Cry I A (c) genes into cotton plants and transformed plants showed high level of resistance to *Helicoverpa*. In USA, the Monsanto Company launched the first product 'Bollgard' in 1996 (Krattiger 1997). The Bt gene from originally genetically engineered mother plant (Coker series) was transferred to advance cotton cultivars through backcrossing. The genetically engineered cotton in China has also been developed combining *Bt* and the cowpea Trypsin inhibitor (CpTI) gene. Transgenic cottons resistant to Lepidopteran pests are commercially cultivated in Australia, Mexico, China, USA and India (Table 3).

In India the transgenic cotton (genetically modified cotton) was introduced into cultivation during 2002-2003 first with Bollgard-I (Cry1Ac) and subsequently the Bollgard-II (Cry1Ac+Cry2Ab) and the transgenic cottons were all based on proprietary germplasm and hybrids were predominantly of *G.hirsutum* x *G. hirsutum* combinations. As a result, predominantly *G. hirsutum* x *G. hirsutum* based transgenic cotton hybrids are grown in more than 11.87 million ha corresponding to over 90 per cent of the total area under cotton (Anonymous

2016-2017).

At present six gene constructs are being used commercially Cry I Ac, Cry I Ac+Cry2Ab, Cry I Ac+Cry IF, Vip3A. However, extensive cultivation of Bt transgenic cotton and selection pressure on target insects in a continuous mode will encourage the development of resistance in insects towards *Bt* (Goud 1988) Therefore, *Bt* cotton will have to be managed in a way that discourages pest resistances to *Bt* toxins by genetic enhancement of germplasm lines through gene pyramiding.

Future prospects

- In cotton distant hybridization has played a significant role in transferring the desirable characters like fineness, strength, resistance to pests like jassids, boll worm, black arm, drought resistance and male sterility besides improvement in yield by releasing hybrids. However the utilization of wild germplasm poses the various problems like reproductive barriers such as failure of pollen germination and slow pollen tube growth, elimination of chromosomes, chromosomal abnormalities, hybrid in-viability and hybrid sterility.
- Despite breeding progress achieved, additional gains in cotton productivity, quality and resistance to pests and abiotic stresses are needed. Agricultural Biotechnology offers opportunity for development of germplasm lines with higher level of resistance to biotic and abiotic stresses. Gene transformation and Marker Assisted selection are useful tools to overcome the limitations of conventional breeding for the improvement of cotton germplasm lines for useful traits through interspecific hybridization or genes sourced across the species barriers.
- For developing multiple adversity resistance (MAR) lines programme in cotton collaborates actively with genome mapping, fingerprinting, gene tagging and transformation.
- Similarly to develop the germplasm lines with multiple insect resistance (MIR) to reduce the expenditure on pesticides. This can be achieved through transfer of morphological and biochemical factors imparting resistance to single genotype.
- Another concept picking up worldwide is the organic farming for which the germplasm need to be screened and genetically enhanced through pre-breeding.
- In the years to come, the wild species of cotton could be looked as a source for the contribution of genes governing the traits like fibre fineness, strength and maturity, pests and diseases resistance, drought resistance, increased photosynthetic rate, uniform maturity, etc. Though handy tools in biotechnology are available for gene introgression, it takes a long time compared to the routine hybridization programme owing to the non responding nature of cotton to the nurture given at the laboratories. Similarly, shortfalls are bound to occur in conventional hybridization owing to the disparity in the genome introgressed

and genetic disturbances. Therefore there is an urgent need to encourage the Scientists to become "Genetic Enhancer or Pre Breeders" and helping the breeders in their breeding programme for development of cultivars to meet the need of human being.

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Evaluation of seed yield, seed oil and fiber quality of promising cotton cultivars in Azarbayejan province, IRAN

ABDOLLAH HASSANZADEH GHORTTAPEH* AND MAHSA SADEGI

Horticulture crops Research Department, West Azarbaijan Agricultural and Natural Resources Research and Education Center, (AREEO), Urmia, Iran

**E-Mail : a.g.hassanzadeh@gmail.com*

ABSTRACT : This research was conducted in 2010 as a randomized complete block design (RCBD) with three replications for comparing of qualitative and quantitative characteristics of eleven cotton cultivars in Urmia weather conditions, west Azarbijan province, Iran. The cultivars studied included Varamin, STB-A, NOZ10, Sahel, SP732, G-R-3, NNB, NNC, NZG-AB, SP731 and SK-SC. The results of this study showed that there is a significant difference between the cultivars in all studied traits.The Sahel cultivar had the highest lint weight also the lowest amount was obtained for NZG-AB. According to the results obtained for the studied cultivars and only Sahel and NNC cultivars had the lower fiber firmness than the other cultivars. The G-R 3 has the finest fiber fineness**.** Based on cluster analysis, cotton cultivars were divided into two groups, in the second cluster, the cultivars Sahl, NZG-AB and SP731 were placed and the other cultivars examined in the first cluster. Correlation between traits showed that there was a positive correlation between fiber and lint yield and number of bolls/plant. Considering that the cotton fiber performance is the most important trait in economic value, because the highest amount was taken from the NNB, therefore it could be said that the best cultivar was among the cultivars studied and suitable for cultivation in the region.

Key words : Cotton, fiber, grain oil, lint, yield

The cultivation of cotton in the Iranian semi-arid region is important for the regional development and for employment growth, since it allows the production of different products that can be used for diverse purposes, generating income through its fiber (textile industry), seeds (biodiesel, cooking oil, *etc.*) and cotton seed cake (animal feeding), stimulating activities of different economy sectors.

The first product of cotton to use is cotton fiber than the seed. But because of the close relationship between lint biomass and seed (since the seed epidermal supports the growth of fibers), number of researchers reported cotton seed yield more important than the cotton fiber yield (Talat, 2010). But in any case, in many definitions, cotton yield is related to the number balls/plant and the amount of lint/boll (Paytas, 2009). According to other researchers, cotton has two main components, first, the number of seeds per boll and the number of fibers produced on each of these seeds. There are four cultivated species of cotton. *G.arboreum*, *G.herbaceum*, *G.hirsutum* and *G.barbadense*. The first two species are diploid

(2n=2x=26) and are native to old world. They are also known as Asian cottons, because they are grown in Asia also the last two species are tetraploid (2n=4x=52) and are also referred to as new world cottons. *G.hirsutum* is also known as American cotton or upland cotton and *G.barbadense* as Egyptian cotton, Sea Island cotton, Peruvian cotton, Tanguish cotton or quality cotton. *G.hirsutum* is the predominant species, which alone contributes about 90 per cent to the global production (Singh and Kairon, 2016). The surface of each cotton seeds, fibers/seed, the fiber/unit area of seeds, the weight of lints/seed, the weight of lints/unit area of cotton seeds and the weight of seeds/length of cotton were all in determine the amount of cotton production (Rauf, *et al.*, 2007). Researchers saied that the most important components of cotton yield are bolls/plant, boll weight, seeds/boll, fiber index, seed index and oil percentage (Worley and Ramey, 1976). Environmental conditions affect on the growth of boll and seed development of cotton, but genotype in the nature affects of plant response and action to environmental conditions (Bölek, and Oklakçi, 2007). Reports indicate that if it is possible to cultivate cotton in the early spring, consequently, due to the increase in the length of the growth period, it can be achieved by increasing the yield, improving the quality of the fiber and expanding the plant’s crop to cooler areas, as well as creating areas newer cultivation is possible. On the other hand, this approach is effective in controlling the population of pests, especially pests that they damage the product at the end of the season. Therefore, increasing seed germination and seedling growth at low temperatures early spring has become one of the important agricultural goals in Iran and elsewhere in the world. Existing of cold tolerant cultivars induce early planting in the spering, increasing of seed, fiber yield, quality and extend cultivation of cotton in the world (Talat, 2014). Small boll size seems to have a negative effect on yield of yield. Therefore, the yield components are plant characteristics that positive or negative effects of yield function. Talat (2010) reported that there was a very low and non-significant correlation between total yield and boll weight, in contrast, the number of bolls/plant play a more important role in determining the performance. The plant uses for changing of number of bolls/plant to adapt to environmental conditions. The aims of study were evaluation of seed yield, seed oil and fiber quality of eleven promising cotton cultivars in west Azarbaijan province.

MATERIALS AND METHODS

This experiment was conducted in Urmia in 2010 at the Research Station of Agricultural and Natural Resources Research and Eduucation Center, Urmia, Iran. The geographical location of the station is longitude 45 degrees 10 minutes 95 seconds east, latitude 37 degrees 44 minutes 18 seconds north and its height from sea level is 1338 meters.The average annual rainfall of the test site was 296 mm. A field Experiment was conducted during 2010-2011 under irrigated condition in Urmia at the Research Station of Agricultural and Natural Resources Research and Eduucation Center, Urmia, Iran. It has a semi arid and sub tropical climate with moderate hot dry summers and cold winters, the temperature ranges from 15° to 39° C with a mean annual rainfall about 296 mm, the soil of the experimental plots is a clay-loam soil type, having pH 8, Ec 0.8 ds/m, organic carbon (1.2 %), N 0.(12 %). P_2O_5 (12ppm), K_2O (125ppm) and lime (16%). This research was carried out based on randomized complete block design (RCBD) with three replications and eleven treatments that treatments were eleven cotton cultivars. Each plot was dimensioned 4×2.3 meters and consisted of 6 rows of 6 meters planting length, row spacing 80 cm and intera row spacing of plants 20 cm. The total number of the plot was 33. Treatments were eleven cotton cultivars include: Varamin (check cultivar), STB-A ¡ NOZ10¡ Sahel¡ SP732¡ G-R-3¡ NNB¡ NNC¡ NZG-AB, SP731 and SK-SC. The bolls were harvested in two stages of the plant and after separation lint, the air was dried for 24 hours in the room. At the time of the second harvest, five plants of each plot were selected and after the separation of different parts of the plant placed into paper bags and put in an oven at 75°C for 48 hours and weighed. Measuring the qualitative characteristics of cotton was carried out at the Cotton Research Institute of the country, the Deputy of Varamin. The oil Measured by in the Soxhlet method and extracted continuously by petroleum ether. Statistical analysis was performed using MSTAT-C software. Means comparison was calculated by Duncan test. Person correlation between studied traits and cluster analysis were performed by SPSS software.

RESULTS AND DISCUSSION

Analysis of variance of quantitative traits showed that there was a significant difference for fiber yield, fiber harvest index, fiber fineness and fiber strength of cotton cultivars at the probability level of 1 per cent (Table 1).

Fiber yield : Cultivars had significantly effect on fiber yield at the probability level of 1 per cent (Fig. 1). According to the results, NNB, G-R 3 and NNc cultivars had the higher fiber yield, respectively. NNB Had the higher fiber yield than the Varamin 207 var. Among the cultivars under study, the lowest fiber yield was related to NZG-AB var. Hassan *et al.*, (2007) also found that there were significant differences in cotton yield among cotton varieties in the study of twenty four new cotton lines. Zangi *et al.,* (2007) reported that the source (leaf area, leaf area index, leaf dry weight of each plant and the efficiency of photosynthesis), sink (number of nodes that producing reproductive branches, fruit form and dry weight of fruit/plant) and flow from source to sink in twenty lines and parent plants differed. In this experiment hybrid cultivars had more yield, this increase could be due to improved source efficiency, sink and asmilate transfer to

Table 1. Analysis of variance of qualitative and quantitative qualities of fibers

S.V	DF	Flexural stretch	Fiber elegance	Fiber strength	Fiber length	Fiber yield	Fiber harvest index
Block	2	0.06	0.16**	6.69	3.48	38109*	27.7**
Cultivar	10	0..22	0.32**	18.97**	32.43	75584**	102.3**
Error	20	0.102	0.027	6.91	77.41	8532	3.19
C.V(%)		4.66	3.91	8.88	6.75	30.24	27.39

* and ** respectively, at a probability level of 5% and 1% respectively

parent plants. There is also a great deal of difference between the different varieties of cotton in terms of the response to fertilizer elements and the efficiency of absorption and consumption (Ahmad *et al.*, 2009). Researchers have reported on potassium nutrient content that cotton cultivars differ in terms of response to this nutrient and it needs for optimal yield. The researchers have presented several possible interpretations for the differences between the cultivars in response to potassium, including the difference in early maturity and the allocation of photosynthetic products inside the plant (Gwathmey, 2005). According to other researchers, cotton has two main components, seeds/boll and fibers produced on each of these seeds.The level of each of these seeds, fibers/ seed, fiber/unit area, the weight of lint/seed and the lint weight/unit area of cotton seeds are all responsible for determining the amount of cotton production (Rauf *et al.,* 2007) .

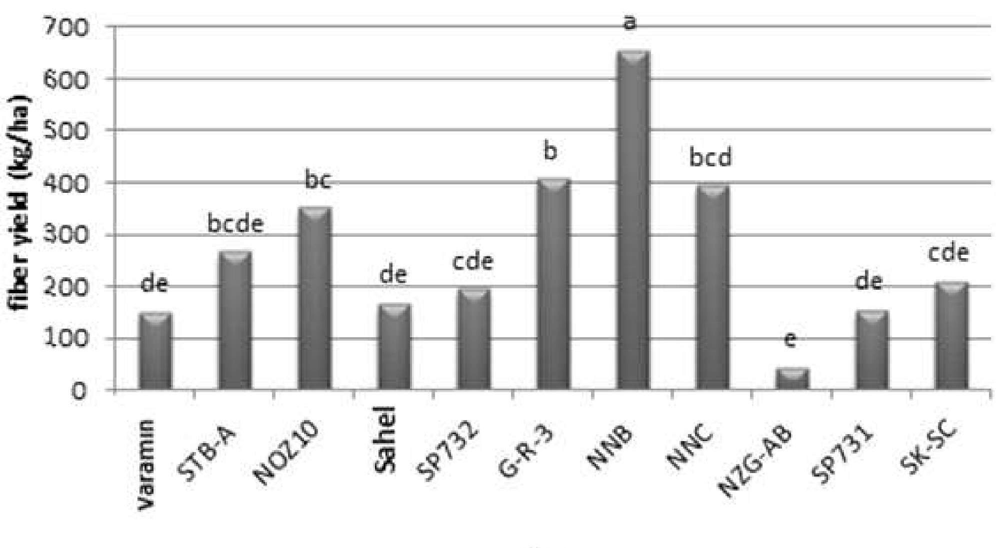


Fig 1. Camper means of fiber yield /ha in cotton cultivars

Fiber harvest index : The effect of cultivar on the fiber harvest index was significantly difference at the probability level of 1 per cent. According to the results, among the cultivars studied, the NNB had a much higher harvest index than other cultivars (Fig 2), this cultivar also had the highest fiber yield per hectare. Therefore, the high harvest index in this cultivar caused increase the fiber yield. Thus, in this cultivar the transfer rate of assimilate to the economic part is stronger, according the weather conditions of the region. After that, the G-R 3 had the highest index of fiber harvesting, the high number of seeds and the weight of the fiber/seed unit represents this. Similar results have been reported by other researchers. Groves and Bourland (2008) reported that there is a significant difference between the different cotton varieties in lint index (100 seeds lint weight). The NZG-AB cultivar had the lowest harvest index.

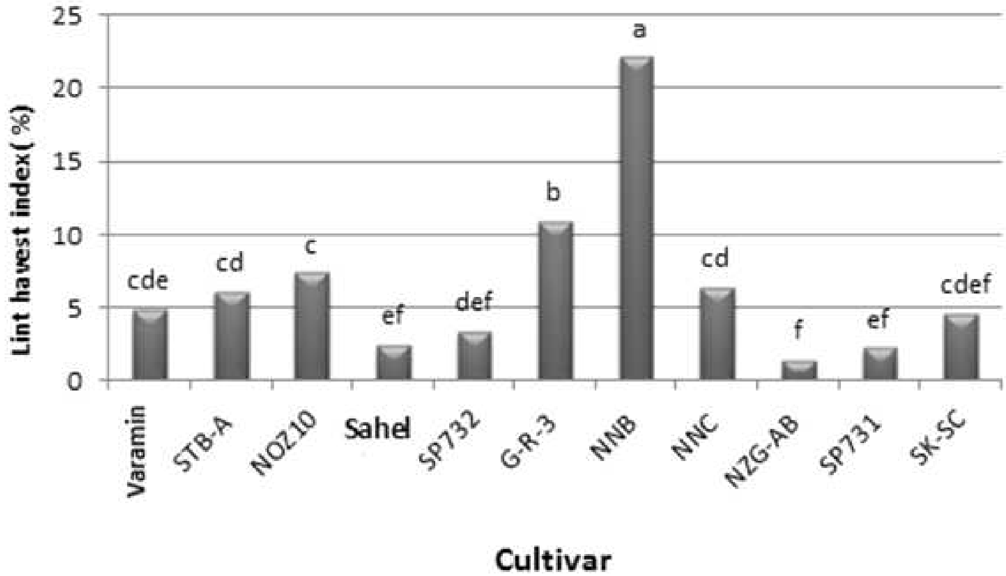


Fig 2. Compar means of lint harvest index in cotton cultivars

Fiber strength : The effect of cultivar on fiber strength was statistically significant at 1 per cent probability level. According to the results, only Sahel and NNC cultivars had lower fiber firmness than the other cultivars non significant difference was found between the other cultivars in fiber strength character (Fig 3). Asif *et al.*, (2008) studied nineteen different cotton genotypes and found to differ in strength between cotton fibers in different cultivars. According to other researchers, the strength fiber of the old cotton cultivar is much higher than the new cotton cultivars (Mora *et al.*,

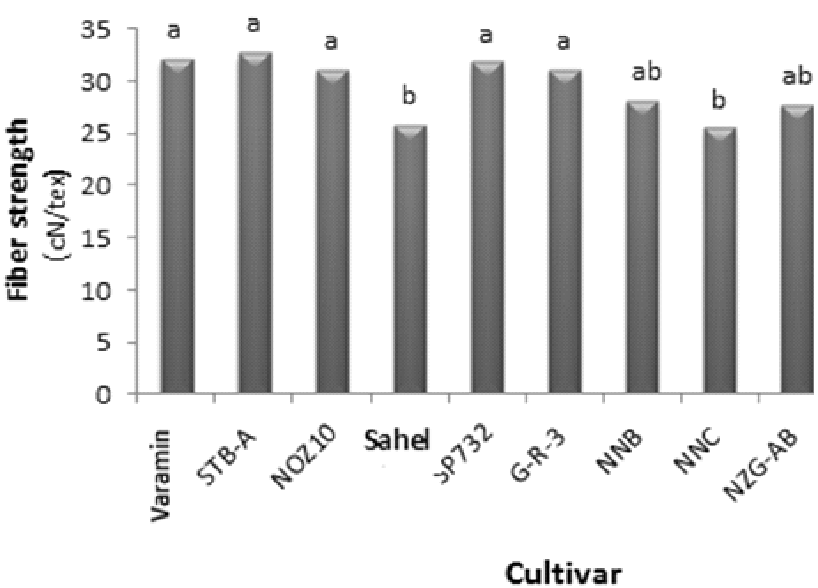


Fig 3. Comparison of fiber strength means in cotton cultivars

2007). In another study, Amjad Ali *et al.*, (2008) observed among cotton cultivars had a significant difference in fiber strength. The strength of cotton fibers is associated with many physiological and morphological processes when thickening the walls of fiber cells. Research has shown that in cultivars with strong fibers, the activity of sucrose synthase and â-1 and 3 glucan synthase is greater, more sucrose, colozes are excised and transported to cellulose synthesis. This leads to longer and more durable fibers (Zhang *et al.*, 2009). In this study, there was no significant correlation between fiber yield and fiber strength, but fiber strength trait had a positive correlation with fiber length (723.0*). Basal and Turgut (2005) reported that there is an inverse relationship between the quality of cotton fibers and cotton yields.

Fiber elegance : The effect of the cultivar on the elegance of the fibers was statistically significant at the probability level of 1 per cent. According to the results of this study, the G-R 3 cultivar had the highest fiber fineness and the SP731 variety had the at least fineness of the fibers (Fig 4). Therefore, the elegance of the fiber was different among the cultivars studied. Asif *et al.*, (2008) observed a significant difference in the fineness of the fibers in the study of nineteen cotton genotypes, While Kilby (2005) reported a negative correlation between yield and fiber quality in nineteen cotton genotypes.

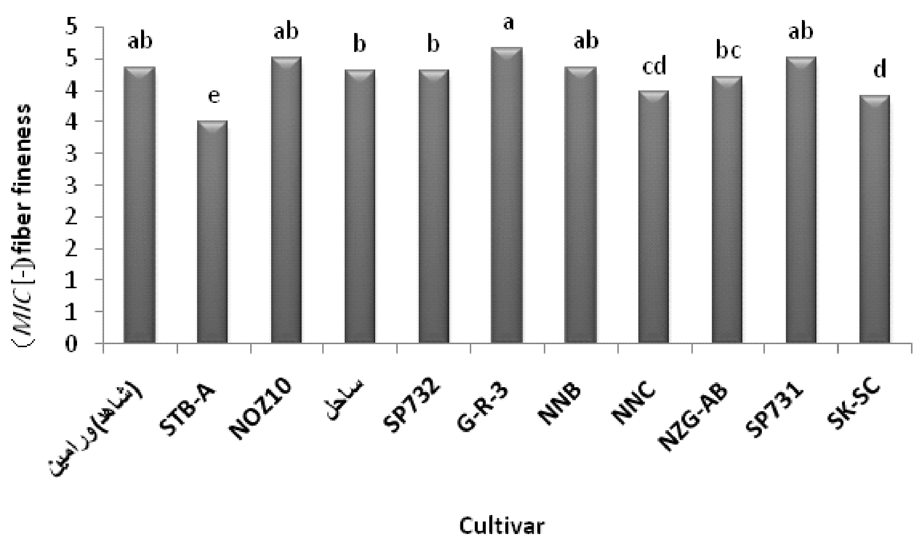


Fig 4. Comparison of fiber firmness means in cotton cultivars

Oil persentage : The effect of cultivar on oil percentage was statistically significant at 1 per cent probability level. Among the cultivars examined, the SP731cultivar had the highest percentage of oil (Fig 5).

Oil yield : The effect of cultivar on oil yield was statistically significant at 1 per cent probability level. The results of this study showed that varamin, NOZ 10, G-R 3, NNB, SP731 and SK-SC cultivars had the highest seed yield. The lowest oil yield was observed in NZG-AB (Fig 6).

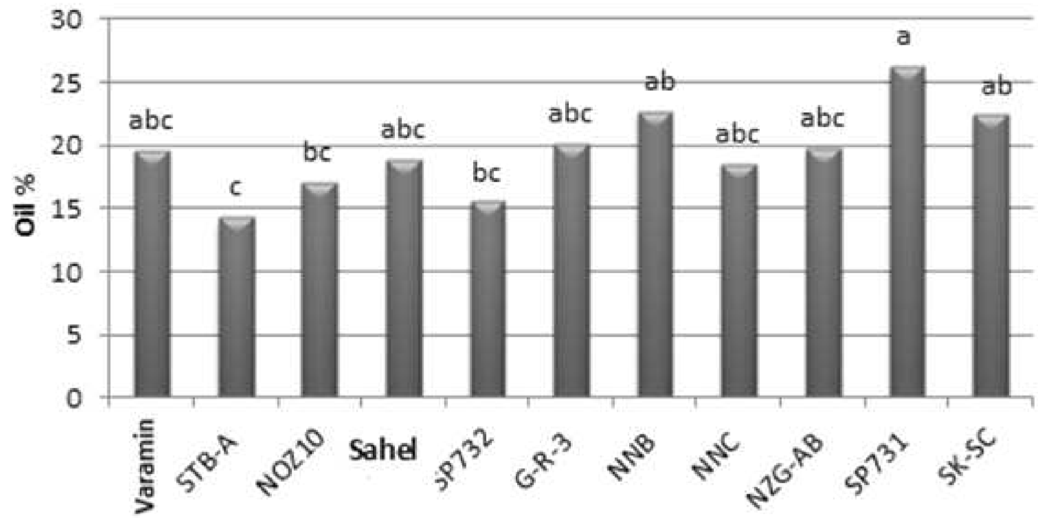


Fig 5. Comparison of oil % means in cotton cultivars

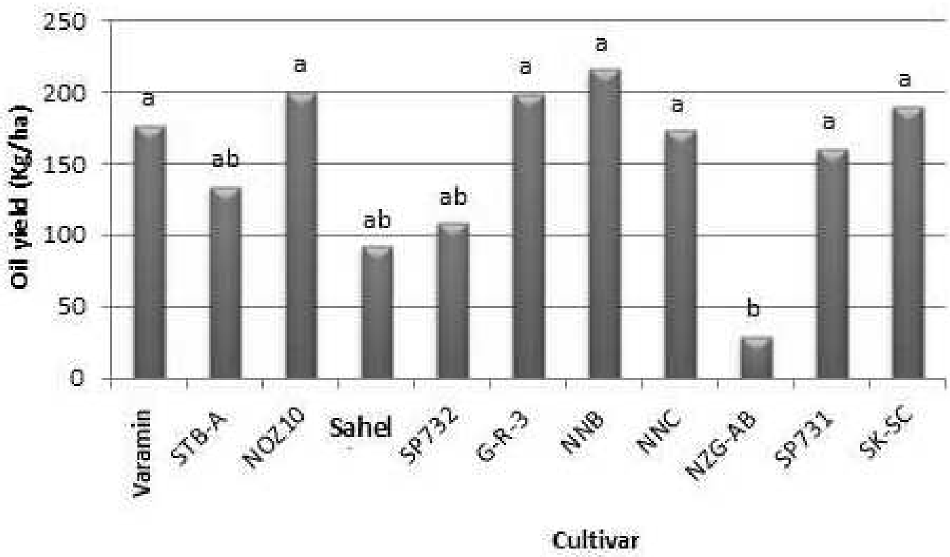


Fig 6. Comparison of oil % means in cotton cultivars

Oil harvest index : The effect of cultivar on the oil harvest index was statistically significant at the probability level of 1 per cent. The results of this study showed that NNB cultivar had the highest seed oil index and the lowest oil harvest index was also found in NZG-AB (Fig 7).

The varieties of Varamin, NOZ 10, G-R 3, NNB, SP731 and SK-SC had the highest yield of seed oil among the cultivars, also the lowest oil yield was observed in NZG-AB. According to the results, only the Sahel and NNC cultivars had lower fiber strength than the other cultivars, the G-R 3 cultivar has the finest fineness of the fiber and the SP731 has the finest fineness

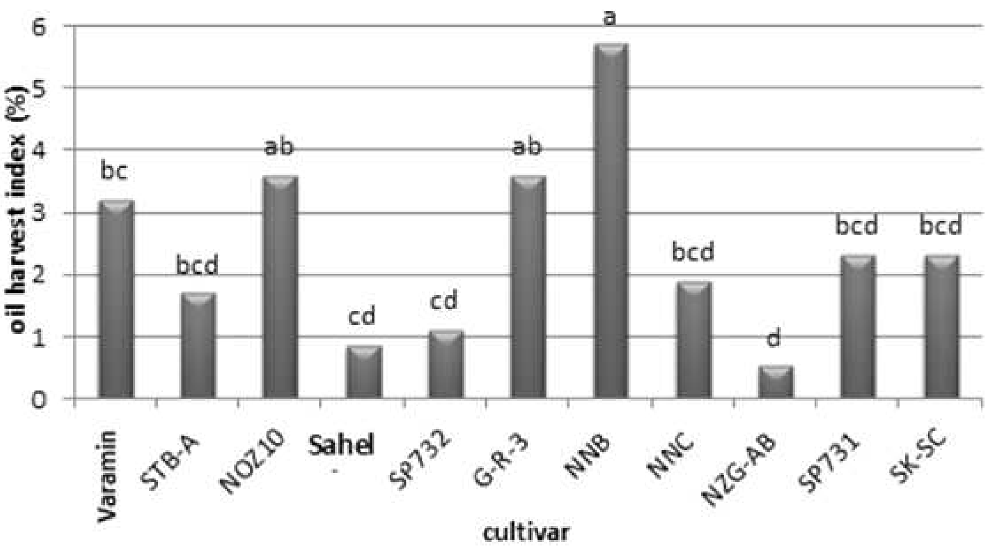


Fig 7. Comparison of oil harvest index means in cotton cultivars

of the fibers.

Classification of cultivars using qualities related to quantity and quality of fibers

Cluster analysis

Classification of varieties using grain yield trait : The cultivars were subjected to cluster analysis using the grain yield of the obtained data . Cutting the dandruram from the method Ward cotton cultivars were placed in 4 separate clusters.

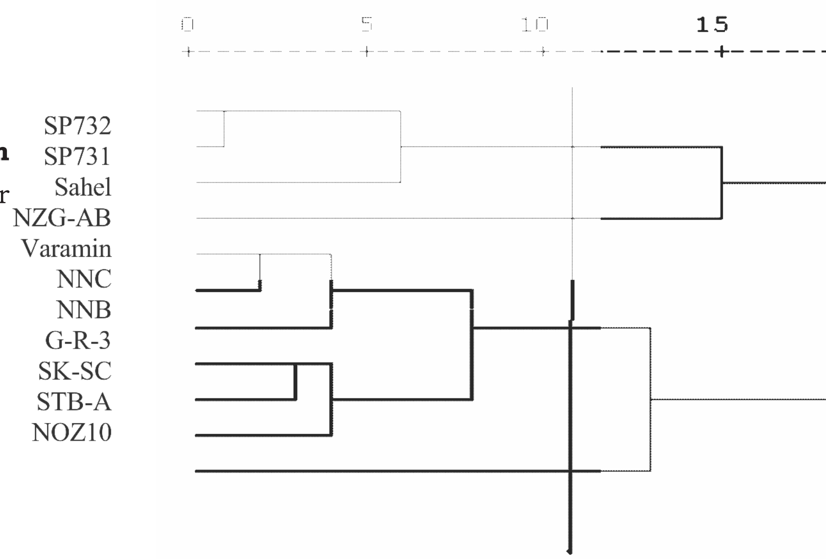
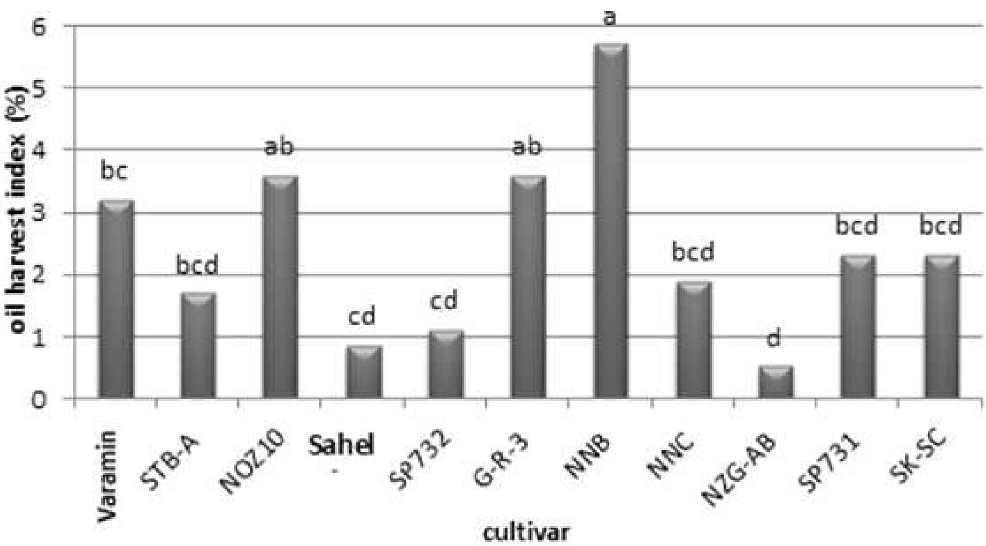


Figure 8. Classification of cultivars according to grain yield traits



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In the first cluster, the cultivars of the Sahel, SP732 and SP731 were placed. These cultivars were the lower grain yield, grain number and grain harvest index.

In the second cluster, NZG-AB, which had

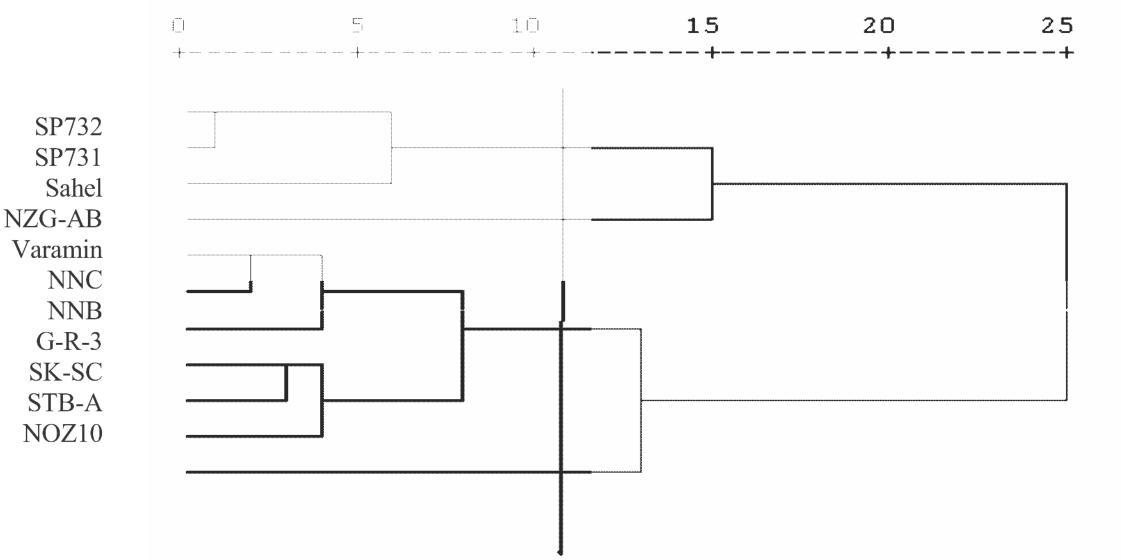

Figure 8. Classification of cultivars according to grain yield traits

Table 2. simple correlation between studied traits(pierson method)

No.	traits	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	Bush height	1																		
2	Stem weigh	0.704*	1																	
3	Plant weight	0.393	0.503	1																
4	Boll weight	0.671*	0.343	0.434	1															
5	Boll/plant	0.207	-0.262	-0.341	-0.004	1														
6	Lint/plant	0.136	-0.326	-0.383	0.01	0.955**	1													
7	Flexible elasticity	0.094	0.21	-0.006	0.362	0.014	-0.041	1												
8	Fiber fine	-0.262	-0.306	-0.357	-0.067	0.029	0.039	0.304	1											
9	Fiber strength	0.273	0.057	-0.292	-0.003	0.392	0.254	0.163	0.025	1										
10	Fiber length	0.339	0.303	-0.32	0.051	0.35	0.277	0.389	-0.137	0.723(*)	1									
11	Fiber yield	-0.133	-0.521	-0.439	-0.019	0.683*	0.858**	-0.092	0.126	-0.098	0.037	1								
12	Fiber harvest index	-0.18	-0.497	-0.619*	-0.028	0.556	0.742**	0.075	0.185	-0.014	0.221	0.938**	1							
13	Grain harvest index	-0.058	-0.418	-0.762(**)	-0.164	0.815**	0.848**	0.169	0.331	0.367	0.401	0.762**	0.804**	1						
14	Seed/plant	0.207	-0.262	-0.341	-0.004	10.000**	0.955**	0.014	0.029	0.392	0.35	0.683*	0.556	0.815**	1					
15	Grain yield	0.278	-0.167	-0.299	0.026	0.990**	0.952**	-0.005	-0.018	0.43	0.383	0.660*	0.528	0.787**	0.990**	1				
16	1000 grain weight	0.628*	0.781**	0.46	0.36	-0.059	0.002	0.044	-0.317	0.101	0.172	-0.111	-0.166	-0.21	-0.059	0.069	1			
17	Oil (%)	-0.36	-0.325	-0.32	0.22	-0.162	-0.122	0.423	0.415	-0.283	-0.341	0.058	0.159	0.136	-0.162	-0.212	-0.337	1		
18	Oil yield	0.113	-0.331	-0.437	0.177	0.895**	0.886**	0.223	0.214	0.233	0.211	0.714*	0.637*	0.844**	0.895**	0.872**	-0.127	0.279	1	
19	Oil harvest index	-0.145	-0.484	-0.765**	-0.067	0.720*	0.797**	0.247	0.387	0.204	0.303	0.814**	0.879**	0.967**	0.720*	0.681*	-0.267	0.323	0.846**	1

the lowest number of bolls, fiber per plant, grain yield harvest index, seed number and grain yield. In the fourth cluster, NOZ10 had the highest number of bolls, number of seeds and grain yield. Other cultivars were placed in the third cluster.

Classification of cultivars using qualities related to quantity and quality of fibers : For classification of cultivars using qualitative and quantitative qualities of the fibers, the obtained data were analyzed by the cluster. The dandruram cut from the method Ward (Fig. 9). Cotton cultivars were divided into 3 separate clusters. In the first cluster, NOZ-10, G-R 3 and NNB cultivars were included in the cultivars with lower fiber yield and harvest index,

In the second claster, Varamin, SP732, STB-A, SK-SC, which were lowest fiber yield and fiber harvest indexes, but had the highest fiber length, fiber strength, and elasticity of the fibers. Other cultivars were placed in the third cluster.

According to the cluster analysis, it is seen that the classification of varieties varies according to different traits. Because of the importance of economic performance (fiber yield and oil yield), NZB 10 , GR 3 and NNB cultivars were included in the same group with the highest fiber yield.

According of oil yield, STB-A, NZG-AB and SP732 cultivars were in the same category, which had the highest oil yields. Regarding the above, NNB, NOZ 10 and G-R 3 cultivars were the best cultivars because of their high grain and oil yield.

Sahel with SP732 cultivars had the highest dry weight of shoot per plant. But there was a huge difference between the number of bolls harvested in the bush of different cultivars. NOZ-10 was the highest and NZG-AB had the lowest number of bolls.

NNB cultivar had the highest lint harvest, fiber yield, fiber harvest index. Therefore, it can be said that the best cultivar is among the cultivars, which is due to the high power of this plant in the production of the economic sector until harvest. The lowest was NZG-AB.

In this study, NOZ 10 had the highest grain yield among the tested cultivars. After this figure, G-R 3, NNB and NNC had the highest grain yield. The lowest value was attributed to the NZG-AB variety, which was 84 per cent less than that of

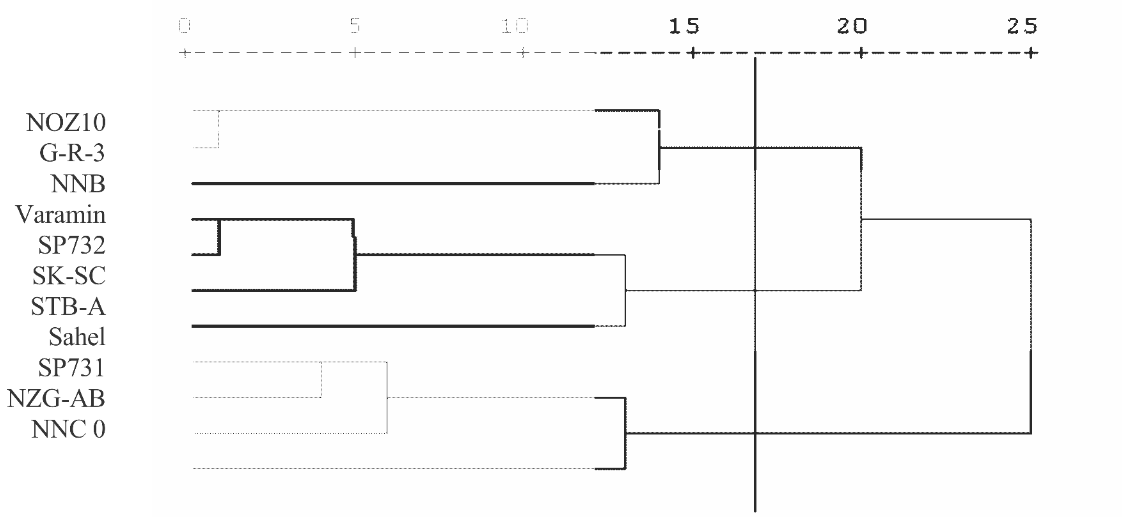

Fig. 9. Dendrogram derived from the classification of cultivars according to the quantity and quality of the fibers

Varamin.

Among of the varieties , Varamin, NOZ 10, G-R 3, NNB, SP731 and SK-SC had the highest yield of seed oil. The lowest oil yield was observed in NZG-AB.

According to the results, only the Sahel and NNC cultivars had lower fiber strength than the other cultivars. The G-R 3 cultivar has the high finest fineness of the fiber and the SP731 has the lowest finest fiber fineness.

In this study, the correlation between grain yield and number of bolls and the number of seeds per plant was significant ly and positive. Also, correlation between traits showed that there was a positive and significant correlation between cotton fiber harvest index with total lint/plant and number of bolls.

Correlation study of the studied traits showed that there is a positive and significant correlation between fiber yield and total number of bolls. Also, there was a positive and significant correlation between fiber yield with seed number /plant and grain harvest index. This correlation shows that by increasing the number of seeds, the fiber yield will be increased.

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Amelioration technologies for calcareous soils

AMBATI RAVINDER RAJU* AND A. MANIKANDAN

ICAR-Central Institute for Cotton Research, Nagpur- 44 0011

**E-mail : bumaraju@gmail.com; AR.Raju@icar.gov.in*

SUMMARY : Cotton is semi tolerant to calcareous (20-40% $CaCO_3$) soils and yield reductions to the extent of 30-40 per cent were observed with a productivity as low as 5 q/ha (40% $CaCO_3$) and as high as 22 q/ha (20% $CaCO_3$) with appropriate management in farmer's fields. Most profitable field crops were *Dolichus purpureus, Brassica oleracea Capitata , Brassica oleracea botrytis, Lycopersican esculantum, Solanum melangena, Capsicum fruitizens, Hybiscus esculantus, Gossypium* sp, *and Triticum aestivum* . *Dolichus purpureus* was most economical with a net profitability of 534 to 714 US $ compared to 357 US $ with *Bt* cotton where average $CaCO_3$ content was exceeding 40 per cent. Farmer's were applying 25-35 per cent higher amount of sulphur containing complex phosphorous fertilizers in 2-3 split applications, supplemental irrigations, spraying humic acid, micronutrients and growth stimulants for cotton. Present interventions for calcareous soils under verification in farmers fields were seed treatment with phosphorus solubilising bacteria (PSB) or humic acid followed by split applications of 125 per cent recommended dose of phosphorus (RDP), early foliar application of humic acid, zinc sulphate ($ZnSO_4$) and magnesium sulphate ($MgSO_4$) found to produce similar results to that of *Bt* cotton in normal soils with (100%) RDF. Rainfed *Bt* cotton with and without nutrient management package produced 11.5 and 8.5 q/ha in farmer's fields. *Bt* cotton with (100%) RDF and two supplemental irrigations (90 x 90m) and drip irrigation (1.2 x 0.3m) produced seed cotton yield of 15 and 25 q/ha, respectively in calcareous soils.

Key words : *Bt* cotton, calcareous soils, cropping systems, nutrient deficiencies, supplemental irrigation

Thirty percentage of world soils and seventy percentage of the Indian *Vertisols* are calcareous. *Bt* hybrid cotton is being semi tolerant grown as one of the major rotational crop in 36 per cent of Maharashtra state soils. Highly calcareous soils with more than 15-85 per cent $CaCO_3$ in the semi arid tropics severely interferes with *Bt* hybrid cotton phosphorous(P) and zinc (Zn) nutrition, besides severe soil moisture stress causing terminal droughts. Hidden hunger of potash (K), magnesium (Mg), sulphur (S), boron (B) and iron (Fe) reduces cotton production to 2/3rd of the potential yield. Inadequate organic carbon quickly looses soil moisture within two weeks after the cessation of the monsoon rains limiting the growing period of crops 120-140 days. Impermeable hard pan (*Caliche*) below 1.5-2' depth, is not a limiting factor in rainfed *Bt* hybrid cotton productivity .

Soil productivity constraints:

Rainfed productivity: Terminal drought, P fixation, Zn, Mg, K deficiencies are the main limitations in calcareous soils. On farm trials found soil available P was below 50 per cent only ranging between 4-6 kg/ha depend upon level of chemical fertilizer application and per cent $CaCO_3$ (Table 2). Sulphur containing complex P fertilizers need to be applied alongwith humic acid (0.02%)/animal manures tripled the available P and also in the cotton leaves.

Table 1. Calcium carbonate and available P content in Linga series, Kalmeshwar, Nagpur(M.S.),India.

Name of the farmer		Irrigations	pH	$CaCO_3$ (%)	Soil P (kg/ha)	Seed cotton yield (kg/ha)
Narayan Bansode	Prabhav Flax	3	8.3	34	4.3	16
Narayan Bansode	Bayer First class	3	8.3	34	4.3	15
Ashok Ambule organic	US 4647	3	7.9	14	4.1	15
Ashok Ambule irrigated	US 4647	3	7.8	7	4	13
Kauduji Sitaram Adle 1	Ankur 3028	3	8.2	10.5	4.1	11
Ukandrao Namdar	Ankur 3028	3	8.4	17	7.7	10
Narayan Bansode	Ankur 3028	3	8.3	34	4.3	10
Rahul Ambule	Polaris	3	8.0	14	4.1	10
Kauduji Sitaram Adle 2	Ankur 216	0	8.5	12.5	6.4	5
Kauduji Sitaram Adle 3	Polaris	0	8.4	16	4.6	5

Farmers are applying basal dose at 20 days as sulphur containing complex fertilizers either or with K fertilizer followed by mixture single super phosphate + urea + K fertilizer at 40 days in two split doses is more effective as compared to single basal application (Table 1). However, sub optimal N, P, K, Mg, S, Zn, B and Fe application resulted in hidden hunger and reduction in seed cotton yields to the tune of 25 per cent. Soil and foliar application of Mg, S, K, humic acid, Zn, chelated micronutrients alongwith adequate complex fertilizers (Table 2) and available animal manures / composts/ PSB/ humic acid seed treatment were quite effective in ameliorating cotton crop productivity in calcareous soils. Biofertilisers consortia consisting of *Azotobacter chrococcum* + *Azospirillum brasilience* + *Bacillus megatherium var. Phosphaticum* and *Trichoderma viridae* as seed treatment alongwith 0.02 per cent humic acid treated RDF (125%) fertilizers followed by chelated micronutrient (0.5%) at 45 and 60 days as foliar spray significantly improved seed cotton yields of *Bt* hybrid cotton Ankur 3028 at station trials compared to PKV 081 Raju *et al.*, (2016).

Irrigation: Calcareous soils are porous, well drained with good percolation, best endowed often with gravitational wells for supplemental irrigations. Farmers provide 1-4 irrigations or terminating the crop early to accommodate late planting of wheat/summer groundnut / vegetables is not uncommon. Sub optimal (<35%) RDF application is one of the common cause of non remunerative/ non significant response returns from calcareous soils under protective irrigations by surface or drip irrigation systems (Table 4-7).

Table 2. Station trial on calcareous soils at CICR, Nagpur

Treatment details	Seed cotton yield (kg/ha)		Net returns in US $		Cost : Benefit ratio		Boll/ plant	
	Ankur 3028	PKV 081	Ankur 3028	PKV 081	Ankur 3028	PKV 081	Ankur 3028	PKV 081
T_1 : RDF (100%), Zn and B soil application.	10.4	16.4	423	685	2.1	2.1	17.3	9.0
T_2 : Biofertilisers seed treatment + RDF (125%) + Mg, S, Fe, Mn, Zn and B as per soil test.	13.8	11.7	664	334	2.6	1.6	24.7	8.0
T_3 : **T_2**+ RDF (100%) as Basal dose + (25%) P, K, Mg split soil application at 45days.	11.5	16.0	513	656	2.3	2.1	29.0	17.0
T_4 : **T_2**+ (0.05%)B, (0.5%)Fe, (0.3%)Mn, 0.5 Zn at 45 days and DAP (2%) at 75 days as foliar spray.	10.9	16.0	458	649	2.1	2.0	23.3	9.0
T_5 : **T_2**+ chelated micronutrient 2.0 kg ha at 45 days.	12.0	13.1	511	419	2.2	1.7	23.3	8.3
T_6 : **T_2**+ chelated micronutrient (0.5%) foliar spray at 45 days.	12.5	11.5	571	329	2.4	1.6	27.0	17.0
T_7 : **T_2**+Animal manure in root zone 2 tonne ha +micronutrient soil application 15kg /ha.	10.7	16.4	431	665	2.0	2.1	22.7	17.7
T_8 : **T_2**+Humic acid (0.02%) treated fertilizers + micronutrient soil application 15kg /ha.	11.9	19.7	520	890	2.3	2.3	17.7	12.3
T_9 : **T_2**+ Humic acid (0.02%) treated fertilizers + chelated micronutrient soil application 2.0 kg /ha.	11.8	12.3	703	640	4.7	2.9	21.0	11.3
T_{10}: **T_6** Humic acid (0.02%) seed treatment chelated micronutrient (0.5%) at 45 and 60 days as foliar spray.	14.6	11.8	685	305	2.5	1.5	24.0	5.7
SEm± (5%)		2.09	69	132			4.42	
CD(p=0.05)	2.04				0.87	0.46		4.31

The most appropriate genotype, its duration and management were found to be Rashi 639 and Ankur 3028 due to their medium duration compared to long duration GK 202 *Bt* hybrid (Table3). Application of sub optimal P, K and sulphur containing fertilizers are key yield limiting factors despite of irrigation water in highly calcareous soils (Table 2) when soil application of Zn was ineffective with poor seed cotton yields and gave good results to foliar application of chelated micronutrients were achieved (Table 3). Fertilizer nutrient application was ranging from N 58-83 kg/ha; P_2O_5 40-93 kg/ha, K_2O 0-75 kg/ha total together N:P_2O_5:K_2O 98 -230 kg/ha produced yields similar to that of normal rainfed cotton despite of 2-3 irrigations clearly indicating a yield limiting factor of Zn, Mg, Fe, K deficiencies as hidden hunger lead to

Table 3. Genotype selection for rainfed calcareous soils

	Yield (q/ha)		Net returns (US $/ha)	Cost: benefit ratio	Boll/ plant	Fertilizer nutrients applied (kg/ha)				
	Seed cotton	Pigeon pea				N	P_2O_5	K_2O	**Total**	S
RCH-639	19	5	2900	3.3	80	73	60	95	**228**	17.5
Ankur 3028	16	2.5	2513	3	35	85	88	85	**255**	
Ankur 651	16	2.5	1969	2.6	25	108	43	18	**168**	42.5
GK 202	13	5	1881	2.7	55	113	70	70	**253**	
Hy-6	11	7.5	1963	2.7	40	103	80	95	**278**	17.5
Phule Dhanwantari	10	7.5	1956	3	25	73	60	20	**153**	17.5
GK 202	13	0	1294	2.3	35	58	50	25	**133**	17.5
CD(p=0.05)	2.8	2.5	472	0.3	18	20	15	33	**53**	14

Table 4. One protective irrigation in calcareous soils

Bt hybrids with OFTs 55:30:28=123 N:P_2O_5:K_2O (Kg/ha)			Pigeon pea yield (kg/ha)	Net returns	
Bt hybrids	Seed cotton yield (kg/ha)	Boll/ plant		US$	C:B
Ankur 3028	22	70	5	483	3.8
Ajit 111	19	60	5	450	3.6
Brahma	16	55	5	418	3.3
Hy-6	16	70	5	418	3.5
Hy-6	8.8	50	7.5	348	3
Phule dhanwantari	13	25	5	385	3.1
Phule dhanwantari	11	25	5	373	3
CD+(p=0.05)	4.3		0.8	223	0.3

Table 5. Two three supplemental irrigations in calcareous soils

	Bt hybrids			Pigeon pea yield (kg/ha)	Fertilizers applied (kg/ha)				Net returns economics	
	Irrigat-ions	Yield (kg/ha)	Boll/ plant		N	P_2O_5	K_2O	**TOTAL**	US $	C:B
Ankur 3028	3	16	55	4	78	93	0	**169**	903	3
	2	16	55	5	165	213	73	**448**	1028	3
	2	16	35	5	165	213	73	**448**	1028	3
Ajit-155	3	16	55	4	78	93	0	**170**	903	3
Kaveri ATM	3	16	55	4	78	93	0	**170**	903	3
Hy-6	3	16	50	3	58	40	0	**98**	810	3
Hy-8	2	16	55	6	115	40	75	**230**	983	3
Vithal GOLD [1]		16	35	5	83	65	65	**213**	915	3
Bhaskar drip[2]	4	22	55	8	120	115	63	**298**	1825	4
Ankur 3028 [3]	3	24	60	6	80	43	13	**135**	1468	4
Ankur 3028 [4]	6	25	120		120	60	60	**280**	1500	4
CD(p=0.05)		2	8	1	22	37	17	**71**	194	0

Note: 1. Deep black soil. 2. Red shallow soils 3 4. Calcareous soil: Nutrient corrections were made with soil and Foliar sprays of Mg SO_4, 19:19:19 and chelated micronutrients 5-6 times.

Table 6. Profitability of irrigated Calcareous silty loams in Sone gaon, Khiri, Village

Bt hybrids	Seed cotton yield (kg/ha)	Irrigations (Numbers)	Cost of cultivation (US $)	Net returns (US $)	Cost: benefit ratio	Fertilizer nutrients applied (kg/ha) N	P_2O_5	K_2O	**Total**	Sulphur
Ankur 3028	14	3	468	556	1:2.19	107	28	12	**146**	18
Ankur Suvarna	14	3	468	556	1:2.19	107	28	12	**146**	18
Ankur 4252	14	3	468	556	1:2.19	107	28	12	**146**	18
Wheat	25	5	421	498	1:2.18	140	65	65	**270**	18

Table 7. Profitability of irrigated silty loams with calcareous substrata in Linga series Linga, Village.

Bt hybrids	Seed cotton yield (kg/ha)	Pigeon pea yield (kg/ha)	Irrigations (Numbers)	Cost of cultivation (US $)	Net returns (US $)	Cost: benefit ratio	Fertilizer nutrients applied kg/ ha N	P_2O_5	K_2O	**Total**	Sulphur	Mg SO_4	Zn SO_4
Ankur3028	16	4	3	529	903	2.71	76	93	0	**169**	18	125	25
Ajit155	16	4	3	529	903	2.71	76	93	0	**169**	18	125	25
KaveriATM	16	4	3	529	903	2.71	76	93	0	**169**	18	125	25

Note : Nutrient corrections were made with 5-6 foliar sprays of Mg SO_4, Biozyme, WSF 19:19:19 and chelated micronutrients.

improve seed cotton yields by 6-8 q/ha by foliar correction by progressive farmers achieved to that of normal black and red soils(Table 5). Soil and foliar application of water soluble fertilizers, Zn, Mg improved 2 q/ha productivity even with sub optimal fertilizers with the same management clearly indicate the narrow genetic base of hybrids producing similar yields in calcareous soils (Table 6.7). Higly calcareous soils in *Kini* village Nagpur (2 ha farm) advance planted with Ankur 3028 under bed and furrow drip irrigation system at 1.2 x 0.4m fertilized with normal fertilizers produced 25-30 q/ha seed cotton yields.

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Commercial cultivation of ramie (*Boehmeria nivea* L. Gaud.) with special reference to integrated nutrient management

H.C. BAYAN*, ANWESHA ANANYA SHARMA AND R. K. GOSWAMI

Department of Agronomy, B.N. College of Agriculture, Assam Agricultural University, Biswanath Chariali, Assam - 784 176

**E-mail : hcbayan@gmail.com*

ABSTRACT : Ramie *(Boehmeria nivea* L. Gaud), is one of the oldest and valuable textile fibre crop native to China, Japan and the Malay Peninsula. It is commonly known as China grass/ white ramie and also referred as the best vegetable fiber crop, which can be harvested up to six times a year. The crop is also a native of north east India and one of the strongest natural fibre crops, but is yet to gain the status of a well established commercial crop globally. This can be accounted due to the absence of an assured market and non-availability of the necessary processing facilities for fibre extraction. The exhaustive nature of the crop is also a setback to its popularization but adoption of integrated nutrient management and Intercropping under crop production practices have proven to be resourceful in ramie cultivation. In a study on the integration of organic and inorganic nutrient management on fibre yield of ramie revealed that application of FYM @ 10 t/ha/yr along with 30:15:15 kg/ha/cutting of N, P_2O_5 and K_2O, respectively showed significantly higher yield over other treatments and there was an increase of 91 per cent fibre yield over control (unpublished data). Integration of chemical fertilizers along with organics exhibited better results with regard to fibre yield and higher benefit cost ratio (Patra and Sinha, 2012).

Apart from producing of the fibre, this crop has manifold importance as food and fodder along with medicinal and antioxidant properties. Cultivation of this crop can be helpful in improving economic status of the farmers as well as improvement of soil fertility through addition of ramie biomass. Introduction of scientific cultivation of ramie with integrated nutrient management and subsequently organized cultivation helps to generate income as well as employment and ultimately lead to sustainable development of agriculture.

Ramie *(Boehmeria nivea* L. Gaud), the hardy perennial tropical shrub is known for its strongest, longest and the oldest natural vegetable fiber. It is one of the oldest and valuable textile fibre crop which was exported from east Asia to the western Hemisphere (Liu *et al.,* 2001, 2003). Ramie is native to China, Japan and the Malay Peninsula. The genus *Boehmeria* consisting 75 species of herbs, shrubs or small trees belongs to the nettle family *Urticaceae* and is distributed in tropical and northern sub-tropical areas. Ramie is one of the ten species of the genus *Boehmeria* native to India. Of these, *Boehmeria nivea* commonly known as China grass/ white ramie (also known as *Riha* and *Kunkhura* in Assamese and Bengali, respectively), is referred to as the best vegetable fiber crop, which can be harvested up to six times a year. It produces a large number of unbranched stems from underground rhizomes and has a crop life of 6 to 20 years. The shrub is 1.5 to 2.5 m in height and diameter of 12 to 20 mm depending on the growth conditions. The leaves are heart shaped about 5.0 to 12.7 cm wide and 10.0 to 15.0 cm long with finely serrated edges. It is recognized for its valuable bast fiber, which is obtained from the bark (Phloem) of the plant. The bark contains gum and pectin causing the fiber to be usable only after chemical treatment.

Ramie fiber has been in use since ancient times. In Sanskrit literature, it is mentioned as Grass Linen (Kalidasa's Shakuntalam). The oldest available reference is found in the Chinese classics. The Book of Odds dating 600 B.C., and the cloth found on some of the Egyptian mummies (6500 B.C. – 5000 B.C.) are known to have been made of ramie fiber. It has been grown in China for many centuries. The main producers of ramie today are China, Brazil, Philippines, India, South Korea and Thailand (Liu *et al.*, 2005) and Pacific Rim countries (Hester and Yuen, 1989, Liu *et al.*, 2001, 2003). Only a small percentage of the ramie produced is available in the international market. Japan, Germany, France and the United Kingdom are the main importers; the remaining supply is used domestically in the country in which it is produced.

Ramie is considered to be originated in China, where most of the wild species are also observed (Vavilov, 1951). In India, some species of ramie have also been reported from western Ghats, northern parts of west Bengal and Uttarankhand. In north east India, it is distributed in Assam, Arunachal Pradesh, Meghalaya, Manipur and Sikkim. About 19 species of ramie have been reported so far from India, most of which are distributed in North Eastern India. The plant was discovered by the Dutch botanist, George Eberfard Rumpf in 1690 in the East Indies who gave the name *Romium Majus*. It was taken to Holland in 1844, where successful extraction of good fiber was accomplished in 1845. However, the first commercial production was reported only in 1930. Presently ramie plays an important role in Chinese economy by covering more than 90 per cent of world's ramie cultivation area (Wang *et al.*, 2007) with an annual fibre production of 1, 14,080 tonnes in 2010 (FAOSTAT; http:// faostat.fao.org)

In India, the most suitable areas for ramie plantation are the districts of Jalpaiguri, Cooch Behar, Siliguri sub division in west Bengal, high lands of all the districts of Brahmaputra valley in Assam. Moreover, in Meghalaya, Arunachal Pradesh, Nagaland, Tripura and Manipur, both cultivated and wild ramie is found.

The plant has two distinct varieties- *nivea* proper (Riha) and *B. nivea tenacissima*. The former is characterized by leaves that are green above and whitish beneath. This is commonly known as 'China Grass' or 'White ramie' and is cultivated in China. It has large heart shaped, crenate leaves covered on the underside with white hair that gives it a silvery appearance. *B. nivea* var. *tenacissima* also known as 'Green Ramie' is believed to have originated in the Malay Peninsula. It has smaller leaves which are green on the underside, and is better suited to tropical climates. The variety *nivea* belongs to somewhat cooler climates than the others.

It is a semi perennial crop, which is propagated through rhizomes and modified stalk cuttings (Plantlets) for its commercial production. In a plantation it can effectively survive for six to eight years after which the growth declines and replantation becomes necessary. The ramie shoot consists of several long and short aerial stems each of which is termed as ‘cane’ and canes together are known as ‘clump’. The ‘clump’ often denotes the whole plant system.

The ramie plant has a special feature in having underground stems known as ‘rhizome’. They are pale brown in color and are often mistaken as roots. They run close below the ground level and produce buds which develop into an aerial shoot system. Thus the ramie plant can perennate by rhizome. Pieces of rhizome are used as planting material instead of true seed for raising a plantation. Ramie produces true seeds which are tiny and black. True seed of ramie germinates on moist media and can be used for raising seedlings.

Ramie fiber is very durable, pure white in color and has a silky luster. It is reported to have a tensile strength eight times than that of cotton and seven times greater than silk. Ramie is one of the strongest natural fibres. It exhibits even greater strength when wet. Ramie fibre is known especially for its ability to hold shape, reduce wrinkling and introduce a silky luster to the fabric appearance, is usually used as a blend with other fibres such as cotton, wool but will not dye as cotton. It is similar to linen in absorbency, density and microscopic appearance. Because of its high molecular crystallinity, ramie is stiff and brittle and breaks easily if folded repeatedly in the same place; it lacks resiliency and is low in elasticity and elongation potential.

Ecological requirement : The most suitable climate for ramie is the one which is warm and humid with an annual rainfall of at least 1000 mm. Well established plants can tolerate drought and frost. A temperature range

Fig. 1. White Ramie

Fig. 2. Green Ramie

from 25^{0}C to 31^{0}C during summer and rainy season and optimum relative humidity is 80 per cent with annual rainfall of 1500 to 3000 mm evenly distributed throughout the year is favorable for the growth of the crop. Extreme cold and extreme hot with low humidity are not suitable for ramie cultivation. Medium shade and moist condition are more favorable for ramie.

Well drained sandy loam or loamy soil having a P^H value of 5.5 – 6.0 with rich in organic matter content is ideal for ramie cultivation. Preferably flat and sloppy land is good for ramie planting.

IMPROVED PRODUCTION TECHNOLOGY :

Planting time: Ramie can be planted throughout the year except heavy rains and low temperature (less than 4^{0}C). Most suitable time for planting in north eastern states is February-March and September –October.

Varieties: Research on varietal development of ramie has been being carried out at Regional Ramie Research Station (ICAR), Sorbhog Assam and to a limited scale at Assam Agricultural University. The recommended varieties as per package of practice for commercial ramie cultivation are, R 1411, R 1449, R 1452 and R 67-34 (Kanai). Other improved selection and genotypes are, R 1414, R 1415, R 1416, R 1418 and R 52.

Land preparation: Ramie does not require fine seed bed preparation. For uniform and better growth of the plants, the field is to be prepared to a good tilth by deep ploughing and 2-3 harrowing followed by two ploughing through cultivator and laddering.

Planting material and planting technique: Ramie usually propagates through cuttings from underground stems (rhizomes) and grows best in well drained, sandy soil and in warm, moist climates. Depending on the quality of rhizome, 375 – 400 kg /ha freshly uprooted rhizome will be required. Rhizomes removed separately and cut into pieces of 10 to 15 cm in length and are planted in field immediately. Rhizome should be treated with 2 per cent Bavistin solution or any other suitable fungicides.

Ramie can be propagated through seed by transplanting of two month old seedlings produced in the seed nursery. About 250-300 g ramie seed is enough for raising the nursery of one hectare of land.

Mature plantlets (tillers) , waste stalk and stem cuttings (0.60 – 0.65 lakh pieces) of less than 1.0 m length along with 2-5 cm underground stem piece from the more than one year old crop were found the best alternative planting material for the multiplication and propagation of ramie crop.

Planting material (rhizomes, plantlets etc.) should be planted with row to row and plant to plant distance of 60 x 30 cm. Furrows are opened up with 5 to 6 cm depth so that it must be ascertained that planting material are fully covered under soil.

Ramie can be planted by seeds, stem cutting and short stalks besides rhizomes. Propagation by seeds has some difficulties like setting of seed, low viability of seeds etc for which it has not become popular among ramie cultivators. In a study conducted on different planting materials

Fig. 3. Rhizome of Ramie

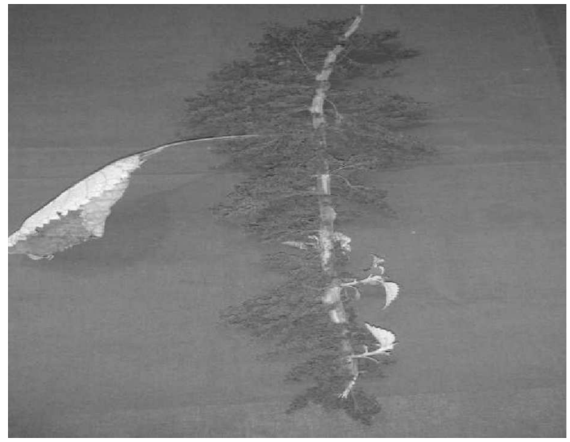

Fig. 4. Seeds of Ramie (Inflorescence)

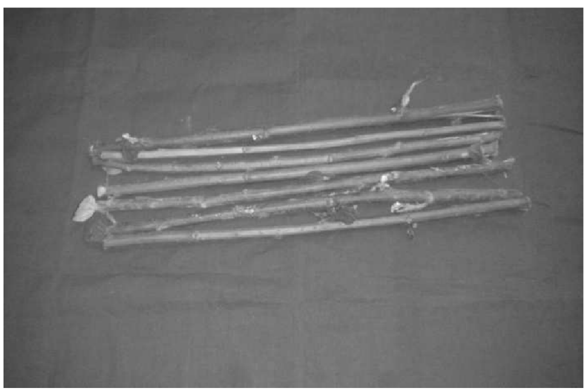

Fig. 5. Stem Cuttings

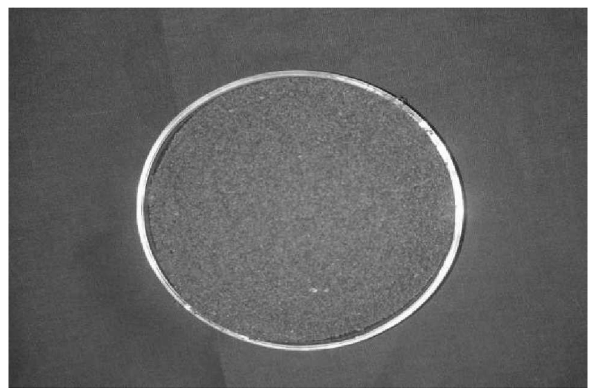

Fig. 6. Seeds of ramie

, stem cuttings of different sizes (20 to 100 cm long) were treated with cowdung slurry / IBA etc and were planted vertically (at 45^o angle) and also horizontally in shallow trenches. Short matured stalks of about 25 -30 cm long with some roots at the base which are not suitable for fibre extraction were planted in nursery beds and all these were compared with the standard method of planting with ramie rhizomes. The study revealed that establishment from stem cuttings was low and was around 30 per cent. Establishment from planting of short stalks was found to be very good results and recorded 91 – 100 per cent establishment, while rhizome planting recorded 85 – 92 per cent germination (Guha *et al.,* 2017). The results also showed that short matured stalk of ramie is a suitable alternate planting material for ramie.

Rhizomes can be obtained after 3 – 5 years after planting while short stalks becomes available at each cutting of ramie crop even from 1st year. To get rhizomes the whole ramie plants are to be uprooted and new planting is to be done to get fibre while in short stalk planting normal cutting for fibre can be continued. In short stalk planning much labour is not required as in case of rhizome planting. Short stalks in polybags can be kept for 1 – 1 ½ month for future planting. In short stalk planting normal fibre yield can be obtained from first year of planting.

Higher fibre yield and net income of ramie are observed under ridge bed planting when supplied with (150%) NPK through chemical fertilizer, which was on par with that of (50%) N with (100%) PK from chemical fertilizers + (50%) N through ramie waste (Maity *et al.,* 2007).

Nutrient management: Ramie is a heavy feeder and requires higher nutrition and water (Kumar *et al*, 2016). At the time of field preparation, 10-12 t/ ha / year well decomposed cow dung or 20 t/ ha / year compost should be applied in the field. Application of 35:15:15 kg/ ha of N: P_2O_5 : K_2O, after two months of planting is recommended for sole ramie cultivation. Ramie Research Station, ICAR, Sorbhog (2014) reported that application of fertilizer @ 40 kg/ ha of N, 20kg/ha P_2O_5 and 20 kg/ha of K_2O per cutting yielded the best result under intercropping in initial two years of plantation. Afterwards, the application of N-35: P_2O_5-15: K_2O-15 kg/ha/cutting results in higher fiber yield. As the biomass yield of ramie is very high it can rapidly deplete the soil nutrients. Application of manure (water hyacinth / farm yard manure/ leaf manure/ green manure) etc., therefore, may be suggested for soil application for maintaining soil health.

Integrated nutrient management (INM): Research studies have shown the importance and utility of compost, biomass addition, crop residue management and useful green manure systems in building the soil organic status. Studies have shown that organic manuring systems often perform better than continuous low input systems or natural fallow system in terms of total production and net economic returns. In addition, crop performance is often superior when there is an integration of organic nutrients with soil conservation (Shapiro and Sanders 2002; Gebremedhin and Swinton 2002) with improved water management (Bationo *et al.,* 1998) or with mineral fertilizers. Thus, organic matter should be returned to the land for mulching and improving soil physical, chemical properties besides as a source of recycled nutrients into the soil system.

Ramie is a heavy feeder of nutrients, hence should be fertilized optimally to get better yield. Ramie being a semi-perennial crop and 4-5 cuts are taken/year; the nutrient uptake by the crop varies between years as well as with cuttings within a year. The trials conducted under TMJ MM 1.3 at RARS, Nagaon, Assam and also under AINPJAF at Barrackpore revealed that fibre yield of ramie was significantly higher with 150 per cent of the recommended fertilizer dose (N: P_2O_5: K_2O – 30:15:15, kg/ha/cut) both when the nutrients were added through sole chemical fertilizer or through INM treatments where 25-50 per cent chemical N was supplemented through different organic sources. Maximum NPK uptake was reported by Saha *et al.,* (2006). INM trials under TMJ-MM 1.3 programme at Nagaon, Assam revealed that maximum uptake was observed at second cutting (Fig 7). The total uptake of N, P and K by ramie cultivars R 67-34 (Kanai) and R 1411 (Hazarika) was found to be maximum with 150 per cent recommended dose of N (RDN), 50 per cent of which was substituted with ramie compost followed by (150%) RDN (Fig. 7). Similar trend was also observed at different cuttings (CRIJAF, 2009). Mitra *et al.*, (2009) reported augmentation of soil microbial activity and increase in microbial population along with enzyme activity in ramie soil in Sorbhog, Assam and Barrackpore, west Bengal as a result of integration of fertilizer nitrogen with organic sources (ramie compost). Appreciable fibre yield (annual) was also observed in crops receiving INM treatments.

Maximum fibre yield of ramie cultivars R 67-34 (Kanai) and R 1411 (Hazarika) was observed at Nagaon, Assam when (150%) recommended dose of N (RDN) was applied to the crop, 50% of which was substituted with ramie compost followed by 150% RDN from chemical source alone (Fig. 7)

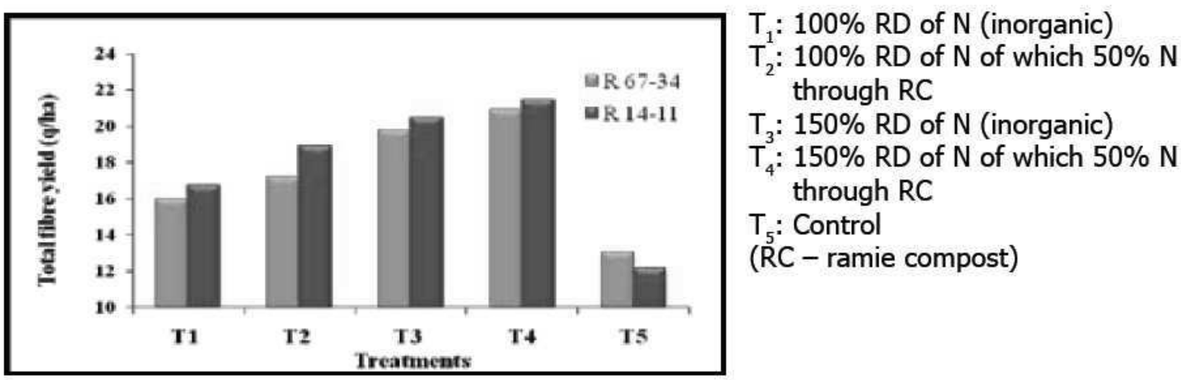

Fig. 7. Effect of INM treatment on fibre yield

Fibre yield showed similar trend at different cuts also (Fig. 8a and 8b). Among the cuts, both varieties recorded highest yield in 2nd cutting after which the yield showed a declining trend (TMJ, 2009).

The yield and agronomic characters of ramie are affected by several cultural and management practices which include

Cost of Cultivation of ramie (Under North Eastern Region):

Sl. No.	Operation/input	New techniques	
		1st Year (Cost/ha in Rs)	2nd Year on wards (Cost/ha in Rs)
1	Land preparation	4000.00	0.00
2	Planting material	6050.00	0.00
3	Planting cost	2000.00	0.00
4	Fertilizer and chemicals	6000.00	12000.00
5	Weed management	2000.00 (Herbicide spray)	4000.00
6	Stagging/ harvest	9000.00 (3 cuttings)	18000.00 (6 cuttings)
7	Irrigation	1000.00 (1 irrigation)	2000.00 (2 irrigations)
8	Labour cost in decortication (2000/cutting)	6000.00 (3 cuttings)	12000.00 (6 cuttings)
9	Decortication charges (fuel), 400/cutting	1200.00 (3 cuttings)	2400.00 (6 cuttings)
	Total Input Cost (Rs.)	**37250.00**	**50400.00**
	Return/ Output (Rs)	**42000.00 (7 q yield)**	**1,08,000.00(18q yield)**

Source: Ramie Research Station (Under CRIJAF), ICAR, 2014

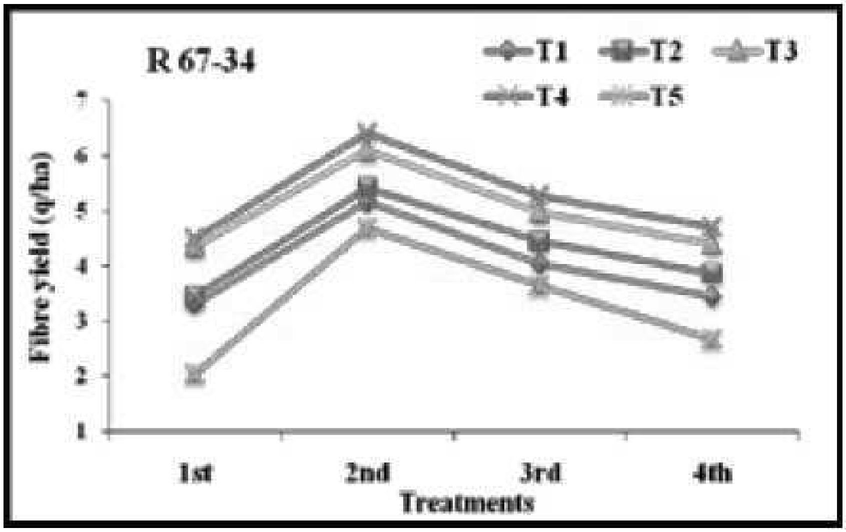

Fig. 8a. Fibre yield at different cuts

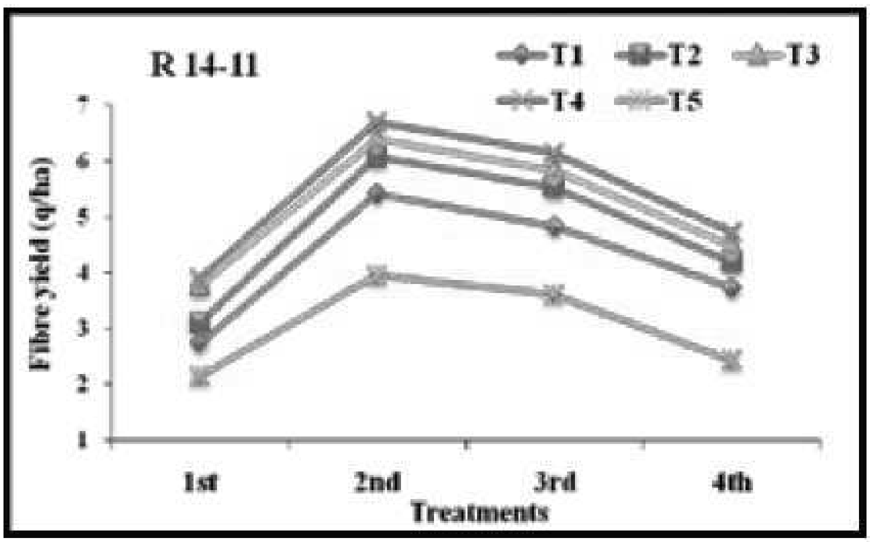

Fig. 8b. Fibre yield at different cuts

fertilization and plant density. Because of the wide soil variation and other growing conditions, a hard and fast rule for ramie fertilization cannot be established as yet. Indiscriminate and continuous use of high level of chemical fertilizers often leads to nutritional imbalance particularly for the micronutrients. Integrated use of chemical fertilizers and organic resources like ramie waste, FYM and glyricidia therefore, has a greater significance for cultivation of ramie.

Menon *et al.*, (1990) and Sajwan (1995) reported that under adequate supply of nutrients, the availability of plant nutrient during growth period increased under combined application of organic manure and chemical fertilizer as compared to chemical fertilizer alone. Higher values of all the growth and yield parameters ultimately help in producing highest fibre yield (2.14 t ha-1) corresponding to T5 (125%) nitrogen through chemical fertilizer+25 per cent nitrogen through ramie waste) followed by T6 and T4. The probable reason might be due to the maximum uptake and availability of primary nutrients. T5 produced 4.17 and 3.79 per cent, 8.33 and 8.06 per cent and 27.78 and 30.33 per cent more fibre yield than T6 (150% N through chemical fertilizer), T4 (100% N through chemical fertilizer + 50 per cent N through ramie waste) and T9 (control) during 2007 and 2008, respectively. Among the different sources of organic nitrogen, ramie waste was found better followed by glyricidia and FYM. Patra and Sinha (2012) also reported that all the growth and yield attributes were found to be highest under application of (125%) N through chemical fertilizer + 25 per cent nitrogen through ramie waste which ultimately helped in producing highest fibre yield (2.14 t/ha) with highest benefit: Cost ratio (1.69).

A specific study initiated at B.N. College of Agriculture, Biswanath Chariali to evaluate the effectiveness of Integrated Nutrient Management (INM) practices comprising three organic manures *viz.,* Farm Yard Manure, Green Leaf Manure and Vermicompost each with different dose of inorganic nitrogenous fertilizers on growth and fibre yield of ramie and revealed that, from the pooled data of six cuttings in first year (during 2016-2017), application of FYM @ 10 t/ha/yr along with 30:15:15 kg/ha/cutting of N, P_2O_5 and K_2O, respectively recorded highest fibre yield and significantly superior over other treatments and there was a increase of 91 per cent higher fibre yield over control (unpublished data).

Weed management: Weed management of ramie field is an important and critical operation as the crop is of perennial habit. Application of any pre plant herbicide or 2 to 3 manual weeding make the ramie field weed free. Targa super (Quizalofop-ethyl 5% EC) @ 2.5 -3.0 ml/l water is recommended for control of grassy weeds. Depending upon the nature of weeds, application of Paraquat or Glyphosate (@ 0.125 – 0.250%) before land preparation for ramie planting and within 1 – 2 days after each cut of ramie (*i.e.* before start of ramie emergence) can be practised for proper weed management.

Water management: Continuous moist conditions are to be maintained in the initial 15 days and thereafter irrigation may be applied as per the water requirement of the plant. Excess moisture or water logging condition is not favorable for ramie crop. Water logging more than 24 hours causes damage to the crop. To avoid excess moisture field should be well drained.

Mitra *et al.,* (2014) reported that application of irrigation to ramie based on IW/CPE ratio of 0.6 and substitution of 50 per cent of recommended fertilizer nitrogen (15 kg/ha/cut) through integration of ramie compost in the fertilizer schedule of the crop showed better growth and fibre yield of ramie, increased the water use efficiency and economized the requirement of inorganic nitrogen by the crop and can be adopted for commercial cultivation of ramie in south Bengal condition.

Plant protection in ramie: Ramie crop suffers from attack by various insect pests and diseases. The major insect pests in ramie are Indian red admiral caterpillar, leaf folder/ leaf roller, lady bird beetle, hairy caterpillar, leaf beetle, termite, black fungus beetle etc. These can be effectively controlled by application of Chloropyriphos (0.4%).

Most common diseases of ramie are Cercospora leaf spot, Anthracnose leaf spot, Collar rot, Curvularia leaf blight, Wilt, Damping off of seedling, Yellow Mosaic etc. which can be controlled by fungicides *viz.,* Mancozeb @ 2.5 ml/ lit or Propiconazole @ 1 ml/l of water.

Intercropping: Introduction of tree crop / forest trees + ramie based cropping system will be helpful in improving economic status of the farmers as well as soil fertility and sustainability of agriculture. In India, ramie has the potential to take additional advantage of sunlight and extract nutrients and moisture from different depths in the soil profile efficiently in a combined canopy planted with coconut, arecanut and pineapple, rubber and forest trees in the tribal areas. Research showed that intercropping with coconut, arecanut, rubber; tea, pineapple etc. provide good results. It will further increase the profit of the farmer and also increase land use value (Mitra *et al.,* 2013) Intercropping with pea, wheat, sesamum, lentil, black gram, moong bean and mustard has also been reported remunerative for the farmers. A multitier cropping system with Areca nut, black pepper and ramie was found profitable cropping system in RRS, Sorbhog, Assam. Waste/ degraded and sloppy land can also be utilized for successful cultivation of ramie.

Fig 9. Intercropping: Ramie + Areca nut

Harvesting: The growth of ramie following the first planting is always uneven, branched and not suitable for fiber extraction. The growth during winter is also similar.

However, with the advent of next summer, the crop should be staged back or cutback at 1-2 cm above ground level, which encourages uniformity and rapid development of new canes in the crop. The harvest of crop for fiber purpose starts only after stage back.

The ramie stem becomes mature in 10 months and changes color from green to brown. For obtaining fine, soft fiber, shoots must be cut before they mature and begin to flower. Ramie is normally harvested 2-3 times/year but under good management conditions can be harvested up to 6 times/year. Harvesting is done just before or soon after the onset of flowering, since there is a decline in plant growth at this stage and maximum fiber content is achieved. Stems are harvested by cutting just above the lateral roots or the stem can be bent, to enable the core to be broken and the cortex can be stripped from the plant *in situ*. Mechanical harvesters have been developed but not used commercially till now. After harvesting, the fresh stems are decorticated. It becomes difficult to remove the bark, ones the plant dries out. The bark ribbons are dried as quickly as possible to prevent attack by bacteria or fungi. The fiber can be removed from cane (ramie stem) by using bast fiber decorticator. After decortications the fiber obtained is washed with clean water and hanged for sun drying.

Fig. 10. Harvesting

Extracted fibre retains some gum and it can market as such. The gum is removed by consumers by using various techniques including boiling with alkali and tripolyphosphate buffer. The extraction of fibre occurs in three stages, *viz.*, first the cortex or

Fig. 11. Decortication of Ramie

Fig. 12. Decorticated Ramie Fibre

bark is removed by hand or machine (decortications), second the cortex is scrapped to remove most of the outer bark, the parenchyma in the bast layer, gums and pectins. Finally, the residual cortex material is washed, dried and de gummed to extract the spinnable fibre.

Yield: The dry weight of harvested stem from both tropical and temperate crops ranges from about 3.4 to 4.5 t / ha / year. A 4.5 t of harvested crop yields about 1600 kg of dry raw fiber. The weight loss during de gumming can be up to 25 per cent, giving a yield of degummed fiber of about 1200 kg/ha/year. RRS, Sorbhog reported that on an average annual yield of raw fiber may vary from 1500 kg to 1800 kg/ha depending on various environmental and management factors under rainfed condition. However, under irrigated condition, 3000 – 3500 kg/ha dry raw fiber can be produced.

Physiological efficiency and abiotic stress tolerance of ramie in relation to productivity : Ramie is a physiologically efficient crop. Among the physiological parameters, leaf area index (LAI), rate of Photosynthesis, biomass production and its distribution can be regarded as the most important parameters contributing towards higher yield. These parameters can also be considered as physiological indices for higher productivity of ramie (Qingquan, 2006).

In general, LAI of ramie increase progressively upto the third cutting and declined thereafter. The varieties having higher LAI exhibit higher yield (Mitra *et al.,* 2014).

Unique characteristics of ramie fibre: Ramie is one of the strongest natural fibres. It exhibits even greater strength when wet. Ramie fibre is known especially for its ability to hold shape, reduce wrinkling and introduce a silky lustre to the fabric appearance, is usually used as a blend with other fibres such as cotton, wool but will not dye as cotton. It is similar to linen in absorbency, density and microscopic appearance. Because of its high molecular crystallinity, ramie is stiff and brittle and breaks easily if folded repeatedly in the same place; it lacks resiliency and is low in elasticity and elongation potential (Goswami, 2017).

Problems related to extension of ramie cultivation : A viable and profitable ramie plantation requires large investment and more land holding (>40ha). Small holdings are regarded unfit for commercial cultivation of ramie. Special textile machinery for scientific extraction of ramie fibre is not easily available. Organized, scientific and commercial ramie cultivation is limited in our country. Lack of awareness on profitability and cultivation practices of ramie among the farmers can be regarded as one of the important reasons related to poor extension of ramie area. Liu *et al.,* 2012 reported that being a semi-perennial crop, ramie occupies land for a minimum of 5 years. Non availability of improved planting materials, poor growth of ramie based industries and lack of minimum support price and organized marketing are also regarded important causes for poor extension of ramie cultivation and its popularization.

In north eastern states, this strongest natural fibre crop is yet to gain the status of a well established commercial crop due to the absence of an assured market and non-availability of the necessary processing facilities for fibre extraction. Domestic level processing unit for fibre extraction should be a priority in the rural sector, imparting trainings for upcoming entrepreneurs for establishment of small scale processing units is essential for making available of a local market for decorticated ramie fibre. Efficient marketing of ramie fibre is a possibility through formation of farmer's cooperative in the rural areas, contract farming etc. There should be proper marketing linkage between the industry and ramie farmers. Ramie can be promoted in the way of 'Contract Farming' with buy back guarantee to the farmers. Linkage has to be established amongst State Agricultural Universities, State department of Agriculture, Department of Industries and NGO's for establishment of processing plants and development of an assured market for ramie.

Some of the problems related to the ramie cultivation in India;

1) Lack of proper technical knowhow for cultivating ramie among the farmers and research developments and the proper management techniques should be made available to the farmers.
2) Non availability of sufficient number of cheap, efficient and easily portable decortications machines for the extraction of ramie fibre.
3) Proper degumming of ramie fibre, non availability of cheap and easy method of degumming of fibre.
4) Lack of assured market for fibre. The formation of a central agency which can provide proper coordination between-the

Table 1. Physical and chemical properties of ramie fibre

Cellulose (%)	Lignin (%)	Hemicellulose (%)	Pectin (%)	Wax (%)	Microfibrillar angle (°)	Moisture content (%)	Density (g/cm^3)
68.6 - 76.2	0.6 - 0.7	13.1 - 16.7	1.9	0.3	7.5	8.0	1.50

Table 2. Mechanical properties of untreated ramie fibres

Fibre diameter (mm)	Fracture load (N)	Tensile strength (MPa)	Fracture strain (%)
0.034	0.467	560	0.025

Table 3. Comparison of chemical constituents and properties between jute and ramie fibre

Properties	Jute fibre	Ramie fibre
Cellulose (%)	60-63	73-74
Hemicellulose (%)	21-23	13-15
Lignin (%)	12-13	0.6-1.5
Pectin (%)	0.2-1.5	4.0-5.5
Length (mm)	0.6-6.5	80-120
Strength (cN/Tex)	18-35	25-65
Density (g/cc)	1.5	1.2

producers and consumers may help future expansion of its cultivation in India to a great extent.

5) Imposition of heavy excise duty on the fibre etc.

Popularization of ramie in north east India for safe, peaceful and beautiful future world: Enhancing the soil organic matter pool in agricultural soils can be considered as one of the most significant sinks for atmospheric carbon since it plays a crucial role in mitigating agricultural green house gas emission (Russell *et al.*, 2005). In this context, ramie may represent an interesting environment friendly non food crop for NE India, due to its perennial or semi perennial cycle and its noticeable agronomic benefits in terms of maintaining soil health. Ramie produces huge amount of leaves having high nutrient content and can be used as a potential source of antioxidants and food supplements (Singh, 1986). Ramie leaves and roots possess medicinal values. Considering several such aspects, ramie can be regarded as a good potential to be grown as a dual purpose crop, both as fibre crop and medicinal crop in the north eastern states of India.

The importance of ramie fibre is increasing gradually in the various textile industries due to its good durability, high tenacity, good lustre and long staple length. Considering the edapho climatic requirement of ramie, the districts of Jalpaiguri, Coochbehar of west Bengal and the Kamrup, Barpeta, Goalpara, Darrang, Karbi Anglong, Lakhimpur and Sibsagar districts of Assam may be regarded as possible places for ramie cultivation. Because of the perennial nature of the crop which involves regular maintenance and huge initial investment, small farmers under private sector may not like to go for commercial cultivation of ramie. It is therefore, suggested that surplus land in tea gardens and other Govt. land available in Assam, North Bengal and in the various districts of north eastern regions may be utilised for developing ramie in India.

Ramie plantation has another socio-economic aspect as well. In a country like India where there is an acute problem of employment, extension of ramie cultivation will generate employment opportunities to the rural poor since the crop is labour intensive. The full value of ramie plant becomes more evident when it is found that the leaves can also be used as a source of highly nutritive green food for cattle. The leaves are rich in protein, mineral and carotene and are also palatable. In this way ramie growers can derive extra benefit from the luxuriant foliage of this crop. Ramie also fits well within the concept of village industry where the ingenuity can be marred with the local resources. The *Khadi* and village Industries therefore, may be able to find out more outlets for the utilisation of ramie fibre in village textile industries and thereby help the Poor masses by producing at least a low cost durable fabric for them.

It is really unfortunate that despite good potentiality of growth, development and utilization of ramie in our country, virtually no serious efforts have so far been made for the proper development of this one of the most useful crops of our country.

CONCLUSION

Enhancing the soil organic matter pool in agricultural soils can be considered as one of the most significant sinks for atmospheric carbon since it plays a crucial role in mitigating agricultural green house gas emission. In this context, ramie may represent an interesting environment friendly non food crop for NE India, due to its perennial cycle and its noticeable agronomic benefits in terms of maintaining soil health. Ramie produces huge amount of leaves having high nutrient content and can be used as a potential source of antioxidants and food supplements. Ramie leaves and roots possess medicinal values. Therefore, ramie can be regarded as a good potential to be grown as a dual purpose crop, both as fibre crop and medicinal crop in the north eastern states of India. In India, the ramie production is scanty but the growing concern for environment protection has led to renewed interest in promotion of ramie cultivation beyond the traditional north eastern states. Introduction of scientific cultivation of ramie with integrated nutrient management and subsequently organized cultivation helps to generate income as well as employment and ultimately lead to sustainable development of agriculture.

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Integrated management approaches for improving non *Bt* and *Bt* cotton productivity through high density planting system under rainfed condition of Vidarbha

A.N.PASLAWAR*, T.H.RATHOD , V.M.BHALE , G.J.BHAGAT P.W.NEMADE AND A.S.DEOTALU

Cotton Research Unit, Dr Punjab Rao Deshmukh Krishi Vidyapeeth, Akola - 444 104

**E-mail : adinathpaslawar@rediffmail.com*

ABSTRACT : The adoption of high density planting along with better genotype with good fertilizer management and boll worm management is one of the option under rainfed to break the current trend of stagnating yield of *Bt* cotton and related problems under *rainfed* ecosystem of Vidarbha region of Maharashtra. The field trials were conducted for development of agro techniques for high density planting system under TMC 1.4 project at Dr PDKV Akola under medium depth soils during 2013-2014 to 2015-2016. The genotypes, plant geometry, integrated management practices for moisture conservation, nutrient and weed management and insecticides for bollworm complex for high density planting of cotton were tested. The soil was clayey and having organic carbon 4.70 g/kg, pH 8.9, EC 0.30/dSm, available N, P and K 225, 14.4 and 342 kg/ha, respectively. The rainfall of the seasons were 908, 593 and 645 during 2013, 2014 and 2015.Dryspell at boll developing stage reduced SCY during 2014 and 2015.

The genotypes AKH 081 , Suraj and NH 615 were found suitable for high density planting at 60 x 10 cm under medium depth soils and sowing of high density planting at 1.66 lakh/ha (60 x10cm) on broad bed furrow (BBF) with (125%) RDF(75:37.5: 37.5 NPK+ 2.5 Zn Kg/ha) and foliar spray of (1%) urea and (1%) magnesium sulphate at boll development stage was found to get higher seed cotton yield, economic returns and conservation of moisture. Pre emergence application of Pendimethaline 38.7 CS PE @ 1.25 kg a.i./ ha (3.3 l in 700 l water) *fb* hoeing at 30 DAS and one hand weeding was seems to be best option to reduce the early weed competition and for effective management of bollworm complex, Flubendamide 480 SC @ 40ml /ac followed by Chlorantraniliprole 18.5 SC @ 60 ml/ac was found better insecticides under HDPS cotton. Similar study was undertaken for BGI cotton and results indicated that productivity was gone up to 2450 to 3750 kg /ha with *Bt* variety under rainfed.

Front line demonstrations on HDPS cotton improved seed cotton yield by 10.5 per cent over farmers practice in Akola District .

A system of high density planting (HDP) leading to more rapid canopy closure and decreased soil water evaporation . In many countries narrow row planting have been adopted after showing improvement in cotton productivity. The adoption of high density planting along with better genotype with good fertilizer, early weed and boll worm management is one of the option under rainfed to break the current trend of stagnating yield of cotton around 568 lint kg/ha in India and 328 lint kg/ha in Vidarbha region of Maharashtra.

In Vidarbha cotton crop is cultivated under rainfed conditions mostly by marginal and small farmers. Socio economic status of the farmers, small land holdings, mono cropping over years, aberrant weather conditions, imbalanced fertilization, non adoption of optimum plant population, indiscriminate use of insecticides and mounting pest and disease complex are the major constraints in cotton cultivation in general. The shallow and medium soils under rainfed conditions which occupied major cotton area after introduction of *Bt* are unable to sustain the crop for longer duration and the full potentiality of these *Bt* hybrids is not being harnessed. Further, the farmers forced to invest the sizable amount of money on purchase of *Bt* cotton seed every year. Even though, significant improvement is seen in seed cotton yield, the cost of cultivation of *Bt* cotton increased tremendously and the major share is taken away by picking of *kapas*, fertilizers and control of sucking pests.

In the Vidarbha region of Maharashtra, 50 per cent of cotton is being cultivated in marginal soils under rainfed conditions. Under these circumstance, high density planting system with suitable varieties associated with management aspects is a viable alternate approach for improving cotton production. The manipulation of plant density and crop geometry is a time tested agronomic technique for achieving high crop yield. High density planting system is highly technical system and practicing the system needs careful planning, rigorous and timely monitoring of agronomic and plant protection measures, précised implements for weed control, use of growth regulators etc. .

The HDPS system comprises of compact short stature, short duration varieties planted in row ranging from 45 to 90cm with10cm spacing between plants in a row, accommodating 1.1 to 2.2 lakh plants/ha. The system is ideally suited for machine harvest . Since, there is synchronous boll maturation picking is done only once. Such varieties in high density produce few bolls (8-10/plant) over a 60 day reproductive phase with a narrow window of 30-40 days vulnerability for bollworm attack. In many countries, the sowing window is adjusted in a manner that the crop escapes bollworms. .Integrated nutrient management with (125%) RDF + Zn and foliar spray of nutrients at flowering and boll development is needed as the population increased/ha but boll load per plant is less (Venugopalan *et al.,* 2013)

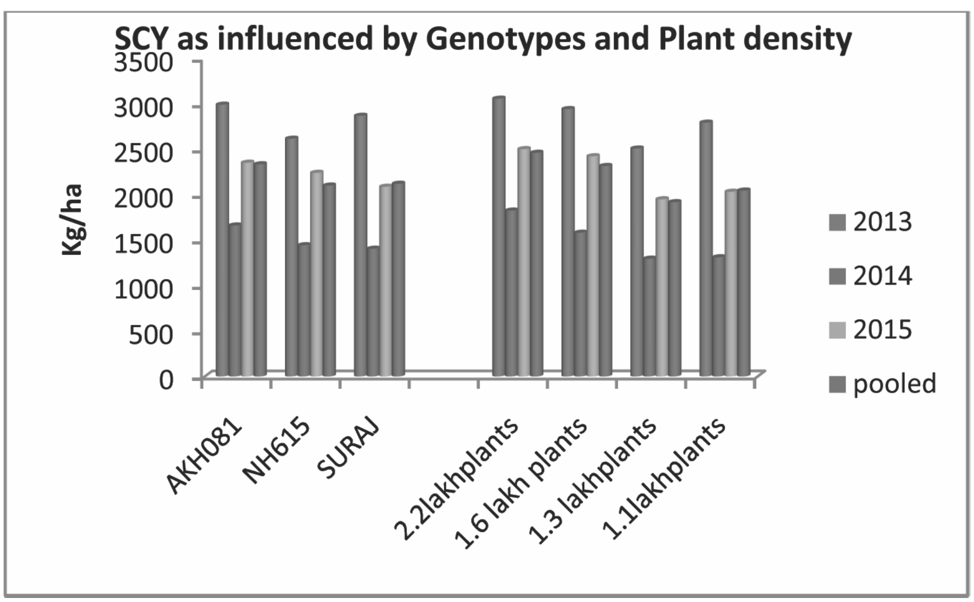
MATERIALS AND METHODS

Experiments were carried out with presently available semi compact genotypes for HDPS with different plant geometry and integrated nutrient with moisture conservation practices and integrated weed management for sustainable production of cotton under rainfed condition during 2013-2016 at AICRP On cotton, Dr PDKV Akola under TMC 1.4 .The soil was medium deep clayey and having organic carbon 4.20 g/kg, pH 7.9, EC 0.30/dSm, available N, P and K 180, 14.4 and 401 kg/ha respectively. The rainfall of the three season were 908 ,593 and 645 mm and rainy days 49,29 and 28 respectively. Dr PDKV cotton variety AKH 081 is dwarf, tolerant to sucking pest and early maturing (140-160 days) is suitable for high density planting under rainfed condition of Vidarbha region. Similarly SURAJ from CICR and NH 615 VNMKV Parbhani for high density plantingwas used. Sowing of HDPS cotton on BBF or furrow opening in between cotton rows for *in situ* moisture conservation is essential under rainfed Three moisture conservation practices and four nutrient management were tested for HDPS cotton. In cotton weed compete for nutrient, moisture and sunlight. The weed free maintenance of 50 days after emergence of cotton is necessary for better yield in HDPS cotton. Hence different cultural practices with herbicides combinations were studied. For control of bollworm complex different insecticide 4 modules with 3 plant spacing were tested at different location. In organic farming with HDPS cotton were tested with different manures with biofertilizer and biopesticides. Intercropping under HDPS cotton was tested with three crops. Demonstration on station and farmers field were tested with *Bt* and non *Bt* cotton.

RESULTS AND DISCUSSION

EVALUATION OF SUITABLE GENOTYPE WITH PLANT DENSITY FOR HDPS :

Seed cotton yield and economics : The seed cotton yield was significantly highest in variety AKH 081 followed by NH615 and Suraj during individual as well as in pooled data. The SCY was less due to delayed onset and early withdrawal of monsoon in 2014 . Variety AKH 081 showed highest Gross monetary returns, Net monetary returns . The highest SCY was recorded significantly highest (2843kg/ha) by AKH 081 with 2.22 lakh/ha (45 x 10 cm), which



is *at par* with 60 x 10 cm (2651 kg/ha). Suraj variety performed better at 75 x 10cm (2220kg/ha). Similar results with gross monetary returns, net monetary returns.

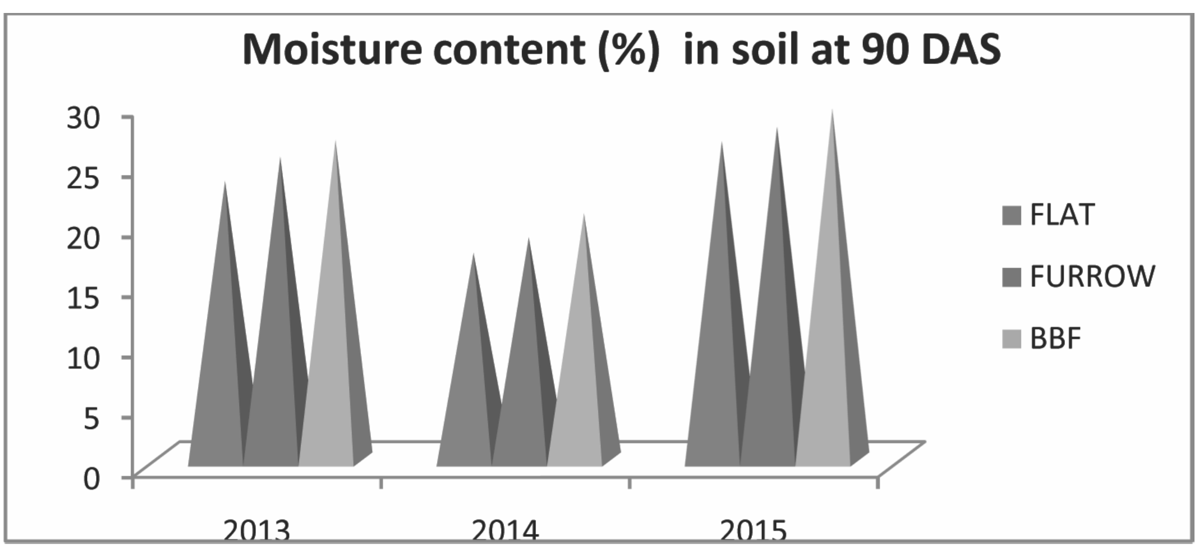
The genotypes AKH 081 , Suraj NH 615 are suitable for high density planting at 60 x 10cm with 1.66 lakh population/ha under medium depth soils of Vidarbha with varied rainfall situation and dry spell periods .Similar results were noted by Mohapatra 2011,Rao *et al.,* 2000 and Paslawar *et al.,* 2015)

Moisture conservation techniques with nutrient management for AKH081.

Moisture conservation techniques: The seed cotton yield per hectare was significantly influenced due to moisture conservation techniques. Significantly highest SCY (2934 kg/ha) was recorded by tractor drawn BBF (3 rows at 60x10cm) followed by opening of furrows at 40-60 DAS over flat sowing. Significantly highest Gross monetary return, Net monetary returns and was obtained with BBF under HDPS. Benefit cost ratio was maximum with BBF sowing.

Nutrient management : Nutrient management with different levels significantly influenced the yield attributes and seed cotton under HDPS. Boll weight and SCY/m square was enhanced with nutrient levels. Significantly highest SCY (3035 kg/ha)was recorded with 125% RDF(75:37.5: 37.5 NPK+ 2.5 Zn kg/ha) over RDF (2428 kg/ha). The gross monetary returns significantly influenced by different nutrient levels. The highest gross monetary returns and Net monetary returns with (125 %) RDF + Zn which is *at par* with (125 %) RDF foliar spray of (1%) urea and (1%) magnesium sulphate at boll development stage , which is the need of higher plant density. Benefit cost ratio was highest recorded with higher doses of nutrient under HDPS (Paslawar *et al.,* 2016).

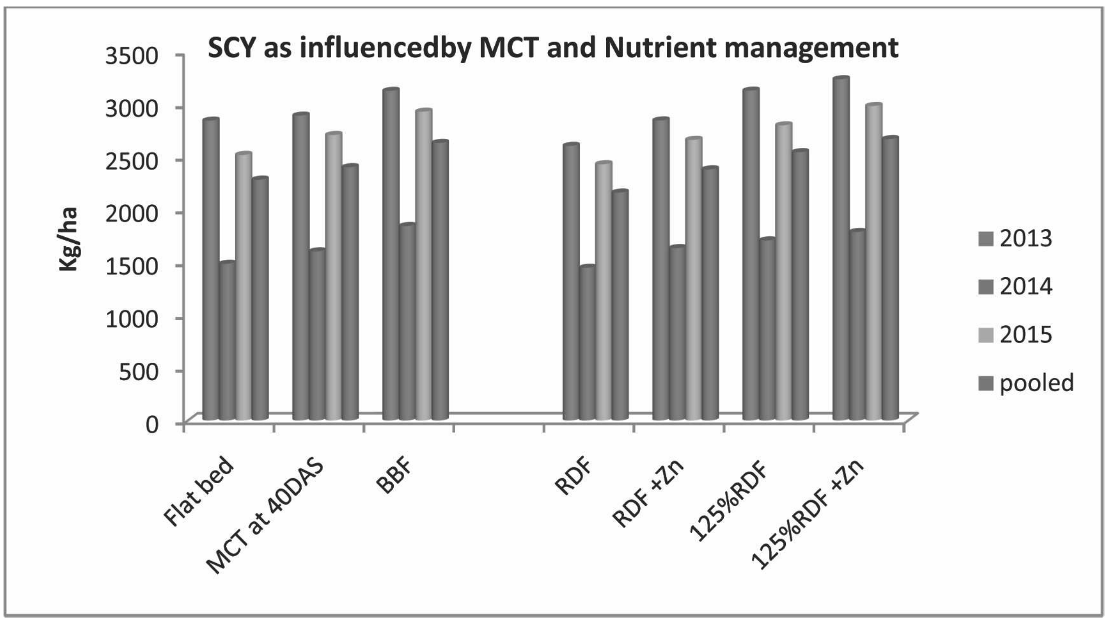
Rain water and nutrient use efficiency : The maximum rain water use efficiency (4.41 kg ha mm) and nutrient use efficiency (16.6 kg/kg) with moisture conservation practice with BBF and nutrient management with (125 %) RDF + Zn and foliar spray of (1%) urea and (1%)



BBF for better conservation of moisture in rainfed

magnesium sulphate at boll development stage.. Moisture content at 90 days after sowing during three years indicated higher moisture content in BBF, which supplied moisture for better growth of bolls and SCY under HDPS.

Sowing of high density planting at 1.66 lakh/ha (60 x 10cm) on BBF with (125%) RDF (75:37.5: 37.5 NPK+ 2.5 Zn kg/ha) and foliar spray of (1%) urea and (1%) magnesium sulphate at boll development stage was found to get higher seed cotton yield economic returns and conservation of moisture



Integrated weed management under HDPS : Dominant weed flora was *Commelina benghalensis, Cynodon dactylon, Cyperus rotundus* among the monocot species *.and in dicots Euphorbia geniculata, Euphorbia geniculata, Parthenium hysterophorus Celosia argentea and Digera arvensis* during experimentation.

Weed control efficiency (%) : The highest WCE was observed with weed free check (83 %) and 87% in early and late sown condition of HDPS followed by weed control efficiency was maximum with PE Pendimethalin (81%) and (77%) at 60 DAS at at picking in early and late sown condition of HDPS AKH081. Glyphosate was found third rank but some phyto -toxic effect was noticed in HDP cotton leaves. Similar studies were reported by Pawar *et al.,* 2015.

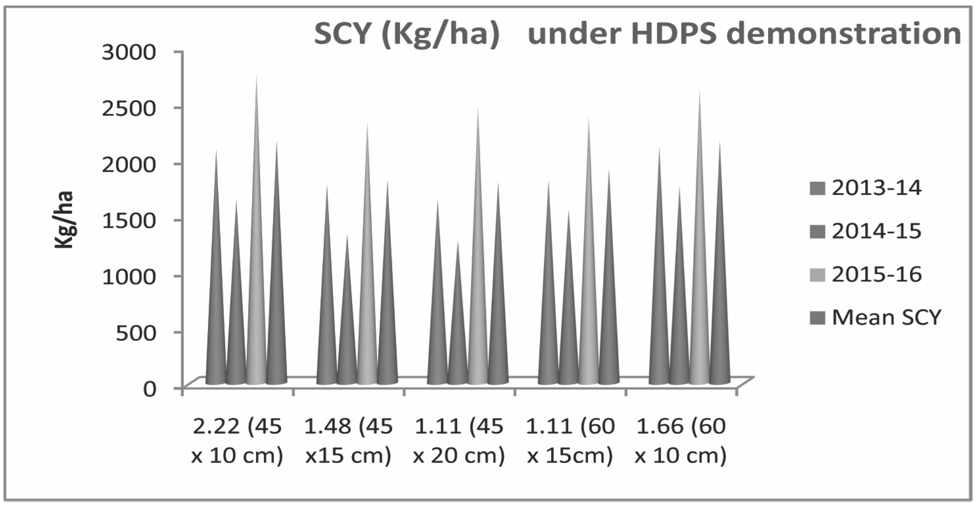
SCY and economics : The plant height, boll numbers , boll weight and dry weight/plant was significantly higher in weed free plot over

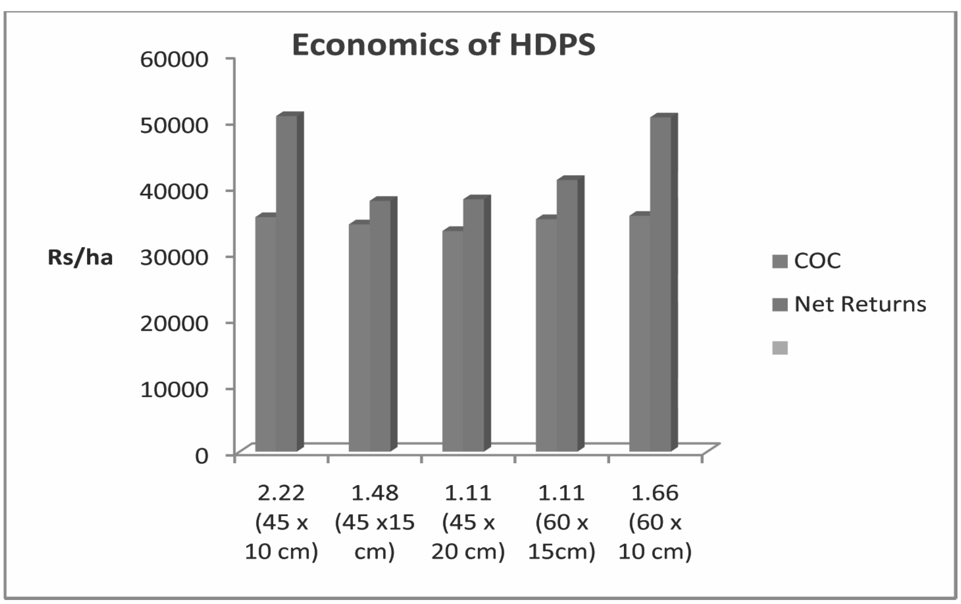
Table 1. WCE, growth, yield and economics as influenced by various weed management practices under HDPS cotton grown on broad bed furrow

Treatments	Weed control efficiency(%) at 60 DAS	Plant height (cm)	Boll number	Boll weight (g)	Dry weight/ plant (g)	SCY (kg/ha)	Lint yield (kg/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)
Pendimethalin 38.7 CS PE @ 1.25 kg a.i./ ha *fb* hoeing at 30 DAS and one hand weeding at 45 DAS	81.05	68.95	5.12	2.51	**50.87**	1866	700	72774	38664
Quizalofop ethyl 10 EC@ 0.075kg a.i. /ha POE 20-25 DAS (2-4 leaf weed stage) *fb* hoeing at 45 DAS	62.11	58.68	4.41	2.27	39.47	1415	518	55198	26441
Pyrithiobac sodium 10 EC @ 0.075 kg a.i./ ha POE 20-25 DAS (2-4 leaf weed stage) *fb* hoeing at 45 DAS	62.52	59.50	4.45	2.22	40.29	1405	516	54808	25001
Pendimethalin 38.7 CS PE @ 1.25 kg a.i./ ha*fb* Quizalofop ethyl 10 EC@ 0.060 kg a.i. /ha + Pyrithiobac sodium 10 EC POE @ 0.062 kg a.i./ haPOE (tank mix) (2-4 leaf weed stage)	65.07	61.46	4.92	2.40	41.42	1520	561	59280	27600
Hoeing at 20-25 DAS *fb* Glyphosate 71 G @ 1.50 kg a.i./ha as directed spray at 45 DAS	73.97	63.11	4.70	2.46	41.58	1643	596	64064	35271
Hoeing at 20-25 DAS *fb* Glyphosate 71 G @ 0.5 kg a.i./ha as directed spray at 45 DAS.	60.30	59.13	4.31	2.39	40.43	1523	551	59410	31513
Weed free check (2 weeding *fb* 2 hoeing)	83.20	72.08	5.57	2.55	52.73	2011	748	78442	38305
Weedy check	0.00	44.87	1.30	2.15	25.87	455	168	17732	-3121
CD (p0.05)	-	8.93	0.55	0.31	7.50	253	91	9876	8610

weed free check followed by spraying of PE Pendimethalin *fob* hoeing + weeding and Glyphosate . The seed cotton yield was significantly highest with weed free plot followed by spraying of PE Pendimethalin *fob* hoeing at 30 DAS + weeding at 45 DAS . The significantly highest gross and net returns with weed free check ,Which is at par with Pendimethalin 38.7 CS PE @ 1.25 kg a.i./ ha *fb* hoeing at 30 DAS and one hand weeding at 45 DAS .

Demonstrations on HDPS : The variety AKH 081 was demonstrated on one acre of HDPS on medium black cotton soil in the month of June with plant density of 2.22 lakh/ha (45 x 10 cm) and 60x10 cm (1.66 lakh /ha) and 60x15 (1.11 lakh/ha) and other spacings 45x10,45x15 and 45x20cm were demonstrated fduring 2013-2016. The highest gross returns and net returns were obtained from HDPS with plant density of 2.22 lakh/ha (45 x 10 cm) and it was at par with 60 x 10 cm (1.66 lakh/ha).



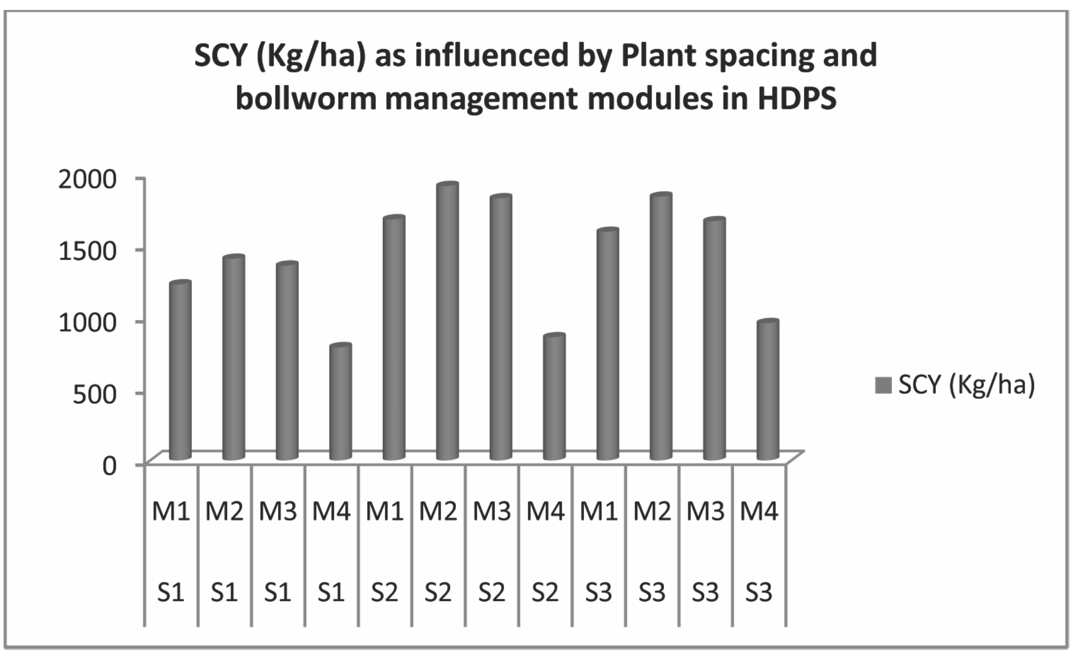


1.5 Bollworm management under HDPS : Bollworm management with different insecticide modules and plant spacing by using cotton variety AKH 081 conducted at Akola Amravati and Yeotmal location of Dr PDKV during 2015-2016.

Minimum larval population, damaged green fruiting bodies (GFB), open boll and loculi damaged was recorded in 60 x 10 cm spacing and it was at par with 60 x 15 cm spacing. Highest SCY and ICBR was recorded in 60 x 10 cm spacing with spraying of M2 module i.e. Flubendamide 480 SC @ 40ml/ac > Chlorantraniliprole 18.5 SC @ 60 ml/ac > Fenvalerate 20 EC @ 200 ml/acre.Earlier study was reortrd by Nemade *et al.,* 2015.

Table 2. Bollworm management with different insecticide modules and plant spacing

Plant spacing			Spraying module for bollworm complex
S1	**45 x 10 cm**	**M 1**	Quinalphos 25 EC@ 400 ml/ac > Spinosad (45%) SC @ 60 ml/ac > Fenvalerate 20 EC @ 200 ml/acre
S2	**60 x 10 cm**	**M 2**	Flubendamide 480 SC @ 40 ml/ac > Chlorantraniliprole 18.5 SC @ 60 ml/ac > Fenvalerate 20 EC @ 200 ml/ac
S3	**60 x 15 cm**	**M 3**	Flubendamide 480 SC 50 ml /ac > Spinosad (45% SC) 2 50ml /ac > Fenvelrate 20EC @ 160 ml/ac
		M 4	Control



1.6 Organic cotton grown on HDPS (1.11 lakh /ha) : The *arboruem* cotton variety AKA 8 was used for organically grown cotton under HDPS condition (60 x 15 cm) with different manures and biofertilizers and pest and disease management with bio pesticides during 2011-2016.

The pooled results indicated that the

highest SCY with castor cake and it was *at par* with 10 t FYM+ application of biofertilizers. But NMR with FYM 10t/ha followed by castor cake .However, Benefit cost with green manuring at 40DAS in cotton row. Sustainable index was highest (0.58) with 500 kg castor cake followed by 10 t FYM/ha. The GMR was maximum with Castor cake @ 500 kg/ha NMR was obtained highest with FYM + green manuring in cotton which is low cost input. The results indicated that the highest SCY with castor cake and it was *at par* with 10 t FYM+ application of biofertilizers. But NMR with FYM 10t/ha followed by castor cake .However, Benefit cost with green manuring at 40 DAS in cotton row. Sustainable index was highest (0.58) with 500 kg castor cake followed by 10 t FYM/ha. Available nutrient balance was improved after 10t FYM. (AICRP on cotton 2016)

Table 3. Mean SCY, GMR,COC, NMR and BC ratio as influenced by various organic manures on Arboreum cotton (AKA 8)

Treatments	**Pooled SCY (kg/ha)**	Gross returns (Rs/ha)	Cost of cultivation (Rs/ha)	Net returns (Rs/ha)	B:C ratio	SYI
T_1 : 5 t FYM/ha	**1248**	56952	28713	28239	1.98	0.50
T_2 : 2.5 t Vermicompost/ha	**1279**	58393	38114	20279	1.53	0.49
T_3 : 10 t FYM/ha	**1457**	66499	34156	32343	1.95	0.56
T_4 : 5 t Vermicompost/ha	**1387**	63330	52842	10488	1.20	0.52
T_5 : In situ green manuring of sunhemp	**1254**	57252	27846	29406	2.06	0.52
T_6 : Castor cake @ 500 kg/ha	**1523**	69505	37899	31606	1.83	0.58
T_7 : RD of nutrient through organic based on P equivalent basis (5t FYM) + GM *sunhemp*	**1257**	57376	29752	27624	1.93	0.50
T_8 : Control	**673**	30709	14500	16209	2.12	**0.17**

Azo +PSB + Trichoderma seed treatment to T1 to T7

Demonstration of rainfed non *Bt* and *Bt* cotton under HDPS (2016-2017) : Demonstrations were conducted on rainfed during 2016-2017. The non *Bt* and *Bt* were grown under HDPS condition. AKA 7 at 60 x 10 cm (1.66 lakh/ha)and Balvan *Bt* hybrid at 60 x 20 cm (87777 plants/ha) was tested for HDPS. AKH 081 and AKA 7 was also tested for 75 x10 cm (1.33 lakh/ha) and Ajeet 155 was sown at 90 x 45 cm as check.

The SCY of AKA 7 was 2381 kg/ha. Whereas SCY of Balvan *Bt* was highest (2660 kg/ha) with 60 x 20 cm. But seed rate required for *Bt* about 18 packets which costs Rs 15000/ ha. Ajeet 155 with recommended practices yielded 2240 kg/ha.

Different species of cotton intercropped with blackgram, soybean and finger millet under HDPS : Intercropping of *arboreum* and *hirsutum* varietyand *Bt* hybrid were grown with two rows grown on 60 x10cm maintained the population of 1.1 lakh in cotton in intercrop and one row of intercrops 60

Table 4. SCY and economics of HDPS non *Bt* and *Bt* cotton demonstration (2016)

Variety/Hybrid	Spacing	P P lakh/ha	Area	SCY (kg/ha)	GMR (Rs/ha)	COC	NMR	B:C
AKH 081 hirsutum variety	60 x 10 cm	1.66	1000 m^2	2425	100638	42405	58233	2.37
AKA 7 arboreum variety	60 x 10cm	1.66	1000 m^2	2381	98812	47353	51459	2.09
Balwan BGII hybrid	60 x 20 cm	0.83	1000 m^2	2660	110390	57860	52530	1.91
BG I variety (No 202)	75 x 10 cm	1.33	36 m^2	2925	121388	45788	75600	2.65
AKH 081 non *Bt* variety	75 x 10 cm	1.33	1000 m^2	1983	82295	38938	43357	2.11
AKA 7 non *Bt* variety	75 x 10 cm	1.33	1000 m^2	2462	102173	47516	54657	2.15
Ajeet 155 (CK) *Bt* BGII Hybrid	90 x 45 cm	0.24	1000 m^2	2240	92960	42570	50390	2.18

x7.5cm. Similarly, two rows of *Bt* cotton maintained population of 36.6 thousand with intercrop and one row of intercrops 60 x 7.5cm under rainfed during 2016-2017. Where as in sole cotton population of 1.66 lakh with variety and 55 thousand with *Bt* hybrid under rainfed. The highest SCY was recorded with *Bt* hybrid in sole cotton but cost seed was higher due to more packets 12 packets costing 10000/ha. The seed cotton equivalent was highest, different species of cotton intercropped with black gram. Finger millet suppressed the growth of cotton.

Frontline demonstrations (FLDs) : AICRP on cotton, Dr PDKV Akola centre conducted 16 FLDs on integrated crop management (ICM) *i. e.* HDPS with opening of furrow in cotton at 40 days after sowing and spraying of (1%) urea and MgSo4 at boll development stage and 15 FLD s with HDPS cotton + pigeonpea intercropping during 2016-2017 in Akola distt of Vidarbha.

Front line demonstrations on HDPS cotton improved Seed cotton Yield by 3.2 per cent over farmers practice of *Bt* cotton and HDPS with

Table 5. Yield of SCY and intercrop yield and Seed cotton equivalent yield

Cotton	Intercrop	Row ratio	SCY (kg/ha)	Intercrop yield	GMR (Rs/ha)	CEQ (kg/ha)
***Arboreum* variety**	**(60 x 10cm) and**	**intercrops 60 x 7.5cm)**				
AKA7	Sole	-	2015	-	83622	2015
AKA7	Soybean	2:1	1676	870	93697	2258
AKA7	Blackgram	2:1	1735	470	95503	2301
AKA7	Finger millet	2:1	1530	132	65838	1586
***Hirsutum* variety**	**(60 x 10cm) and**	**intercrops 60 x 7.5cm)**				
AKH081	Sole	-	2150	-	89225	2150
AKH081	Soybean	2:1	1710	755	91916	2215
AKH081	Blackgram	2:1	1745	430	93918	2263
AKH081	Finger millet	2:1	1630	116	69646	1678
Bt hybrid	**(60 x 30cm) and**	**intercrops 60 x 7.5cm)**				
PDKV JKAL116	Sole	-	2350	-	97525	2350
PDKV JKAL116	Soybean	2:1	1910	735	99661	2401
PDKV JKAL116	Blackgram	2:1	1855	490	101483	2445
PDKV JKAL116	Finger millet	2:1	1735	135	74331	1791

Table 6. SCY (Kg/ha) under FLD's during 2016-2017

Technology Demonstration	No. Of FLD s	Improved technology			Farmers practice Seed cotton yield (kg/ha)	Percent yield increase over FP
		Seed cotton yield (kg/ha)	Pigeonpea Intercrop yield (kg/ha)	SCYEQ		
ICM (HDPS & MCT)	16	1945 (1450 to 2250)	-		1884	3.2
Cotton + Pigeonpea (8:1)	15	767 (475 to 1375)	380 (125 to 500)	1265	1113	13.7

intercropping of pigeonpea improved the yield percent over farmers practice in Akola district of Maharashtra.

CONCLUSIÓN

The genotypes AKH 081 , Suraj and NH 615 were found suitable for high density planting at 60 x 10 cm under medium depth soils and Sowing of high density planting at 1.66 lakh/ ha (60 x 10cm) on broad bed furrow (BBF) with (125%) RDF (75:37.5: 37.5 NPK+ 2.5 Zn kg/ha) and foliar spray of (1%) urea and (1%) magnesium sulphate at boll development stage was found to get higher seed cotton yield, economic returns and conservation of moisture. Pre emergence application of Pendimethaline 38.7 CS PE @ 1.25 kg a.i./ ha (3.3 l in 700 l water) *fb* hoeing at 30 DAS and one hand weeding was seems to be best option to reduce the early weed competition and for effective management of bollworm complex, Flubendamide 480 SC @ 40ml /ac followed by Chlorantraniliprole 18.5 SC @ 60 ml/ ac was found better insecticides under HDPS cotton. BGI variety was performed better under HDPS condition (75 x10cm) .

For organic farming with HDPS cotton indicated highest SCY and sustainable yield index with castor cake + biofertilizers and it was at par with 10 t FYM+ application of biofertilizers.

HDPS with non *Bt* and *Bt* cotton under intercropping of cotton + blackgram (2: 1) proportion was found to be most remunerative under rainfed .

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Candidate traits for enhancing drought tolerance in rainfed cotton

RAMESH THATIKUNTA*, B. SANTHOSH , P. GOUTHAMI , V. GOURI SHANKAR, S. A. HUSSAIN AND D. V. V. REDDY

Department of Crop Physiology, Professor Jayashankar Telangana State Agricultural University Hyderabad -500 030

**E-mail : thatikuntaramesh@gmail.com*

Drought stress has been the major environmental factor that negatively impacts cotton yield throughout the world : Cotton cultivation covers nine states in India with 12.73 m ha, production of 39 m bales and productivity of 565 kg/ha. Telangana state has 17.13 la ha with 103.5 la MT and 1039 kg/ha (*Agriculture action plan*, 2015-2016). Seventy percent of cotton crop acreage has been rainfed (Singh, 1998). Thirty eight percent of cultivated area has irrigation. Rainfed cotton suffers from moisture stress or otherwise referred to as drought. Intensity of drought has been severe in regions of erratic rainfall. Also, soils with low moisture holding capacity and steep slope have been more prone to drought. Water deficit stress has been defined as the condition where a plant's water potential and turgor decreased sufficiently to inhibit normal plant function. Growth, development, yield, quality decreased under drought and limited the full expression of genetic potential. Dry matter accumulation under moisture stress was reduced by 50 per cent of *Gossypium barbadense* and also reproductive development. Water stress effects depended on the severity and duration of the stress, growth stage at which stress occurred and also on the nature of genotype (*Ullah et al.,* 2017). Therefore, productivity could be increased by increase in the irrigation facilities, adoption of scientific innovations and modern technologies. The paper discusses the traits that confer drought tolerance, effects of drought on crop growth and development, methodologies to screen for drought tolerance, sources of drought tolerance and screening facilities available for evaluation of drought tolerance of cotton genotypes**.**

Mechanisms of drought resistance : Four mechanisms have been defined for drought resistance viz., drought escape, avoidance, tolerance and recovery. Drought escape is the ability of plants to adjust their growth period or life cycle. For example cotton variety with a short life cycle avoids the seasonal drought stress. Drought avoidance is the maintenance of key physiological processes during moderate drought conditions. Drought tolerance is the capability of plants to withstand severe dehydration through specific physiological activities. Drought tolerance mechanism is very complex because it is a multigenic system that is related to various morpho-physiological, biochemical and molecular processes. Cotton has evolved several signal transduction pathways in response to drought stress. Drought recovery of plants is the capability to resume growth and yield after exposure to severe drought stress. Effects of drought stress has been understood by exposure of crop to limited moisture at various phenological phases as detailed below.

Sensitivity of vegetative growth to water deficit stress : Cotton has evolved several common morpho-physiological strategies against drought or moisture stress. Drought severely restricts cotton growth and development such as affecting plant height, leaf dry weight, stem dry weight, leaf area index, node number, fibre quality, canopy and root development. For example, *Gossypium hirsutum* cotton variety YZ1 compared to Y668, produced smaller leaves under stress. Parameters that decrease significantly during drought conditions include net photosynthetic rate, transpiration rate, stomata conductance, carboxylation efficiency and water potential (*Loka et al.,* 2012).

The traits that contribute to high seed cotton yield under water deficit have been identified. Characters that correlate with drought tolerance includes epicuticular wax, leaf temperature, photosynthetic rate, transpiration rate, nitrate reductase activity, protein content, reducing sugar, phenol, amino acid, relative water content, leaf water potential, chorophyll stability index. Seed cotton yield depended on characters like boll weight, fibre length, uniformity ratio, fibre strength, micronaire values and elongation, strength to length ratio and short fibre content.

Sensitivity of reproductive development to water deficit stress : Water deficit effects on different plant physiological processes have been complex and interrelated. For ease of discussing these physiological functions, water deficit effects have been addressed at pre-flower, during flowering and post flowering on boll development.

Water deficit prior to flowering : Pre flowering is a critical period for yield determination. Cotton yield positively correlates with the number of bolls produced which again depended on the number of carpels and anthers that have been determined 30-35 days before anthesis. Upon withholding irrigation at the preflowering stage there was increased numbers of flowers and bolls/plant accompanied by yield increase possibly by the inhibition of excessive vegetative growth or by increased fruit retention (Smith and Cothren, 1999). However, reduction was recorded in nodes, fruiting branches, and fruiting sites.

Water deficit during flowering : Significant reductions in yield have been recorded when water-deficit stress occurred during flowering. Moisture stress at 14 days after anthesis lead to boll abscission (Smith and Cothren, 1999). Peak flowering has been reported as the most sensitive stage of cotton development. Maximum yield decreased because of water stress. Pollen and pollen tube growth have been found to be highly sensitive to environmental stress. ABA levels of such water stressed flowers increased compared to the control. Water deficit on the other hand had a minimal effect on IAA concentrations and a consequent increase in levels of conjugated IAA.

Water deficit during boll development: Cotton bolls rather than the leaves appear to be less sensitive since they are considered essentially non-transpiring under water deficits. Mild water stress had no effect on bract and capsule wall water potentials while the leaf water potentials were significantly decreased. This was attributed to the xylem connections of the fruits. Photosynthate flow was not affected by the water-deficit stress treatment while no differences in dry weights were observed between water stressed and well watered bolls. Despite the prevalence of water stress bolls have been retained.

Basis of drought tolerance : Morphological, physiological and molecular traits have been associated with drought tolerance and discussed below

Morphological traits earliness : In cotton drought occurs in late season. Early varieties escape drought by maturing early and these can be harvested before onset of drought.

Stomata regulation : Closure of the stomata has been the first step to reduce water loss during drought. Rapid closing types have been preferred in breeding programmes. Adaxial compared to abaxial have been found to be more sensitive water stress. Stomatal characters associated with drought resistance include sunken type, small size and less number. Stomatal conductance has been a potential indicator of drought tolerance as there exists a negative correlation between drought tolerance and stomata conductance in cotton.

Leaf characters : Drought resistance has been associated with characters like thick cuticle, waxiness, small fleshy leaves with thick layers of palisade tissue, glossiness and hairiness. These characters reduced the leaf area, lowered the leaf temperature and showed reduced transpiration.

Root development : Mild and initial stage drought stress has been reported to enhance root length in cotton. Transgenic cotton plants that harboured 1/ homodomain glabrous 11 AtEDT1/ HDG11 gene enhanced drought tolerance by way of well developed roots. Diploid species showed high degree of drought tolerance by virtue of their deep root system.

Growth habit : Plant growth habit affects drought tolerance. Indeterminate types produced flowers whenever sufficient moisture was available and resulted in high yields. Determinate types as compared, produced only one flush of flowers and if drought period coincided with flowering it lead to heavy loss in yield.

Optimum leaf area index : Water stress reduced the growth rate of the crop through a reduction in size and number of leaves. Maximum crop growth rate (CGR) (2.4 g/plant/ day) was recorded at boll initiation with 75 x 10 cm in genotype H 4. LAI recorded (2.9) was observed to be influenced by sampling time (flowering to boll initiation stage 60-90 DAS), genotypes (H4) and spacing (75 x 10 cm). Optimum LAI resulted in maximum seed cotton yield. Increased leaf area in other genotypes subjected to moisture stress did not result in high yields (Ramesh *et al.,* 2016 and 2017).

Physiological traits photosynthesis : Photosynthesis as well as transpiration was affected under drought conditions.

Photosynthesis decline under water-deficit conditions decreased the lint yield. Drought tolerant genotypes maintained high photosynthetic rate under moisture stress. Young leaves subjected to high temperature (37°C) were tolerant to drought and heat whereas mature leaf net photosynthesis declined by 66 per cent. Water potential values upon exceeding –1.5 MPa decreased the assimilate translocation, xylem transport, respiration, CO_2 assimilation and activity of hydrolytic enzymes.

Osmotic adjustment : Numerous organic compounds have been demonstrated to be involved in osmotic adjustment which included amino acids (proline, glycine), sugars (trehalose, fructan), sugar alcohols (mannitol, sorbitol, D ononitol), amines, polyamines (betaines), polyols, ectoine, alkaloids and inorganic ions known as osmoprotectants / osmolytes. These compatible osmolytes accumulated in the cytoplasam while the ionic concentration increased in the vacuoles. Proline levels as such can be used as indicator of water stress but not as a measure of drought resistance. Osmotic adjustment provided a major mechanism of turgor maintenance and favourable water status for crop plants subjected to water deficits. Solutes under drought stress protected the proteins and membranes from the damage due to high concentrations of inorganic ions, oxidative damage and multiple stresses such as drought and salinity. Successful stories of exogenous application to enhance the drought tolerance capability have been presented (Table 1)

Biochemical traits abscisic acid (ABA) : Osmotic stress enhanced the synthesis of ABA which activated the gene expression and adaptive physiological changes. Many stress-related genes have been regulated by ABA which enhanced drought tolerance in cotton. Over expression of ABA induced cotton gene *GhCBF3* enhanced drought and salinity tolerance in transgenic lines. ABA presence resulted in small stomatal aperture in transgenic lines and expression of remarkably higher level of AREB1 and AREB2.

Reactive oxygen species (ROS) : During drought conditions, excessive leakage of electrons to O_2 has been recorded. Mehler reaction reduced O_2 to O_2 by donation of an electron in photosystem I. O_2 thereby has been converted to H_2O_2 by SOD which was further converted to water by ascorbate peroxidase. The antioxidant machinery has been developed by the plants to ensure survival. It has two arms, (i) enzymatic components such as catalase (CAT) and (ii) nonenzymatic antioxidants (Fig. 1.). To

Table 1. Effect of osmoprotectants and various plant growth regulators on drought stress

Osmoprotectants and various plant growth regulators	Beneficial traits of transgenic cotton against drought stress effect on yield of cotton
Proline and glycinebetaine	Reduced the adverse effects of drought stress
GA	Enhanced the net rate of photosynthesis, transpiration rate and stomata conductance
ABA, JA and MeJA	Differentially induced *Gossypium barbadense* receptor like kinase gene (*GbRLK*)

scavenge ROS, these two arms work together. APX along with MDAR, NADH and GR, removes H_2O_2 *via* the Halliwell Asada pathway. Down regulation of *GbMYB5* in *G. barbadense* resulted in a decrease in antioxidant enzyme activities such as SOD and peroxidase (POD).

Plant growth regulators and nutrients: Water stressed plants treated with PGR IV (blend of PGR and nutrient uptake enhancer) enhanced the dry weight of roots (24%) and nutrient levels of P, Zn, Cu, Mn and Fe (170%).

Polyaspartic acid a synthetic protein

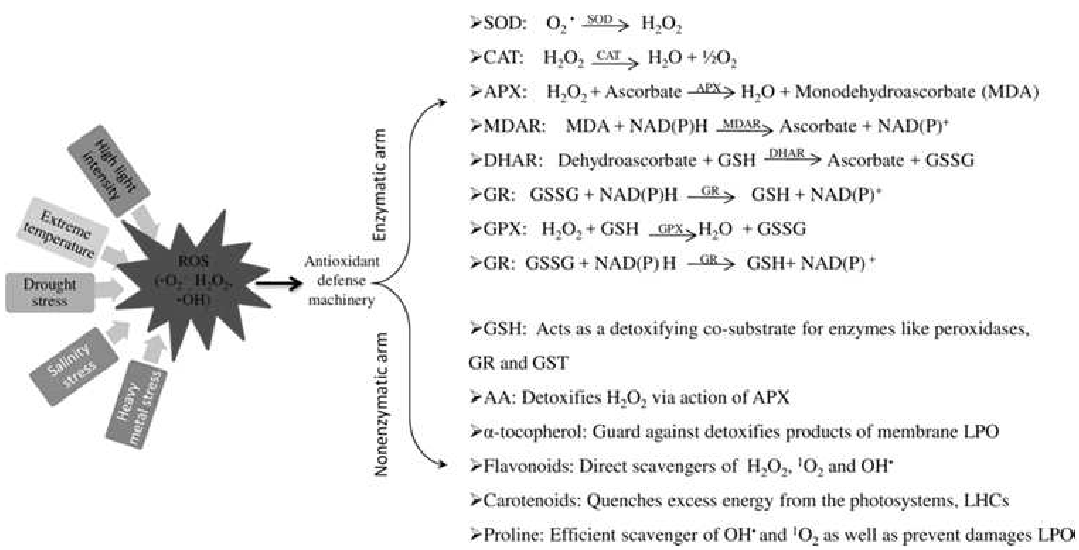

Fig. 1. Schematic representation of antioxidant defense mechanism

treatment augmented the nutrient uptake and plant growth. Root and root hair growth was recorded in some species but the underlying physiological mechanism has not been understood.

Heat stress and heat shock proteins : Water stress accompanies heat stress and as such these factors can not be separated. First signs of heat stress were shown when temperatures exceeded 27^0C. Gross photosynthesis, boll size and fibre strength recorded a decrease and increased the boll fill period above 32^0C. Poor flower survival and fruit production was recorded above 35^0C. Bolls represented <1 per cent of plant mass when plants were exposed to 40^0C for 12 h periods during fruiting. Heat shock proteins were not unique to high temperature stress though recorded in varied environmental conditions like salinity, water deficit, wounding, ABA treatment and cold.

Molecular traits

Transcription factors : To increase the tolerance in cotton against drought stress, transcription factors have been excellent candidates for the plant scientists. TF's activate signalling cascade of entire network of drought stress responsive genes that operate together in inducing plant tolerance to drought and other abiotic stresses. Involvement in normal development as well as under drought stress response have been worked out for various transcription factors such as MYB, WRKY, ERF, NAC, bZIP (Table 2) (*Ullah et al.,* 2017).

Genes involved : Transgenic plants that show enhanced plant tolerance to drought stress, traits involved for enhanced yield have been presented (Table 3).

Table 2. Transcription factors involved in drought and other abiotic stresses

Genes encodingtranscription factors	Beneficial features under drought and salt
GhABF2 (bZIP)	Regulated genes related to ABA, increased the activities of SOD and CAT
GhNAC2	Produced higher root length
GbMYB5	Reduced stomatal size, rate of its opening and water loss, while proline content and antioxidant enzymes increased
GhWRKY41	Induced stomatal closure, higher antioxidant activity and lower malondialdehyde content
GhWRKY17	Impaired ABA induced stomatal closure, reduced ABA level, decreased the expression of ROS scavenging genes, reduced proline content, elevated electrolyte leakage and malondialdehyde
GhNAC8-GhNAC17	Drought, salt, heat and cold

Table 3. Plant gene source and environmental conditions that show enhanced plant tolerance to drought stress (*Ullah et al.,* 2017).

Gene(s)/ Promoter	Plant gene source and environmental condition	Beneficial traits of transgenic cotton against drought stress on yield
ScALDH21 CaMV 35S	*Syntrichia caninervis,* greenhouse and field	Increased drought soluble sugar and proline content, higher peroxidase activity, reduced loss of net photosynthetic rate, reduced lipid peroxidation, greater plant height, larger bolls and increased yield
AtEDT1/ HDG11 CaMV 35S	*A. thaliana* Laboratory, greenhouse and field	Increased drought and salt soluble sugar and proline content, well-developed roots, low stomatal density, increased ROS scavenging enzymes and 43 per cent higher seeds
SNAC1 CaMV 35S	Drought and salt	Enhanced proline content and root development while transpiration rate decreased, produced 131 per cent more bolls

Breeding for drought tolerance

Characterization for drought tolerance: steps involved

1. Selection of parents
2. Combining several drought resistant characters in one genotype with Interconnected breeding population method
3. Screening of material under drought
4. Yield testing with large populations and testing at several locations. Grouping

of genotypes into tolerant and susceptible types by cluster analysis and identification of the stable yield genotypes across the environments using multivariate analyses

Sources of drought resistance and breeding method to be followed :

1. Exotic variety – good source, introduced after testing, if found suitable released as variety. Asiatic cottons *viz., G arboreum* and *G herbaceum* possess drought resistance or tolerance because of deep root system
2. Land races or mixed population – pure line selection or mass selection
3. Unadapted genotype and wild species – backcross method, poses problems of cross incompatibility, hybrid inviability, hybrid sterility, linkages between desirable and undesirable genes
4. Adapted genotype / cultivated varieties – pedigree method
5. Germplasm of cultivated species – mutation breeding

Screening facilities for evaluation of drought tolerance

1. Rain out shelters
2. Managed environment facility
3. Growth chamber experiments
4. Lysimeter / gravimetric facilities
5. Phenotyping platforms and drought phenotyping for drought tolerance during rain free hot dry summer days
6. Pot experiments with cotton with imposition of various soil water levels
7. DRIP method
8. Carbon isotope discrimination: Selection pressures for high stomatal conductance and associated leaf cooling resulted in avoidance type of heat resistance under high irradiance and temperature conditions in pima cotton (*G. barbadense*).

CONCLUSIONS

International interest has been increasing to understand the growth and the basis of drought tolerance in cotton and other crops despite the fact that drought has been a complex trait. Few aspects of moisture stress have been understood in cotton. The effects of water stress depended on the severity, duration of the stress, growth stage and involved genotype. Water stress at flowering stage was found to be most critical as it resulted in abscission of bolls. To enhance the drought tolerance capability of cotton physiological, morphological, biochemical and molecular basis and their correlation with seed cotton yield has to be understood. Material has to be identified in segregating population and subjected to suitable stress environments and analyzed with suitable statistical design to find out the drought resistant trait and genotypes. Role of few genes have been studied in cotton. Transgenic cotton plants were mostly studied under greenhouse conditions or tested in the field under natural water deficit environments to a limited extent. The studies need to be further explored. Exogenous application of substances help in temporary amelioration of water stress. Linking plant traits with physiological mechanisms would improve the drought tolerance and result in moisture stress tolerant genotypes in cotton.

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Status and prospect of traditional fibre crops in Garo hills district of Meghalaya, india

MOKIDUL ISLAM*, N. ARUNKUMAR SINGH, UTPAL BARUAH AND POPIHA BORDOLOI
Krishi Vigyan Kendra, Ri-Bhoi, ICAR Research Complex for NEH Region, Umroi Road, Umiam-793103
**E-mail* : mislam01d@yahoo.co.in

ABSTRACT : Cotton, Jute and Mesta are the important traditional cash crops of Garo hills district of Meghalaya. These fibre crops are grown exclusively in five district of Garo hills i.e., East Garo hills, North Garo hills, West Garo hills, South West Garo hills and South Garo hills. Cotton has the highest area (7292 ha) under cultivation followed by Jute (6598ha), Mesta (2479 ha) and Ramie (244 ha). The productivity trend of fibre crops in Garo hills district are 198, 1769, 1093 and 1200kg/ha in Cotton, Jute, Mesta and Ramie, respectively. The cotton grown in Garo hills is also known as Comilla cotton because historically cotton trade flourished from the hills of Garo hills through the markets of Comilla district of Bangladesh. Garo hills cotton has find excellent markets for production of Sarees and other garments for women like Salwar Suits, lehenga, Choli etc. The cotton variety D. 46-2-1 belonging to the *Gossypium arboreum* has a good market as short staple cotton for its softness and durability which are also used for mixing with wool. The cotton species *Gossypium hirsutum, Gossypium barbadens and Gossypium harbaceum* are also grown in Garo hills with the varieties G 54-1 and G 135-49. The *Capsularis* jute varieties JRC 321, D 154, JRC 7447 and *Olitorious* varieties JRO 632, JRO 514, JRO 7835, JRO 878, JRO 204 and JRO 524 are grown in Garo hills besides *Tossa or desi* local variety. The Mesta varieties grown are *Hisbiscus Sabdariffa* (HS 4288 and AMVI) *and Hibiscus Cannabinus* (H.C. 583). The stagnated and decreasing yield of the fibre crops, especially Jute and Mesta may be attributed to the un-remunerative price received by farmers'. Wildly grown ramie species *(Boehmeria platylus)* have been reported to be found in Garo hills where the local farmers made fishing rod from ramie stem, strings of local musical instrument from the fibres and for feeding of tender leaves of ramie crop to cattle.

Key words : Cotton, Jute, Mesta, Ramie, Fibre

Meghalaya (25.47–26.1°N latitude and 89.45–92.47° E longitude) is one of the most picturesque states of India, offering a spectrum of sylvan surroundings, rich cultural heritage and luxurious vegetation comprising of a large variety of flora and fauna. Meghalaya is divided into eleven districts *viz.*, east *Jaintia* hills, east *Khasi* hills, West *Khasi* hills, *Ri-Bhoi*, east Garo hills, north Garo hills, west Garo hills, south west Garo hills and south Garo hills. It is among the wettest places on earth and is the home of an extraordinary diversity of people that includes the *Khasi*, *Jaintia* and *Garo* tribes. Meghalaya experiences two distinct seasons, *i.e.*

winter and monsoon and is characterized by a cool climate throughout the year. The village of Mawsynram (about 16 km west of Cherrapunji) in the southern slopes of *Khasi* hills district receives the heaviest rainfall (11690 mm) in the world. Numerous rivers flow through Meghalaya although none of them are navigable, due to steep slope, rocky beds followed by strong water currents. Agriculture is the main occupation of the people of Meghalaya. About 83 per cent of the total population of state depends on agriculture for their livelihood. However, agricultural land is accounted as only 48 per cent of the total geographical area of the state. The state offers scope for cultivation of a wide variety of agricultural crops because of highly diversified topography, altitude and climatic conditions. Rice (*Oryza sativa* Linn.) and maize (*Zea mays* Linn.) are the major food crops. Important fruits grown are orange (*Citrus reticulata* Blanco), pineapple (*Ananas comosus* Merrill), lemon (*Citrus limon* Burm. f.), guava (*Psidium guajava* Linn.), jack fruit (*Artocarpus heterophyllus* Lam.) and bananas (*Musa* sp.). Potato (*Solanum tuberosum* Linn.*)*, jute (*Hibiscus cannabinus* Linn.), cotton (*Gossypium* sp.), arecanut (*Areca catechu* Linn.), ginger (*Zingiber officinale* Rosc.), turmeric (*Curcuma domestica* Valeton), betel leaf (*Piper betle* Linn.) and black pepper (*Piper nigrum* Linn.) are the chief commercial crops. *Jhum* or the shifting cultivation and terrace cultivation are predominant in the state, bringing land under permanent cultivation in later case.

The **Garo hills** are part of the Garo Khasi range in Meghalaya, India. They are inhabited mainly by tribal dwellers, the majority of whom are Garo people (Subba and Ghosh 2003). People who reside in the Garo hills are known as the Garos. Besides the Garo hills, there are Garo settlements in the plains of Assam and Bangladesh. The Garos call themselves A·chik (Locally used).The society is matrilineal like the Khasis and the Jaintias. Till death, the new-born baby belongs to the mother's family, irrespective of sex, even after marriage. Marriage within the clan is completely prohibited and severely punishable for both the Khasis and the Garos.

Cotton, Jute and Mesta are the important traditional cash crops of Garo hills district of Meghalaya. These fibre crops are grown exclusively in five district of Garo hills. *Gossypium arboreum* L., commonly known as tree cotton or *desi* cotton is native to India which is under cultivation from time immemorial. *Arboreum* cottons have wide adaptability and are relatively tolerant to biotic and abiotic stresses (Singh and Punit Mohan, 2005). The cotton grown in Garo hills is also known as Comilla cotton because historically cotton trade flourished from the hills of Garo hills through the markets of Comilla district of Bangladesh. Wildly grown ramie species *(Boehmeria platylus)* have been reported to be found in Garo hills where the local farmers made fishing rod from ramie stem, strings of local musical instrument from the fibres and for feeding of tender leaves of ramie crop to cattle.

The traditional agricultural production systems evolved from the traditional; knowledge systems are performing very well even today in conserving bio-resources/ natural resources and in sustaining hill ecosystem of north east. Garo Hill districts of Meghalaya are one of the most promising areas within NEH Region as far as the potentiality and variability of fibre crops is concerned. These district offers scope for cultivation of a wide variety of fibre crops because of highly diversified topography, altitude and climatic conditions. Major fibre crops grown in Garo hills are **cotton, jute, mesta and ramie**. Fibre crops are also receiving attention because they can be grown on marginal or difficult land. Due to growing population, pressure on land has increased and farmers have to move onto marginal lands with difficult soil, weather or other environmental conditions. Keeping in view , the present article reviews the status and prospects of traditional fibre crops in Garo hills district of Meghalaya.

Table 1. Area, Production and yield of cotton in India from 2012-2013 to 2016-2017

Year	Area (Lakh ha)	Production (Lakh bale)	Yield (kg/ha)
2012-2013	119.77	342.20	486
2013-2014	119.60	359.02	510
2014-2015	128.19	348.05	462
2015-2016	118.72	301.47	432
2016-2017	105	321.23	520
Average	**118.26**	**334.39**	**482**

PRESENT STATUS OF FIBRE CROPS IN GARO HILLS : Garo hills of Meghalaya receives early and heavy to moderate rains. Jute and mesta crop can be grown in low to medium lands under both moisture stress and water stagnating condition whereas cotton and ramie are mostly grown in medium to high lands under moisture stress conditions. In the state Meghalaya, these fibre crops are only grown in all the districts of Garo hills. Cotton, Jute and Mesta are grown in all the districts of Garo hills namely east, west, south, south west and north Garo hills of Meghalaya whereas ramie starts to grow commercially recently in west Garo hills district only. Cotton has the highest area (7292 ha) under cultivation followed by Jute (6598ha), Mesta(2479 ha) and Ramie (244 ha). Among the districts, west Garo hills largely contributes maximum area and production to the tune of about 54.5 and 62.4 per cent respectively of the total average area and production of the State followed by east Garo hills, north Garo hills, south west Garo hills and south Garo hills. The area and production under jute is 6598 ha and 67064 bales of which west Garo hills district shared about 59.1 per cent area and 60.9 per cent of total area and production of the state. The area coverage and production of jute in this district is maximum as 75 per cent of the area is under low land condition where water is available during the growing period of the crop. At present, the area coverage under mesta crop is decreasing mainly due to lack of marketing facilities and unavailability of good quality high yielding varieties of the crop. The average area and production of mesta in Garo hills is 4475 ha and 26242 bales contributing the maximum by west Garo hills district (49.6 % area , 48.4 % production) followed by south west Garo hills to a tune of 29.1 per cent area and 29.9 per cent production respectively. It has been observed that the area coverage and production of all the three fibre crops decreased slightly from 2014-2015 to 2015-2016 due to the diversion of farmers' mindset towards growing of tuber and plantation crops as the market demand for these crops are increasing in Garo hills.

Mesta is an herbaceous annual crop. It is an important fibre crop after jute and cotton. The plants are hardier than jute and can withstand drought conditions .This crop has been

Table 2. Global status of area, production and productivity of ramie

Year	World			Asia		
	Area (ha)	production (tonnes)	Yield (kg/ha)	Area (ha)	Production (tonnes)	Yield (kg/ha)
2005	136011	281537	2070.0	135472	280379	2069.6
2006	145458	291545	2004.3	145011	290324	2002.1
2007	146621	296096	2019.5	146227	295024	2017.6
2008	129758	255204	1966.8	129311	254181	1965.7
2009	88945	147892	1662.7	88794	147393	1659.9
2010	75299	118593	1575.0	74930	117762	1571.6

Table 3. Area, production and productivity of ramie in NE India

States	Area(ha)			Production(Tonnes)			Yield(kg/ha)		
	2004-2005	2005-2006	2006-2007	2004-2005	2005-2006	2006-2007	2004-2005	2005-2006	2006-2007
Arunachal Pradesh	100	100	-	-	24	-	-	0.24	-
Assam	185	89	97	47	128.9	147.1	0.25	1450	1520
Meghalaya	25	-	-	5	-	-	0.20	-	-
Nagaland	10	-	-	3	-	-	0.30	-	-
All India	**320**	**89**	**97**	**79**	**128.9**	**147.1**	**0.25**	**-**	**-**

Source : Directorate of Jute Development, Govt. of India

the traditional cash crops of Garo hills. The area of mesta are confined to some few pockets of Garo hills and has not spread much, though they are of commercial importance. In Garo hills, Meghalaya, mesta is cultivated both on plains and slightly higher lands under rainfed conditions. In plain areas of Garo hills, mesta is sown in the month of February March and harvested in August- September whereas in hilly areas it is mostly grown in July August and harvested in January February. Mesta seeds are sown @ 2kg/ *bigha* through broadcasting method after the soil are ploughed once or twice. Two types of local species which is commonly known as desi mesta are mostly grown in Garo hills one is long leaves with 6-7ft in height and the other is short leaves which are of 4-5ft in height where the local farmers mostly used the leaves for vegetable purposes. After the harvest of the crop, they dip in running water for a period of 25- 30 days and dried in sun for 2-3 days. The average yield of mesta fibre ranges from 250 – 300 kg/ *bigha*. The farmers keep the plants for 6- 7 months for seed purpose to store for the next season to come. In the previous years, farmers used to get good price of fibres in the market @ Rs.40- 50/ kg but at the present scenario due to lack of marketing linkage or knowledge the price drops to Rs.10-12/kg. The local farmers used the fibres for making ropes and the remaining stems are kept for fuel purpose, boundary fencing or sold in the market @ Rs.5-6/ bundle (100 nos). The tribal farmers of Garo hills also consumed the young leaves of the crop as vegetables during the vegetative growth stage.

The cotton grown in Garo hills is also

known as Comilla cotton because historically cotton trade flourished from the hills of Garo hills through the markets of Comilla district of Bangladesh. Garo hills cotton has find excellent markets for production of Sarees and other garments for women like *Salwar* Suits, *lehenga*, Choli etc. The cotton variety D. 46-2-1 belonging to the *Gossypium arboreum* has a good market as short staple cotton for its softness and durability which are also used for mixing with wool. The cotton species *Gossypium hirsutum, Gossypium barbadens* and *Gossypium harbaceum* are also grown in Garo hills with the varieties G 54-1 and G 135-49. The *Capsularis* jute varieties JRC 321, D 154, JRC 7447 and *Olitorious* varieties JRO 632, JRO 514, JRO 7835, JRO 878, JRO 204 and JRO- 524 are grown in Garo hills besides *Tossa or desi* local variety. The Mesta varieties grown are *Hisbiscus Sabdariffa* (HS 4288 and AMVI) and *Hibiscus cannabinus* (HC 583). The stagnated and decreasing yield of the fibre crops, especially Jute and Mesta may be attributed to the un-remunerative price received by farmers'. Under the initiative of District Agriculture Office (DAO), west Garo hills, Tura, ramie (*Boehmeria nivea*) has been brought to cultivation in Garo hills by implementing Ramie Development Project in the year 2015-16. A total area of 244 hectares has been covered with ramie cultivation in four different districts of Garo hills, Meghalaya west Garo hills district (80 ha), south Garo hills (40 ha), north Garo hills (40 ha) and south west Garo hills (84 ha). However ramie based technologies and fashion products have not spread to a greater extent in other parts of the world due to its expensive post harvest technology.

TRENDS OF AREA, PRODUCTION AND PRODUCTIVITY OF FIBRE CROPS IN GARO HILLS : The trend of area under cotton in India was decreased by 12.33 per cent from 2012-2013 to 2016-2017. However, the production was recorded highest during 2013-14 and productivity in 2016-2017. The average area, production and productivity of cotton in India was 118.26 lakh ha, 334.39 lakh bales and 482 kg/ha, respectively (Table 1). The global, Asian and Indian status on area, production and productivity of ramie are presented in Tables 2 and 3, respectively. The average area of ramie in world is only 3.4 per cent higher than Asian countries but decreasing trends both in world and Asian countries from 2005 to 2011. On the other hand, ramie area was 320 ha in India and only 25 ha in Meghalaya during 2004-2005 (Table 3). Cotton has the highest area (7292 ha) under cultivation followed by Jute (6598ha), Mesta (2479 ha) and Ramie (244 ha) The productivity trend of fibre crops in Garo hills district are 198, 1769 ,1093 and 1200kg/ha in Cotton, Jute, Mesta and Ramie, respectively. A total area of 244 hectares has been covered with ramie cultivation in four different districts of Garo hills, Meghalaya – west Garo hills district (80 ha), south Garo hills (40 ha), north Garo hills (40 ha) and south west Garo hills (84 ha). However ramie based technologies and fashion products have not spread to a greater extent in other parts of the world due to its expensive post harvest technology (Table 4).

NUTRITIONAL VALUE OF FIBRE CROPS: Jute leaves are being used as vegetables in Africa, middle east and south east Asia for a long time. Besides, it is also used as herbal medicine to control or prevent dysentery,

Table 4. Average area, production and yield of fibre crops in Garo Hills (2013-2016)

District	Cotton			Jute			Mesta		
	Area (ha)	Production (MT)	Yield (kg/ha)	Area (ha)	Production (MT)	Yield (kg/ha)	Area (ha)	Production (MT)	Yield (kg/ha)
East Garo Hills	1805	1707	161	45	513	2065	18	111	1110
North Garo Hills	864	758	149	407	4605	2035	50	323	1165
West Garo Hills	3974	5531	236	3899	40877	1887	222	12707	1030
South West Garo Hills	445	603	230	1732	18461	1918	1305	7858	1083
South Garo Hills	203	253	212	515	2699	943	884	5282	1076
Garo Hills	**7292**	**8851**	**198**	**6598**	**67155**	**1769**	**2479**	**26281**	**1093**

Source. *: Dept. of Statistics, West Garo Hills, 2015-16*

worm and constipation *etc.* Jute leaves are being used as health food in Japan. Jute leave is rich in vitamins, carotinoids, calcium, potassium and dietary fibers. Mesta leaves are used for preparing pickles and curries. The mesta seed contain about 16 to 20 per cent oil which can be used for culinary purposes and for manufacturing soaps. Kenaf seeds yield a vegetable oil that is edible with no toxins. Kenaf oil is high in omega polyunsaturated fatty acids (PUFA) which are now known to help in keeping humans healthy. Kenaf seed oil contains a high percentage of linoleic acid (Omega 6) a polyunsaturated fatty acid (PUFA). Linoleic acid (C18:2) is the dominant PUFA, followed by oleic acid (C18:1). Alpha-linolenic acid (C18:3) is present in 2 to 4 percent. The PUFAs are essential fatty acids for normal growth and health. Furthermore, they are important for reducing cholesterol and heart diseases.

Wildly grown ramie species *(Boehmeria platylus)* have been reported to be found in Garo hills where the local farmers made fishing rod from ramie stem, strings of local musical instrument from the fibres and for feeding of tender leaves of ramie crop to cattle

QUALITY PARAMETERS OF FIBRE CROPS : Degummed ramie fibre is pure cellulosic (>90%) with little hemicellulose (<3%) and negligible lignin (<0.5%) (Table 5) (Satya *et al.*, 2010). Degummed ramie, the strongest bast fibre of nature and fibre contains of >85 per cent á-cellulose. The ramie cellulose exists in four crystalline forms, designated as cellulose I, II, III and IV. A parallel two-chain structure for ramie cellulose has been established by X-ray diffraction analysis (Woodcock and Sarko, 1980). The cellulose chains are oriented through eight glucose units to form the crystalline structures, providing the chain structure high tensile strength. The degree of polymerization of cellulose sub-units in ramie is very high (5800) compared to cotton (4700) and jute (4700) (Timmell, 1957). Degree of polymerization is an indicator of viscosity of the fibre and resistance to microbial degradation. Highly pure cellulose content with high polymerization makes the fibre more resistant to fungal and bacterial degradation compared to other bast fibres. The chemical properties of ramie fibre exhibit high variability indicating these properties to be highly influenced by genotype, age of fibre,

Table 5. Fibre quality parameters of ramie in comparison with other major fibre crops

Fibre quality parameters	Ramie	Cotton[a]	Jute[b]
Fibre physical characteristics			
Ultimate fibre cell length (mm)	200 – 250	16 – 52	0.8 – 6.0
Ultimate fibre cell breadth (ìm)	15 – 80	15-20	5 – 25
L/B ratio	3500	2500	110
Gravimetric fineness (tex)	0.4 – 0.8	0.1 – 0.3	1.25 – 3.
Fibre filament tenacity (g/tex)	40 – 65	30 – 35	20 – 30
Chemical composition of fibre (%)			
á-Cellulose	86.9	88 – 96	61.0
â-Cellulose	5.0	-	-
Hemicellulose	3.9	-	15.9
Lignin	0.5	-	13.5

Source: Sarkar *et al.*, 2010, Satya *et al.,* 2010 a – average of 4 cotton species; b- average of *C. capsularis* and *C. olitorius* at 120 days

processing of fibre, gum content and agro-climatic conditions (Pandey, 2007). Industrially available of nature ramie fibres obtained by special degumming and bleaching technologies exhibit better fibre fineness and fibre strength than ramie fibres obtained by simple alkali based degumming methods. Fibre quality parameters of ramie in comparison with some other fibre crops are presented in Table 5.

MORPHOLOGICAL CHARACTERISTICS OF GARO HILLS COTTON GERMPLASM : The germplasm accessions collected was having specific morphological character *viz.,* long petiole, deeply palmate leaves, cordate base, central lobe once or twice toothed near the sinus, long broad bracts, elongated- ovate acute, acrescent capsule/boll, white and yellow petals, yellow and creamy pollens, tri-locular ovary, high boll weight (5 g -7.5 g), high locule retentivity, locules with 12-20 seeds free from each other and firmly bound through interlacing of their wool. They also possessed high ginning outturn (upto 51%) short staple (17-21.8 mm) and coarse fibre (micronaire upto 8) (Table 6). High boll weight was recorded in the germplasm accessions GHA 11, GHA 6, GHA 3, GHA 18, GHA 23, 30826 and 30838, respectively. The ginning outturn ranged from 38.0 to 51.0 per cent (Table 1), however earlier studies (Singh and Nandeshwar 1983; Singh and Raut, 1983 : Punit Mohan *et al.,* 1992) have reported higher ginning outturn (GOT) with high seed density/boll in selected genotypes of *cernuum* race. Bolls/plant is one of the important components of yield and is positively correlated with it. All the available reports indicated a significant positive correlation between boll no. and yield (Shinde and Deshmukh, 1985 and Aher *et al.,* 1989). Boll number was negatively correlated with boll weight. Therefore, simultaneous improvement of boll number and boll weight may be difficult. (Butany *et al.,*1966; Bhatt *et al.,* 1967; Singh *et al.,* 1968 and Singh *et al.,* 1979). The improvement of genetic make up of cotton plant for assured yield contributing characters, namely (a) boll number, (b) boll weight, and (c) ginning outturn. Extensive genetical investigations of the above three important yield contributing characters have been carried out by several workers. The findings reported by them have been summarised in Table 6. Amount of lint obtained from the seed cotton and staple length are the important criteria that determine the genetic potential of a cultivar. These two components are correlated with the density development of fibre per unit area on seed coat. The ginning outturn is another important component of lint yield but it is again polygenic character. The values for ginning outturn of *arboreum* cottons in India ranges from 22 to 52 per cent. Comilla cotton belonging to race *cernuum* ginns to 49 per cent or even more (Barooah and De, 1950). The race *bengalense* and the race *indicum* types occupy the second and third position, respectively. In *bengalense* cottons those possessing white flowers and narrow central leaf lobes *i.e.,* like Roseum, N. Roseum 6 and 231 Rosea, show higher ginning (36 to 43%) Therefore, *cernuum* and Roseum cottons been used in hybridization programme, wherever necessary, for improving the ginning character of *arboreum* cottons of different tracts . The variability potential in *Gossypium arboreum* race *curnuum* offers immense possibilities in breeding for improvement in boll weight, fibre strength and ginning outturn of *desi* cotton.

Shedding of seed cotton locules from the fully opened mature bolls is a serious problem in *arboreum* cottons (Singh and Punit Mohan 2004). Most of the released varieties of this species suffer from locule shedding after boll bursting. As a result the seed cotton loaded locules falls on the ground, get mixed with leaf bits and soil particles resulting the deterioration of the cotton quality. This species warrants immediate picking after boll bursting. The high locule retentivity was observed in race *cernuum* than race *bengalense* and *indicum* (Singh and Punit Mohan 2005). Locule retentive cultivars help in reducing the pre harvest seed cotton loss due to adverse weather in the form of high wind, rain and hailstorm. Therefore, race *cernuum* can be utilized in the future breeding programmes for the development of locule retentive cultivars of *arboreum.*

The Gray mildew disease of cotton especially *G. arboreum* caused by the fungus *Ramularia areola* Atk (*Ramularia gossypii*) has been reported as a disease of great economic importance in India and other cotton growing areas in the world. In all of 1592 accessions of *Gossypium arboreum* were screened against the grey mildew disease (*Ramularia areola, synonym Ramularia gossypii*) six germplasm lines resistant to grey mildew disease have been identified namely G 135-49, 30805, 30814, 30826, 30838 and 30856, belong to *G. arboreum* race *cernuum* and can be utilized in development if varieties/ donor lines resistant / tolerant to gray mildew disease. Morpho- anatomical investigations of resistant lines were carried out which indicate host immunity and greater variability in anatomical features viz., thick smooth cuticle, interlocked epidermal cells, high degree of lamina thickness in comparison to commercial susceptible *G. arboreum* cultivars viz., AKH 4 and AKA 8401 (Punit Mohan *et al.*, 1997). The variability in foliar anatomical features has been summarized in Table 7. The race *cernuum* is an ecotype representing the final product of localised selection tendencies among perennial cottons in north east India as reported by Simlote (1956).

Table 6. High ginning outturn and high boll weight germplasm accessions of *Gossypium arboretum* cotton in Garo Hills

Sr. No.	Name of germplasm	Boll weight (g)	Bursted locule length (cm)	Ginning outturn (%)	2.5 per cent staple length (mm)	Uni-formity ratio (%)	Fine-ness micro-naire 10^{-6} g/in	Bundle strength tenacity (g/tex) at 3.2 mm gauge	Elon-gation (%)
1.	GHA 1	6.5	14.0	40.1	18.9	52	7.9	15.3	5.7
2.	GHA 2	6.3	14.0	40.0	18.2	51	8.0	14.8	5.4
3.	GHA 3	7.2	13.5	42.3	18.6	51	8.0	14.8	4.9
4.	GHA 4	6.8	12.3	38.5	19.0	51	8.0	15.4	5.1
5.	GHA 5	6.8	13.2	40.2	17.9	52	8.0	14.6	4.9
6.	GHA 6	7.5	13.5	48.5	19.4	52	8.0	15.4	4.8
7.	GHA 7	7.0	14.5	39.5	18.0	51	8.0	14.7	5.3
8.	GHA 8	7.2	14.0	39.0	19.6	51	8.0	15.1	5.1
9.	GHA 9	6.8	13.3	40.1	19.9	52	7.5	14.8	4.6
10.	GHA 10	6.0	13.0	42.0	18.1	54	8.0	14.4	5.3
11.	GHA 11	7.5	14.2	41.0	18.9	51	7.9	15.3	5.2
12.	GHA 12	7.3	15.0	48.0	18.2	53	8.0	14.4	5.2
13.	GHA 13	6.9	14.2	39.5	18.6	53	8.0	14.8	5.2
14.	GHA 14	6.0	14.0	40.2	18.2	53	7.9	14.8	5.2
15.	GHA 15	5.8	12.4	38.0	18.9	55	7.5	14.8	5.0
16.	GHA 16	6.9	13.7	38.3	17.6	51	7.8	14.8	5.5
17.	GHA 17	6.3	13.7	44.0	18.0	52	7.5	15.2	5.3
18.	GHA 18	7.3	15.3	40.1	17.8	51	7.9	15.0	5.4
19.	GHA 19	7.0	14.0	49.3	17.6	52	7.8	15.4	5.5
20.	GHA 20	6.3	13.2	40.3	18.5	51	7.3	16.0	5.0
21.	GHA 21	5.5	12.8	38.7	18.0	51	7.5	15.4	5.5
22.	GHA 22	5.0	13.3	38.0	17.6	52	7.8	14.5	5.1
23.	GHA 23	7.3	14.9	40.5	17.9	51	7.8	14.9	5.3
24.	G 135-49	5.9	13.0	39.6	21.8	50	7.5	19.7	5.0
25.	30805	6.4	13.0	43.1	20.2	50	7.9	17.9	4.4
26.	30814	6.1	13.0	48.7	17.5	52	7.3	16.4	5.0
27.	30826	7.3	15.3	51.0	18.5	49	7.0	17.0	5.1
28.	30838	7.1	15.5	48.1	20.3	50	7.5	16.4	4.9
29.	30856	6.3	14.3	46.1	17.0	48	7.5	16.0	5.1
	Range	**5.0-7.5**	**12.3-15.5**	**38.0-51.0**	**17.0-21.8**	**48-55**	**7.0-8.0**	**14.4-19.7**	**4.4-5.7**

Source: (Punit Mohan *et al.,* 2010)

The results presented in Table 6 show that a significant variability for boll weight, ginning percentage, fibre properties and their extent of association with several economic traits have been observed However, their mode of inheritance need to be studied as it will help in better selection of parental genotypes and their effective manipulation in breeding

Table 7. Foliar anatomical features of immune and susceptible tree cotton (*Gossypium arboreum* L.) in relation to grey mildew disease (*Ramularia areola* Atk) in Garo Hills

Germplasm accession	Cuticle thickness (μ)*	Lamina thickness (μ)*	Thickness covered by palisade parenchyma (μ) *	Thickness covered by spongy parenchyma (μ) *	Epidermal cell*	Stomata*
‘Bangladesh’	5.166	115.62	46.90	39.52	19.31	71.19
‘G 135-49’	4.936	113.16	51.82	39.52	19.23	67.50
‘30805’	4.166	113.16	41.98	39.52	19.45	69.31
‘30814’	4.920	113.16	41.98	39.52	19.38	69.28
‘30826’	4.920	113.16	41.98	39.52	19.55	71.53
‘30838’	4.920	110.70	41.98	39.52	21.74	71.46
‘30856’	3.690	113.16	41.98	39.52	19.55	71.81
‘AKH 4’	2.460	108.24	37.06	39.52	14.77	89.44
‘G 27’	2.460	105.75	37.48	39.52	17.53	103.35
Range	3.690	110.70	41.98	39.52	19.23	67.50
(immune)	5.166	115.62	51.82	39.52	21.74	71.81
Range(susceptible)	**2.460-2.460**	**105.75-108.24**	**37.06-37.48**	**39.52-39.52**	**14.77-17.53**	**89.44-103.35**

* = Per microscopic field., (Punit Mohan *et al.,* 2010)

programme. The traditional cultivation practices of fibre crops in Garo hills are depicted in Table 8.

TRADITIONAL AGRICULTURAL IMPLEMENTS USED FOR RAMIE CULTIVATION IN GARO HILLS : The tribal farmers of the villages in Garo hills use simple tools and implements for various farm operations as shown in Table 9 for cultivation of ramie crop. The local implements are either bought from the market or made by themselves with help of local specialists such as carpenters and blacksmiths. Every household has its own various agricultural tools and implements based on the landholding size of the farmer.

PROSPECTS OF TRADITIONAL FIBRE CROP PRODUCTION IN GARO HILLS : Fibre yielding plants have been of great importance to man and they rank second only to food plants in their usefulness. In Meghalaya, Garo hills districts are recognized as one of the fibre crop producing areas. Among the fibre crops, cotton, jute, ramie and mesta are prominent traditional cash crops supporting the livelihood and improving the economic level of many farmers of Garo hills. The cultivation of these fibre crops is undertaken in slightly sloppy and plain lands spread over the hills and tribal areas of the entire region. The soil and climatic condition of Garo hills are highly favourable for cultivation of the mention four fibre crops and it would helped to bring few lands which are waste and degraded under its production as it require less inputs. These fibre crops can be grown on marginal lands, require less care and the produce can be stored for a longer period of time. The farmers grow fibre crops as pure crop due to higher yield as compared to yield obtained in mixed cropping

Table 8. Traditional cultivation practices of Fibre crops (cotton, Jute, Mesta & Ramie) in Garo Hills, Meghalaya

Characteristics	Cotton	Jute	Mesta	Ramie
Varieties	Assam Comilla, Kil Bolma (local)	JRO-524, 632	Local (*Kosta*)	Kilkra (local), R-114, Kanai
Sowing time	March -April	March- April	February- March (plains) April- May (hills)	May- June
Soil condition	Red lateritic soils (jhum lands)	Sandy to sandy clay loam	Sandy to sandy clay loam	Sandy to Red sandy clay loam
Climates	Sub tropical humid climate	Warm humid climate	Warm humid climate	Warm sub-tropical humid climate
Seed rate	7.5 kg/ha	7.5 kg/ha	15 kg/ha	Rhizomes (8-10q/ha)
Method of sowing	Digging the soil by using local made dibbler known as *Matha* in Jhum areas	Broadcasting	Broadcasting	*Zig-zag* in Jhum land, Line sowing
Fertilizers /manures	No application	75 kg urea/ha in plainsNo application in hills	No application	5-10t FYM/ha
Intercultural operations	2 times manual weeding 30DAS and 60 DAS	1 time manual weeding (25 DAS)1 time manual weeding + thinning (60DAS)	1 time manual weeding 30 DAS	2 times manual weeding30DAS,60DAS
Harvesting	Last week of November- 15th of December	ManualLast part of August- First week of September	ManualAugust- September (plains)November-December (hills)	1st cutting harvest in August - September After that every 45 days cutting (4times)
Yield (kg/ha)	6500-7000 kg/ha	3000 kg/ha	2400- 2500 kg/ha	1500-1700 kg/ha
Processing	Locally made by wood spinning machine	Traditional retting in running waters of rivers	Traditional retting in running waters of rivers	Fibre extraction machine provided by ICAR & DAO
Marketing	In weekly markets	In weekly markets @ Rs.25/kg	In weekly markets @Rs.15/kg	No market for ramie in Garo Hills but DAO, Govt. of Meghalaya is buying back from farmers @ Rs.70/kg

conditions. Since these crops do not require much attention or care and no serious disease or insect damages are observed, they get preference as risk aversion crops in this difficult region. Studies carried out on fibre yielding plants (Palni *et al.,* 1999) and reveal that fibre yielding plants and their products played a significant role in the different activities of rural setup in mountain villages. Traditionally, the local farmers of Garo hills are not so aware about the economic value of these fibre crops but now at present with the help of State Government, various areas of hill villages which were wastelands and degraded are converted and convinced to grow as they know the potential and value of these crops. Processing and marketing of fibre crops is a big problem for the farmers due to lack of knowledge about the market linkages, remoteness of the state and moreover role played by the middleman/ commission agents contributing to less profit of the produce to the farmers. The price of fibre crops varies from area to area and place to place. The price rate is lesser in remote areas or interior of the village comparing with urban areas. The reason is that the mode of transportation in remote areas are very poor and moreover no processing units in areas nearby. Therefore, market promotion would be very much helpful to play an important role and village or community level small co-operatives where collection and processing of raw fibre from a particular area/region can be done and which can make a direct approach to market is need to be encouraged. This will provide a supplementary job and bonus income to villagers. Since hill economy and agriculture is women folk based, the action to empower them through training in technical, leadership and organization skills can led to successful outcomes from implemented strategies, individual household food security and conserving agriculture diversity. Till date no scientific studies have been carried out in Garo hills in relation to yield enhancement of these fibre crops and therefore, in depth research is needed to improve its quantity and yield potential.

The cotton variety D. 46-2-1 belonging to the *Gossypium arboreum* has a good market as short staple cotton for its softness and durability which are also used for mixing with wool. The cotton species *Gossypium hirsutum, Gossypium barbadens* and *Gossypium harbaceum* are also grown in Garo hills with the varieties G 54-1 and G 135-49. The *Capsularis* jute varieties JRC 321, D 154, JRC 7447 and *Olitorious* varieties JRO 632, JRO 514, JRO 7835, JRO 878, JRO 204

Table 9. Local Agricultural implements used by farmers in ramie crop cultivation

Local Name	English Name	Uses
Cheni	Small sickle	Weeding
Gitchi	Small Spade	Weeding and to dig up the soil, harvesting
Ate Ganga	Dao (Sword)	Clearing the jungle
Ate Mande	Dao (Sword)	Cutting of stems and clearing of jungle for Jhum cultivation
Kudal	Spade	Harvesting and earthingup
Matha	Dibbler	Digging stick seeding
Katchi	Sickle	Weeding and cutting of leaves for animal consumption purpose

and JRO 524 are grown in Garo hills besides *Tossa or desi* local variety. The Mesta varieties grown are *Hisbiscus sabdariffa* (HS 4288 and AMVI) *and Hibiscus cannabinus* (HC 583). Generally ramie fibre is strong, lustrous and durable compared to any other major textile fibres. The tensile strength, absorbency, and the drying properties of ramie fibre are often superior to cotton, flax and jute. The ramie is considered as the finest among all the textile fibres and its fineness is comparable only to that of cotton and silk. The ultimate fibre length and tenacity of ramie is highest among all bast fibres. The strength, lustre and absorbance capacity of the fibre makes it a special one among the natural fibres. It is commonly known as 'China Grass' in the trade market and is also known as 'Grass linen' or 'China Linen'.). Ramie fibre is primarily used for blending with cotton and silk for its unique strength and absorbance. It is also used for making apparels, curtains, draperies, upholsteries, towels, canvass, filter cloths, etc. The fibre has tremendous scope for blending with other natural and synthetic fibres for manufacturing of apparels and also for production of diversified items. The waste fibre can be used for manufacturing currency notes and cigarette papers while the woody portion can be used for producing several other bio-degradable products like plywood, particle board, fibre board, etc.

CONCLUSION

The traditional agricultural systems help in improving soil fertility through decomposition of plant material left on soil as the people of Garo hills, Meghalaya believe in traditional agricultural system. The fibre has tremendous scope for blending with other natural and synthetic fibres for manufacturing of apparels and also for production of diversified items. The traditional agricultural production systems evolved from the traditional; knowledge systems are performing very well even today in conserving bio resources/ natural resources and in sustaining hill ecosystem. Cotton, jute, mesta and ramie are the major traditional cash crop in Garo hills. The cotton belonging to the *Gossypium arboreum* has a good market as short staple cotton for its softness and durability which are also used for mixing with wool. The ginning outturn ranged from 38.0 to 51.0 per cent. The jute variety JRO 204 and JRO 524 are grown in Garo hills besides *Tossa or desi* local variety. The Mesta varieties grown are *Hisbiscus sabdariffa* (HS 4288 and AMVI) *and Hibiscus cannabinus* (HC 583). Generally ramie fibre is strong, lustrous and durable compared to any other major textile fibres. The tensile strength, absorbency, and the drying properties of ramie fibre are often superior to cotton, flax and jute. Hence, the traditional fibre crop production in Garo hills need for improvement to enhance production and productivity and marketing linkage for better prices by the farming community of the region.

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Precision nutrient management in cotton under northern transition zone of Karnataka

M. P. POTDAR*, GURUPAD B. BALOL, SUNIL A. SATYAREDDI, C. P. CHANDRASHEKAR AND N. A. YELEDHALLI

Project on Precision Farming in Maize and Cotton, Directorate of Research, University of Agricultural Sciences, Dharwad – 580 005

**E-mail: mppotdaruasd@gmail.com*

ABSTRACT : Field investigations were carried on precision nutrient management in cotton at MARS, Dharwad for three years under rainfed conditions. Spatial soil variability was assessed from 1.6 ha area by dividing the entire area into 40 grids (each 20 x 20 m size) and soil fertility maps were prepared. Management zones were delineated based on the soil fertility maps using nearest neighborhood technique. Nutrient prescription maps were generated based on site specific nutrient management principles. Target yield of 15, 20, 25, 30, 35 and 40 q/ha were assigned to different management zones (LHH, LHM, MHH, LLH and LMH) and compared with RDF and absolute control. Target cotton yield of 25, 30 and 35 q ha^{-1} resulted in expected yield during 2014-2015 which received well distributed and normal rainfall during the cropping period. During 2015-2016 which received deficit rainfall resulted in achievement of 15 and 20 q/ha target yield of cotton. Target cotton yield of 35 and 40 q/ha resulted in higher cotton yield of 83.8 and 87.5 per cent, respectively over RDF during normal rainfall year. Under deficit rainfall year, target yield of 25 and 30 q/ha recorded 58.1 and 72.5 per cent higher cotton yield, respectively over RDF. Results conclusively indicated scope for improvement of the cotton yield by following SSNM (target yield) approach over the RDF under rainfed conditions.

Key words : Management zone, precision nutrient management, spatial variability, target yield

Cotton (*Gossypium* sp) is one of the most important textile fibers grown commercially across world. Globally, cotton production has markedly increased because of the steep rise in productivity due to the introduction of insect resistant transgenic technology. Contribution from the Asian countries accounts for the major share in global cotton improvement (Singh, 2017). Currently, in India cotton is cultivated on an area of 105 lakh ha with production of 351 lakh bales and productivity of 568 kg/ha. Karnataka accounts for 4.64 lakh ha area, 21 lakh bales production and productivity of 769 kg/ ha (CCI, 2017). Statewise and national average productivity trends have shown an increasing trend over years, yet lower than the potential of the crop. Sustainable cotton production requires better understanding of the specific crop demand, soil nutrient supply capacity, moisture regime, better pest management etc. Cotton being high input demanding crop requires better nutrient management for enhanced efficiency and improved yield. Precision nutrient management is one of such tools which offer scope for the improvement of the yield levels. Embedding 4Rs principles, right nutrient source, at right rate, right time, and in right place with precision nutrient management principles enhances the efficiency and sustainability in cotton production. SSNM based "target yield" approach was used in the study which considers soil fertility linked fertilizer dose to attain the desired yield which is opined to be the approach for balanced fertilization aiming at sustainability (Aladakatti *et al.,* 2011). Scope for adoption on small scale precision farming technology is often considered as challenging yet it's a potential approach. Thus one of such attempt was made to study the effect of SSNM based target yield approach on *Bt* cotton yield under rainfed condition at UAS, Dharwad.

MATERIALS AND METHODS

The experimental site was distributed from 15° 30.01' to 15° 30.11' N latitude and 74° 59.16' to 75° 59.15' East longitude comprising 1.6 ha. Experiment was divided into 40 grids with each grid having 20 x 20 m size. Soil samples (from each grid) were drawn up to 30 cm depth. Sampling spot was recorded using GPS. The soil spatial variability for N, P_2O_5 and K_2O were assessed as per the procedure by following standard analytical techniques. Soil spatial variability was observed with respect to all chemical properties within the study area.

Soil type of the experimental site was deep vertisol. Based on the soil fertility status, management zones were delineated by using nearest neighborhood technique. Management zones were denoted as L- low, M-medium, H-high indicating the status of available N, P_2O_5 and K_2O comprising LHM and LHH (two zones); LHH, LMH, LLH and MHH (four zones); LLH, LMH, LHH and MHH (four zones) during 2014-2015, 2015-2016 and 2016-2017, respectively (Fig 1). Each zone was allotted with 4 target yields *viz.*, 25, 30, 35 and 40 q/ha during 2014-2015 and 2016-2017.

During, 2015-16, due to moisture stress for 40 days the target yields were reduced to 15, 20, 25 and 30 q/ha. RDF treatment was included as check along with absolute control for assessing the yield improvement and efficiency indices. Distribution of the rainfall during the cropping period is presented in Table 1. Intra

Table 1. Distribution of the rainfall during the cropping period

Year	Rainfall (mm) distribution month wise								
	Pre-sowing period (May-June)	Deviation from normal	July	Aug	Sept	Oct	Nov	Dec	Total	Deviation from normal
2014-2015	226.4	+79.3 %	242.2	158.4	100.2	103.4	48.8	26.2	679.2	+29.9%
2015-2016	289.6	+129.3 %	42.8	34.4	22.4	179.8	28.6	0.0	308.0	-41.1%
2016-2017	158.4	+25.4 %	150.2	112.2	73.4	44.8	5.8	0.0	386.4	-26.1%
LT mean (1950-2013)	**126.3**	**-**	**153.5**	**100.7**	**107.6**	**124.5**	**31.6**	**5.0**	**523.0**	-

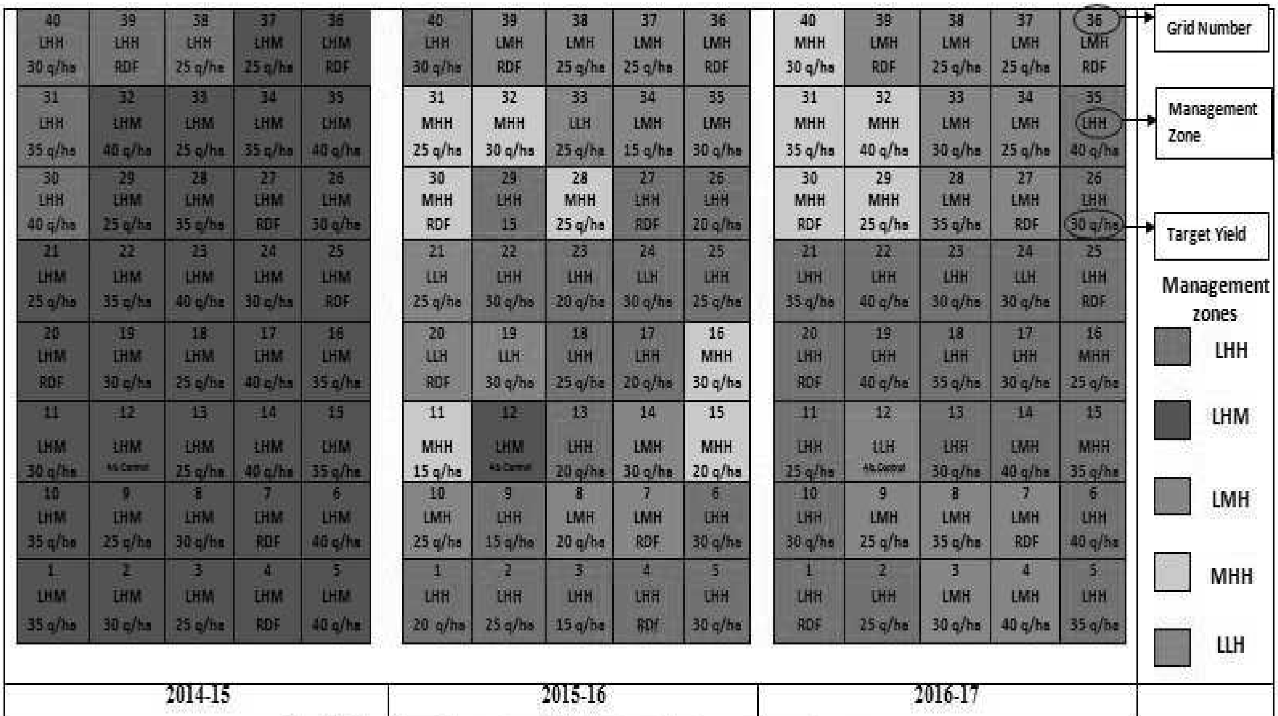

Fig. 1 Delineation of experimental site into nutrient management zones

hirsutum *Bt* cotton (BG II) hybrid (First class) with spacing of 90 x 60 cm was used during the study.

Nutrient uptake by cotton (4.48:1.76:5.77 kg N:P_2O_5:K_2O/ha) to produce 100 kg *kapas* yield based on the previous studies in the agro climatic zone (Zone 8) was considered for working out required quantity of nutrients based on the target yield (Gowramma, 2017).

The amount of nutrients required to achieve target yield were calculated by using the following formulae (Biradar *et al.*, 2012). The nutrient prescription maps were generated based on site specific nutrient management

Table 2. Nutrients required to achieve target yields

Target yield (q/ha)	Nutrients (kg/ha)								
	N			P_2O_5			K_2O		
	L	M	H	L	M	H	L	M	H
15	80.6	67.2	53.8	31.7	26.4	21.1	103.9	86.6	69.2
20	107.5	89.6	71.7	42.2	35.2	28.2	138.5	115.4	92.3
25	134.4	112.0	89.6	52.8	44.0	35.2	173.1	144.3	115.4
30	161.3	134.4	107.5	63.4	52.8	42.2	207.7	173.1	138.5
35	188.2	156.8	125.4	73.9	61.6	49.3	242.3	202.0	161.6
40	215.0	179.2	143.4	84.5	70.4	56.3	277.0	230.8	184.6
RDF	100	50	50						
Absolute control	0	0	0						

Status of available N, P_2O_5 and K_2O denoted as L- low, M-medium, H- high

(SSNM) principles and the target yield to be achieved.

NR= {Nutrient uptake by crop (kg/q) × T} ± per cent ENR

Where,

NR - Nutrient required (kg/quintal seed cotton yield)

T - Target of seed cotton yield (q/ha)

ENR - Extra nutrient recommendation

Soil nutrient status	Per cent ENR
LOW	20 per cent more than the calculated value
MEDIUM	As per the calculated value
HIGH	20 per cent less than the calculated value

Fertilizer application: N, P_2O_5 and K_2O were applied based on uptake studies in the form of Urea, DAP, 10:26:26, SSP and MOP. The entire P_2O_5 and K_2O was applied as basal and nitrogen in two split during 2014-2015 and 2016-2017 (50 % as Basal and 50 % at 60 DAS) and three splits during 2015-2016 (33.3 % as Basal, 33.3 % at 60 DAS and 33.3 % at 90 DAS) due to utilize the nutrients efficiently in view of moisture stress situtation. Variable rate of nutrients as per nutrient prescription maps were applied to each grid manually (Table 2)..

RESULTS AND DISCUSSION

Growth and growth attributes: Response to the nutrient prescription as per target yield was recorded with respect to the plant height (Table 3). Plant height in cotton is important growth parameter with respect to harnessing solar radiation and ease of cotton picking. Irrespective of the management zones, higher plant height was recorded with target yield of 40 q/ha over target yield of RDF and absolute control at harvest during 2014-2015 and 2016-2017. Similarly target yield of 30 q/ha recorded higher plant height over rest of the nutrient management treatments. The treatment absolute control recorded shorter plant. Across the management zones and years of experimentation RDF treatment recorded shorter plant height than the target yield of above 20 q/ha.

SPAD : The SPAD (leaf chlorophyll content) values differed across the nutrient management

Table 3. Influence of precision nutrient management on plant height at harvest

Target yield (q/ha)	Plant height (cm)									
	2014-2015			2015-2016			2016-2017			
	Management zones									
	LHM	LHH	LLH	LMH	LHH	MHH	LLH	LHH	LMH	MHH
15	-	-	-	**96.1**	98.9	98.1	-	-	-	-
20	-	-	-	**102.4**	99.4	102.1	-	-	-	-
25	148.9	155.9	100.6	**102.2**	105.7	108.9	-	140.1	139.5	138.7
30	151.2	163.6	107.1	100.1	104.6	106.8	-	139.5	138.8	140.3
35	155.1	168.3	-	-	-	-	-	141.8	142.5	143.0
40	163.6	170.4	-	-	-	-	-	149.2	146.1	151.3
RDF	140.5	151.8	94.7	96.7	99.2	98.9	-	132.2	136.7	135.7
Absolute control	-	93.1	90.1	—	-	-	85.1	-	-	-

Table 4. Influence of precision nutrient management on SPAD at 120 DAS

Target yield (q/ha)	SPAD at 120 DAS									
	2014-2015			2015-2016			2016-2017			
	Management zones									
	LHM	LHH	LLH	LMH	LHH	MHH	LLH	LHH	LMH	MHH
15	-	-	-	41.9	39.7	39.3	-	-	-	-
20	-	-	-	42.6	43.4	44.7	-	-	-	-
25	43.3	45.6	45.8	45.3	43.9	44.9	-	43.6	39.8	44.3
30	45.9	47.7	47.3	48.8	46.9	46.3	-	44.0	43.7	40.3
35	47.1	48.6	-	-	-	-	-	44.2	44.5	44.1
40	47.8	49.5	-	-	-	-	-	44.8	44.9	44.3
RDF	42.0	42.4	42.7	42.2	42.5	42.9	-	40.8	38.8	36.2
Absolute control	-	36.9	36.4	-	-	-	28.4	-	-	-

zones and target yield treatments. The SPAD value increased up to 90 days from the beginning and declined then onwards. SPAD values at peak growth stage of 120 DAS are presented in Table 4. Target yield of 35 and 40 q/ha recorded higher SPAD values over target yield of 25, 30 q/ha, RDF and absolute control during 2014-15. During 2015-16, target yield of 30 q/ha higher SPAD values above rest of the nutrient management treatments. Whereas in 2016-2017, target yield of 30, 35 and 40 q/ha recorded higher SPAD values above 25 q/ha, RDF and absolute control. Similar results were observed by Yadachi *et al.* (2017). Significantly lower SPAD chlorophyll meter reading were recorded in absolute control.

Normalized difference vegetation index (NDVI): The Normalized Difference Vegetation Index (NDVI) values differed across the management and the precision nutrient management treatments across the years of experimentation. Higher NDVI values were recorded with target yield of 40 over target yield of 25, 30, 35 q/ha, RDF and absolute control. Whereas, absolute control recorded the significantly minimum NDVI value (Table 5). Variation among the target yield level treatments was in narrow range. Similar

Table 5. Influence of precision nutrient management on NDVI at 120 DAS

Target yield (q/ha)	NDVI values									
	2014-2015			2015-2016			2016-2017			
	Management zones									
	LHM	LHH	LLH	LMH	LHH	MHH	LLH	LHH	LMH	MHH
15	-	-	-	0.81	0.83	0.80	-	-	-	-
20	-	-	-	0.83	0.83	0.83	-	-	-	-
25	0.84	0.85	0.84	0.85	0.85	0.83	-	0.86	0.87	0.86
30	0.86	0.88	0.89	0.86	0.87	0.87	-	0.87	0.87	0.87
35	0.88	0.87	-	-	-	-	-	0.89	0.89	0.88
40	0.88	0.89	-	-	-	-	-	0.89	0.89	0.89
RDF	0.82	0.82	0.82	0.82	0.82	0.80	-	0.85	0.85	0.85
Absolute control	-	0.77	0.60	-	-	-	0.76	-	-	-

Table 6. Influence of precision nutrient management on monopodial branches at harvest

Target yield (q/ha)	Monopodial branches									
	2014-2015			2015-2016			2016-2017			
	Management zones									
	LHM	LHH	LLH	LMH	LHH	MHH	LLH	LHH	LMH	MHH
15	-	-	-	2.4	2.4	2.3	-	-	-	-
20	-	-	-	2.6	2.7	2.5	-	-	-	-
25	3.4	3.7	2.9	2.9	2.5	2.5	-	3.3	3.2	3.3
30	3.6	3.6	2.3	3.4	2.7	2.5	-	3.6	3.5	3.3
35	3.6	3.7	-	-	-	-	-	3.6	3.7	3.7
40	3.7	3.8	-	-	-	-	-	3.5	3.7	3.7
RDF	3.4	3.4	3.3	2.6	2.2	2.3	-	3.2	3.2	3.3
Absolute control	-	2.8	2.4	-	-	-	2.6	-	-	-

Table 7. Influence of precision nutrient management on Sympodial Branches

Target yield (q/ha)	Sympodial branches									
	2014-2015			2015-2016			2016-2017			
	Management zones									
	LHM	LHH	LLH	LMH	LHH	MHH	LLH	LHH	LMH	MHH
15	-	-	-	24.1	19.8	23.0	-	-	-	-
20	-	-	-	26.5	24.6	24.3	-	-	-	-
25	51.7	59	25.1	24.3	26.2	27.7	-	33.6	35.7	35.7
30	55.4	60.1	27.7	29.0	25.6	24.8	-	37.5	37.2	38.3
35	55.5	59.2	-	-	-	-	-	36.7	37.7	34.3
40	61.4	62.3	-	-	-	-	-	41.3	38.7	40.7
RDF	49.9	57.9		21.7	20.2	25.1	-	32.0	33.5	33.3
Absolute control	-	36.4	19.7	-	-	-	24.1	-	-	-

results were observed by Yadachi *et al.,* (2017).

Yield and yield attributes: The observations on crop spatial and temporal variability revealed differential response with respect to the yield attributes like sympodial branches and number of bolls/plant. Variation in monopodial branches across the treatments was minimal except the control treatment which recorded lower number of monopodial branches (Table 6).

Sympodial : At harvest, higher number of sympodial branches/plant were recorded with target yield of 40 q/ha over target yield of 25, 30, 35 q ha^{-1}, RDF and absolute control at harvest during 2014-2015 and 2016-2017 (Table 7). Whereas in 2015-2016, target yield of 30 q/ha recorded higher number of sympodial branches/plant. Differential response of the sympodial branches due to management zones was minimal.

Number of bolls/plant : Boll/plant is one of the important yield attributes which was influenced by management zones and target yield based precision nutrient management practices. Higher target yield induced increase in boll number per plant over RDF across the management zones (Table 8). Similar trend was recorded over the years. Control recorded lower boll per plant.

Seed cotton yield: Influence on the seed cotton yield due to the management zone and precision nutrient management treatment was significant. Except in 2015-2016, target yield treatment induced increment in the yield response over RDF. Favorable soil moisture regime induced achievement of target yield of 25, 30 and 35 q/ha; 15, 20 and 25 q/ha and 25 and 30 q/ha during 2014-15, 2015-16 and 2016-17, respectively in response to the management zone and precision nutrient management treatments (Table 9). Wider variation in response to the precision nutrient management practices across the management zones was observed across the years (13.4 q/ha to 36.15 q/ha; 7.1 to 27.7 q/ha and 11.7 to 30.5 q/ha in 2014-15, 2015-16 and 2016-17, respectively). Yield improvement in LHM and LHH at target yield of 40 q/ha resulted in 89.4 per cent and 85.6 per cent, respectively over RDF during 2014-15. Similarly, yield improvement in the target yield of 30 q/ha across the management zones was 50.6 to 127.4 per cent above the RDF.

Table 8. Influence of precision nutrient management on number of bolls

Target yield (q/ha)	Number of bolls									
	2014-2015			2015-2016			2016-2017			
	Management zones									
	LHM	LHH	LLH	LMH	LHH	MHH	LLH	LHH	LMH	MHH
15	-	-	-	36.2	34.4	35.3	-	-	-	-
20	-	-	-	44.5	41.8	42.9	-	-	-	-
25	55.7	63.8	45.3	50.1	46.3	44.8	-	30.3	31.5	31.7
30	61.5	73.8	52.9	47.6	51.4	49.6	-	28.6	31.8	34.7
35	61.9	74.1	-	-	-	-	-	28.9	31.7	35.7
40	68.6	77.8	-	-	-	-	-	30.1	35.3	36.7
RDF	54.2	52.0	36.3	35.1	33.3	37.9	-	23.8	27.7	33.3
Absolute control	-	29.3	26.3	-	-	-	19.3	-	-	-

Table 9. Influence of precision nutrient management on seed cotton yield

Target yield (q/ha)	Seed cotton yield (q/ha)									
	2014-2015			2015-2016			2016-2017			
	Management zones									
	LHM	LHH	LLH	LMH	LHH	MHH	LLH	LHH	LMH	MHH
15	-	-	-	13.9	16.9	16.0	-	-	-	-
20	-	-	-	19.2	20.6	19.9	-	-	-	-
25	25.3	26.0	24.2	23.8	24.1	24.3	-	25.1	25.3	23.1
30	30.4	30.9	26.6	26.2	27.4	27.7	-	28.6	28.0	25.8
35	34.5	35.1	-	-	-	-	-	28.9	29.5	28.9
40	35.6	36.2	-	-	-	-	-	29.9	30.5	29.6
RDF	18.8	19.5	11.7	17.4	14.3	17.4	-	23.8	23.5	22.5
Absolute control	-	13.4	7.1	-		-	11.7	-	-	-

Correspondingly during 2016-2017, target yield of 40 q/ha, resulted in 25.6 to 30.5 per cent improvement over the RDF. Results conclusively indicate the progressive response of the *Bt* cotton to precision nutrient management practices to achieve target yield over RDF. Concomitantly Manjuanth *et al.,* (2014) observed similar improved cotton yield in target yield approach over RDF. However the varied response to the target yield was due to the differential rainfall induced soil moisture regime under the rainfed conditions.

CONCLUSION

Precision nutrient management offers scope for increase in cotton yield in sustainable approach over RDF even under rainfed condition.

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Physiological manipulation of cotton for enhanced production under changing climatic conditions

S. RATNA KUMARI*
Regional Agricultural Research Station, Lam, Guntur- 522 034
**E-mail:ratnaks47@gmail.com*

Cotton, "white gold" its historical name, scientifically known as gossypium plays an important role in Indian Agriculture, industrial development, employment generation and in improving national economy. The cultivated species, *Gossypium hirsutum* is grown under both irrigated and rainfed conditions, in an area of 105 lakh ha with a productivity of 568kg/ha. More than 70-80 per cent of the total cropped area is under rainfed condition and the production mainly depends on the amount and distribution of rain, which is unique for every year. Having indeterminate growth habit, the environment has conspicuous effects on growth and development of cotton plant.

The indeterminate habit of cotton crop throws up many intricacies in respect of growth and developmental events in terms of varied expressions influenced considerably by biotic as well as abiotic factors. So, modifying cotton crop through mechanical or chemical means has become an essential component of cotton production. Application of growth regulators at different stages of crop growth has shown to be an effective cultural practice to improve productivity and to bring some more amenability for cultural manipulations. Increasing number of sympodial branches, thereby increasing number of squares, flowers and bolls, reducing the drop of reproductive parts, defoliating the leaves, increasing the boll size by different means *i.e.* through foliar application of growth regulator or chemicals is possible in present day *Bt* Cotton cultivation.

In the present review, the effect of different growth regulators /chemicals on physiological manipulation of cotton plant, there by improvement in cotton production is discussed. The indeterminate growth habit of cotton crop gives it leverage to overcome early damage considerably and give opportunity for getting adequate yields due to mid and late season growth. Certain kinds of mechanical damage to young cotton such as early damage to cotyledons through feeding by beetles; effect of thrips and water stress prior to flowering have shown to cause little or no reduction in yield.

Green revolution resulted in tremendous improvement in cotton production and productivity in independent India, mainly due to the combined effect of genetic improvement through introduction of high yielding varieties, hybrids and later on hybrid Bt. Cotton, increase in area under cotton crop and agronomic management. In recent years, plateau has reached in terms of genetic improvement due to non availability of genetic diverse genes in cotton. The suitable cultivable land is becoming limitation for further increase in cotton area. There is a steady increase in the demand for natural fibre to meet the requirements of increasing population and also for export needs. Due to the population explosion and also the saturation in cotton area, new efforts should be initiated to enhance the productivity. This is only possible through the second green revolution which involves the physiological manipulation of crop growth and development, thereby enhancing the productivity/unit area. Till date, not many efforts were made to understand the physiological factors for enhancing better yield through judicious use of plant growth regulators for better plant architecture, growth and development.

As 70 per cent of cotton is grown under rainfed conditions, the crop suffers from various biotic and abiotic stresses right from germination to maturity. Under changing climatic conditions, even though there is not much variation in total rainfall, the distribution is getting changed a lot. Both the day and night temperatures are reaching peak in addition to changes in relative humidity. So, modifying cotton crop growth has become an essential component of cotton production, whether by making adjustments in fertility, water management and use of harvest aids. There is potential to influence yield if the application of growth regulators are used as and when required based on the crop growth and weather conditions. In present review, the effect of different growth regulators / chemicals on physiological manipulation of cotton plants, thereby improvement in cotton production is discussed.

Morphological development of cotton plant initiates with the vegetative growth. The primary axis of the plant remains vegetative throughout. Auxiliary branches differentiate at the base of each leaf on the plant, these branches arise at the base of vegetative leaves; initiation and the rate of formation of sympodia are partially dependent on vegetative growth. After initiation, the continuation of flowering is a function of vegetative growth. Flowering habit of cotton plant is complex and extends over a long period. The first flower buds are borne on branches at fifth to tenth main stem node. It takes three weeks for flower buds to open as blossoms about after their first appearance. After the first bolls are set, the growth rate of the main stem eventually slows down. For a time, blossoms open at faster rate than new floral branches. When all floral bud sites formed in the initial vegetative growth phase matured into blossoms, there is stop in flowering known as cut-out. Subsequent redemption of vegetative growth produces new floral sites and a second flush of flowering occurs. All these processes lead to square, blossom, boll initiation and boll maturation which are temperature dependent. Plant growth regulators can be used effectively to induce rooting, decrease or regulate the number of monopodia, increased fruit set and aid in mechanical harvesting of bolls. Based on the need, the plant growth can be regulated at various stages by using action specific plant growth regulators.

Delay in flowering: Application of ethylene induces the young squares to shed, there by delay first bloom. Prakash *et al.,* (2005) stated that application of 30 ppm ethylene (2 – chloro – ethyl phosphonic – acid) in the form of commercial formulation ethrel at 35-40 days after sowing induced the shedding of young pin head size squares and reverted back to the vegetative growth for 10 days more which changed the morphoframe of the plant before entering the reproductive stage and enhanced the seed cotton yield.

The reproductive sink removal increased plant height (Patterson *et al.,* 1978); increased the root development and branching (Prakash *et al.*, 2005), fruit removal increased square production (Rao *et al.*, 1990), stimulated square shedding triggered the photosynthates from reproductive sink to vegetative sink, thereby robust plant type (Makhdum *et al.,* 2002, Prakash *et al.*, 2004). Nipping of squares, spraying ethrel @ 30 ppm and 45 ppm at square initiation stage improved the seed cotton yield in cotton varieties and hybrids in black cotton soils through delayed and increased flowering (Ratna Kumari and Mridula George,2013). Fruit abscission due to any reason can cause plant to redirect assimilate to alter sink and shift dry matter allocation from reproductive to vegetative organ. The yield gap between potential and actual yield is very high in cotton. This can be reduced through the physiological manipulation of plant growth with the use of ethrel at lower concentration.

Reduction in monopodial number : Application of 2,3,5 Tri-iodobenzoic acid (TIBA) @ 5g/ha lowers the position of the first fruiting node by five nodes, increases boll size and boll number (Freytag and Coleman, 1973). They postulated that TIBA inhibited Auxin transport and decreased ethylene concentration, thereby increase in number of sympodial branches which stimulated the seed cotton yield to an extent 16 per cent.

Enhancement in flowering : Walhood (1958) stated that application of GA3 @ 100 ppm improved the percentage square to flower open and flower to boll set thereby the seed cotton yield. The application of GA3 increased the plant height and boll number but decreased the boll size.

Square and boll retention : Application of NAA @ 10 ppm is effective in control of square and boll shedding. Application of silver thiosulphate @ 5 ppm at peak flowering reduces the shedding of reproductive parts and enhance the yield by 20-30 per cent.

Delay in leaf senescence : Application of urea (1%) + Magnesium sulphate (1%) at peak flowering will delay leaf senescence. Application of thiourea (1%) will protect the leaf from senescence and thereby increase the photosynthetic area. Especially in *Bt* cotton, the premature senescence of leaves can be controlled by the foliar application of potassium nitrate (2%) at boll formation and boll development stage.

Vegetative growth retardant : The growth regulator PIX (1,1 dimenthyl piperidinium chloride) is an effective chemical in controlling vegetative growth. Foliar application of PIX @ 25-50G a.i./ha at early bloom stage reduced the plant height by 20-40cm than the control. It also reduced the length of the lateral branches, thereby reducing the shading effect on developing squares and bolls which in turn increased the boll retention and yield in cotton.

Application of CCC (Cycocel and chloromequat) @ 40 ppm at 80-90 days after sowing (DAS) reduces the unproductive growth and increases the yield by 16 to 34 per cent and induces uniform bursting also.

Foliar application of maleic hydrazide @ 500 ppm at peak boll development stage, suppressed the apical growth but enhanced the leaf area expansion by 10-15 per cen (Ratna kumari and Mridula George(2012). Similarly application of chlorethyl hydrazonium chloride (CMH) @ 480 & 720 g/ha reduced the growth and increased the boll retention which ultimately resulted in higher seed cotton yield.

The field experiments conducted at Regional Agricultural Research Station, Lam, Guntur, Andhra Pradesh with stance 110SC (Ratna Kurmari and Mridula George, 2013) on cotton revealed that foliar application of Stance 110 SC (Cyclanilide 22+ Mapgnat Chloride) @ 200 ml/ha at 45, 60 and 75 DAS reduced the plant height, increased the number of sympodial branches, number of bolls, ultimately seed cotton yield without any adverse effect on fiber quality.

Defoliants : Cotton being an indeterminate in growth habit produces stems and leaves continuously along with the reproductive development. At boll bursting stage, the defoliants can be used to encourage the process of defoliation. In cotton, the defoliants / harvest aids can be used for two different purposes *viz.,* defoliation and limiting the crop duration. The studies conducted at ANGRAU (Ratna Kumari *et al,* 2013) for 3 years revealed that application of ethrel @ 3000 ppm at 145 days after sowing defoliated the plant without any adverse effect on yield and quality of cotton. Foliar application of Dropp Ultra (Thiadiazuron + Diaron) @ 250ml/ha at 70 per cent boll opening defoliated the cotton plant facilitating the picking of cotton and also reduced the crop duration without any deleterious effects on yield and quality of cotton (Ratna Kumari and Mridula George, 2013))

Use of growth regulators in present day cotton cultivation : Now a days, we are having the varieties of cotton which flower readily without special photo periods or hormonal modifications. Sometimes, the cotton crop fails due to excessive vegetative growth which can be related to continuous heavy rainfall especially in heavy black cotton soils. The cotton crop of 2 to 2.25m height with fully over lapping luxuriant and dense canopy is heaven for insects, verticilium wilt and boll rots and it ineffective insect control. In addition, square and small boll dropping will be there due to shade effect. Hormonal control of vegetative growth reduce plant growth facilitating better light penetration, earlier boll opening and higher harvest index. Auxins, cytokinens and gibberellins promote growth and delay cut out. On the other hand, ABA promotes cut out as it inhibits growth and prolongs bud dormancy. In later stages of crop growth *i.e.,* at the time of crop maturity, foliar application of ethylene induces boll bursting and defoliation. Hormonal regulation of plant height is possible, and may be a useful practice where bushy growth of plant is observed and the insect pest infestation is severe.

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Scope and potential of fiber crops cultivation and processing in north east India

B.K.SETHY*, H. MARBANIANG, H.J.SINGH, ANUP DAS, H.DAYANANDA SINGH AND N. PRAKASH

ICAR Research Complex for NEH Region, Umiam - 793 103

**E-mail: bsethy088@gmail.com*

Fibre yielding plants have been of great importance to man and they rank second only to food plants in their usefulness. Fibres are elongated cells having very dense cell walls originated in plant stems, leaves, bark and seeds. From ancient time, different types of plants like cotton, flax and hemp have been grown to use for fibre, that can used for making clothes, ropes and paper etc. Plant fibres are flexible in nature, having very little elasticity and good resistance to damage by scratch and can withstand both heat and sunlight. With the advancement of civilization, the use of plants fibres has gradually increased and their importance today is very great. Although many different species of plants, roughly about two thousand or more, are now known to yield fibres, commercially important ones are quite small in number.

Traditionally jute like fibres are being used for packaging as sacking, hessians, bags and soil savers besides being used as carpet backing, jute scrims, tarpaulins, canvas, tar felts etc. There are other diversified uses too as technical textiles, geotextiles, agro-textiles and handicraft. In rural sector, utilization of plant fibres for creating employment opportunity is cost effective process and ecologically sustainable. Natural fibres yielding plants which are abundantly available in various parts of India *i.e.* jute, sisal, banana, coir etc. are major resources. Nowadays, India produces more than 400 million tonnes natural fibres (Rai and Jha 2004).Natural fibres are used in technical applications, civil engineering and construction materials as renewable and environmental friendly raw materials. Flax, hemp, linseed, jute, sisal, kenaf, yucca, abaca and ramie are well known natural fibres yielding plants. Mechanical properties of natural fibres are influenced by various factors such as the growth and weather conditions, date of harvest, the degree of maturity at the harvest, the retting process, decortication, processing and cleaning procedure etc. (Munder and Hempel 2006).

History of natural fibres : Natural plant and animal fibres have provided the raw materials to meet our fibre needs. No matter which climatic zone humans settled, they were able to utilise the fibres of native species to make products such as clothes, cloths, buildings and cordage. The first composite material known was made with clay and straw to build walls in Egypt 3,000 years ago. Many of the ancient plant fibres are no longer in use. Fibres such as jute, sisal, coir and kapok only started to be imported into Europe from the nineteenth century. The common nettle has a long history as a source of fibre. Archaeological remains in Denmark and Britain showed evidence that it was used for string and cloth in Neolithic times. In post medieval times drag nets for fishing were made of nettle fibre. Nettle cloth was manufactured in Scandinavia and Scotland from early times until the 19th century and was known as Scotch cloth in Britain. Shortages of cotton during the First World War forced the Germans to use nettles to make fabric. The bast from the inner fibrous bark of the lime tree has been used for fibre for cordage and halters in England in the past. The word ‘bast’ has now been applied to the fibrous layer of many kinds of plants. Hemp and linen are amongst the oldest plants used for fabric products. Hemp was cultivated in China in 2,800 BC. In the Indo-European languages that led to English ‘hemp’ is related to the Greek and Latin cannabis which also gave rise to the term canvas, because hemp was commonly used to make sails. Sails were also woven from linen at times. Cotton has been produced in India for millennia and was introduced into Europe in the 1300s. Some of the more recently introduced natural plant fibres reflect their origins and distribution. Jute originated in India and its name in Bengali means ‘braid of hair’. The name ‘ramie’ comes from the Malay and has been variously known as grass linen, China linen and grass cloth. Another Malay word that has given itself to a fibre is ‘kapok’. Kapok is a silky fibre from the east Indian tree which is sometimes called silk cotton or Java cotton (Natural fibre, Sen and Reddy 2011).

In the 18th and 19th centuries, the Industrial Revolution encouraged the further invention of machines for use in processing various natural fibres, resulting in a tremendous upsurge in fibre production. The introduction of regenerated cellulosic fibres (fibres formed of cellulose material that has been dissolved, purified, and extruded), such as rayon, followed by the invention of completely synthetic fibres, such as nylon, challenged the monopoly of natural fibres for textile and industrial use. A variety of synthetic fibres having specific desirable properties began to penetrate and dominate markets previously monopolized by natural fibres. Recognition of the competitive threat from synthetic fibres resulted in intensive research directed toward the breeding of new and better strains of natural fibre sources with higher yields, improved production and processing methods, and modification of fibre yarn or fabric properties.

Production of fibre crops : Humans dominate the landscape in nearly every corner of the planet. Today, croplands occupy nearly 18 million km^2 (an area roughly the size of South America), pastures take up another 34 million km^2 (an area roughly the size of Africa), and urban areas use roughly 2.5 million km^2 (an area roughly the size of a third of Europe) (Klein Goldewijk, 2001; Ramankutty and Foley, 1998; Turner *et al.,* 1993). The fibre crops grown in and around the world accounts to about 95 thousand km^2 of the total harvested area (FAO, 2014). These crops serves as input sources to textile and industrial use and include agave fibres, bananas, bast fibres, coir, flax fibre and tow, hemp tow waste, hempseed, jute, kapok fruit, Manila fibre (abaca), pineapples, ramie and sisal. Table 1 shows the most important sources of plant fibre along with its origin and production globally.

Increased use of natural fibre as raw materials can be found in developing countries like India. Ninety percent of the world's jute is supplied from India and Bangladesh and 75 per cent of kenaf production from India and China (Ray *et al.,* 2001). India has abundant resources for other natural fibres namely, silk, cotton, sisal, banana, coir, etc., available in many parts of the country. The present production level of natural fibres in India is more compared to previous years (Rai and Jha, 2004). India is the world's second largest producer and consumer of fibres, textiles, and manufactured products, next to China. The country has diverse agro-climatic conditions and consumer preferences, and hence it produces a wide variety of agricultural fibres. According to the data of FAO, 2014, India stands as the highest producer of coir, banana and jute with a production of 0.49, 19.38 and 1.78 million tonnes respectively against the world production of 1.13, 114.13 and 3.39 million tonnes respectively (Fig. 1, 2 and 3). It stands second and third in the production of cottonseed and cotton lint respectively with a production of 6.91 and 3.40 million tonnes respectively (Fig. 4 and 5).

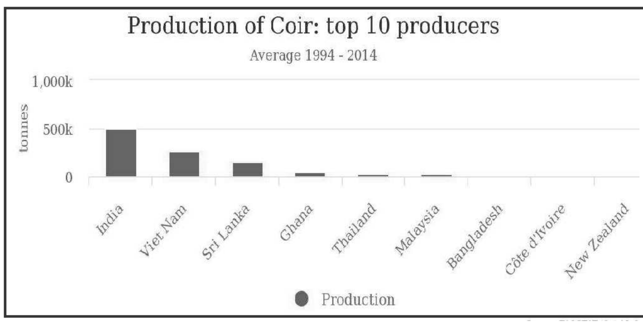

Fig. 1. Top countries in the world in coir production

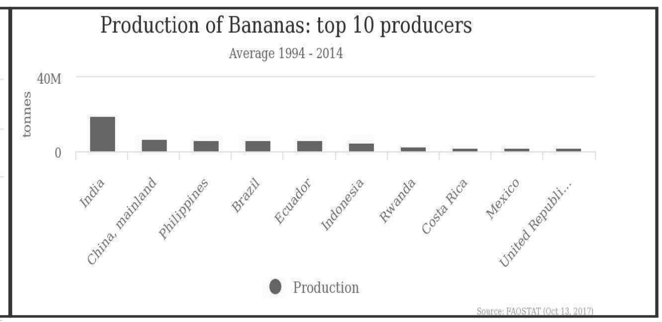

Fig. 2. Top countries in the world in bananas production

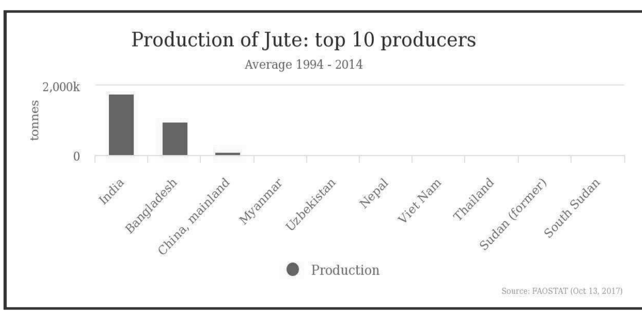

Fig. 3. Top countries in the world in jute production

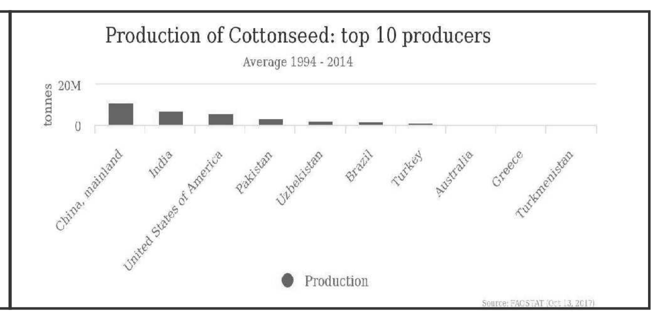

Fig. 4. Top countries in the world in cottonseed production

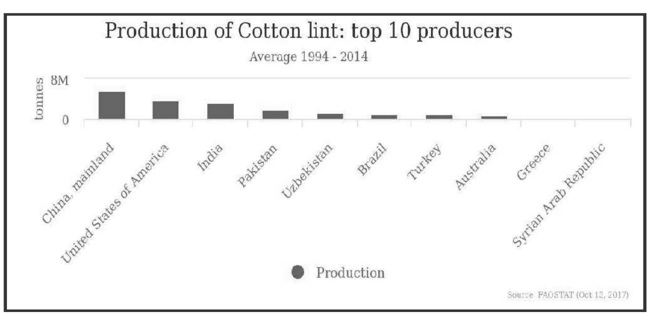

Fig. 5. Top countries in the world in cottonlint production

Table 1. Natural fibres sources, its origin and production

Fibre source	Species	Origin	World production (million tonnes)	Countries of Origin
Abaca	*Musa textilis*	Leaf	0.11	Philippines, Malaysia and Uganda
Coir	*Cocos nucifera*	Fruit	1.13	India, Sri Lanka, Philippines, and Malaysia
Cottonlint	*Gossypium* sp.	Fruit	26.16	China, USA, India and Pakistan
Cottonseed	*Gossypium* sp.	Seed	46.98	China, India, USA and Pakistan
Flax	*Linum usitatissimum*	Stem	0.32	China, France, Russia and Belarus
Hemp	*Cannabis sativa*	Stem	0.66	China, Korea and Netherlands
Jute	*C. capsularis*	Stem	3.39	India, Bangladesh and China

FIBRE CROPS IN DIFFERENT STATES OF INDIA, ITS PRODUCTION AND YIELD

Cotton : Cotton is one of the most important fibre and cash crops of India and plays a dominant role in the industrial and agricultural economy of the country. India has the largest area under cotton cultivation in the world ranging between 10.9 to 12.8 million ha and constituting about 38 to 41 per cent of the world area under cotton cultivation, though she is the world's third largest producer of cotton after China and the USA accounting for about 26 per cent of the world cotton production. The yield/ ha (*i.e.* 504 to 566 kgs/ha) is however still lower against the world average of about 701 to 766

Table 2. Statewise area, production and productivity of cotton for the year 2012-2014

Year	2012-2013			2013-2014		
States	Area	Production	Yield	Area	Production	Yield
Punjab	4.8	21	744	4.46	21	800
Haryana	6.14	26	720	5.36	24	761
Rajasthan	4.5	17	642	3.93	14	606
North total	15.44	64	705	13.75	59	729
Gujarat	24.97	93	633	25.19	124	837
Maharashtra	41.46	81	332	41.92	84	341
Madhya Pradesh	6.08	19	531	5.14	19	628
Central total	72.51	193	452	72.25	227	534
Telangana	—	—	—	—	—	—
Andhra Pradesh	24	84	595	23.89	78	555
Karnataka	4.85	17	596	6.62	23	591
Tamil Nadu	1.28	6	797	1.52	5	559
South Total	30.13	107	604	32.03	106	563
Orissa	1.19	4	571	1.24	4	548
Others	0.51	2	667	0.33	2	1030
TOTAL		370			398	
GR TOTAL	**119.78**	**370**	**525**	**119.6**	**398**	**566**

Source: The Cotton Corporation of India Ltd.

Note: Area in lakh hectares, production in lakh bales 170 kgs and yield in kgs/ha.

kgs/ha. Cotton in India provides direct livelihood to 6 million farmers and about 40-50 million people are employed in cotton trade and its processing.

In India, the major cotton growing states in order of importance are Maharashtra, Gujarat, Karnataka, Madhya Pradesh, Punjab, Andhra Pradesh, Tamil Nadu, Rajasthan and Haryana. These states together contribute 95 per cent of India's cotton acreage. Gujarat leads in cotton production, followed by Punjab, Maharashtra, Karnataka, Haryana, Andhra Pradesh, Tamil Nadu, Rajasthan and Madhya Pradesh (Table 2).

Jute : Jute is the most important of the bast fibres, and the second most important plant fibre after cotton. Jute is primarily grown in India, Bangladesh, and to a certain extent in China. At the time of partition of the country in 1947, the area under jute in India was only about 2.6 lakh ha with a production of about 16.7 lakh bales and the productivity of jute was about 11 q/ha. But the country's requirement at that time was about 60 lakh bales. Thereafter, through various development efforts, the area and production has increased and at present, it is about 110 lakh bale of raw jute. The productivity

Table 3. Statewise area, production and productivity of jute for the year 2014-2015

State	2014 - 2015			2015 - 2016		
	Area ('000 ha)	Production ('000 Bales)	Yield (kg/ha)	Area ('000 ha)	Production ('000 Bales)	Yield (kg/ha)
Andhra Pradesh	7	50	1286	5.6	0	0
Assam	75	795	1908	76.4	767	1917
Bihar	111.2	1500	2428	113.4	0	0
Chattisgarh	1.1	2.2	360	0	0	0
Jharkhand	0	0	0	0	0	0
Karnataka	0	0	0	0	0	0
Madhya Pradesh	0.3	0.8	480	0	0	0
Maharastra	0	0	0	0	0	0
Meghalaya	0	0	0	8	0	0
Nagaland	0	0	0	3	0	0
Odisha	12.9	67.8	946	14.3	0	0
Tamilnadu	0.2	4.3	3870	0	0	0
Tripura	0	0	0	1.1	0	0
Uttar Pradesh	0	0	0	0	0	0
West Bengal	576.1	8969	2802	519	8075	2801
Others	19.1	104.9	989	1.7	0	0
Total	**802.9**	**11494**	**2577**	**742.5**	**8842**	

Source: Office of Jute Commissioner

of jute has crossed 23 q/ha (five years average of 2006-2007 to 2010-2011).

The production and cultivation of jute in India which is the largest producer in the world is restricted mainly to the states that lies along the Ganga-Brahmaputra delta in West Bengal and in Assam, Bihar and Orissa. In recent years, jute cultivation has also been extended to the states of Meghalaya, Tripura, Tamil Nadu, Maharashtra and Uttar Pradesh. (Table 3)

Coir : India accounts for more than two-thirds of the world production of coir and coir products. Kerala is the home of Indian coir industry, particularly white fibre, accounting for 61 per cent of coconut production and over 85 per cent of coir products. The Indian share in the world of coconut production is about 16.28 per cent and 17.07 per cent in the area harvested. Annual production is about 216651 million nuts with an average of 10122 nuts/ha. The high producing state is Kerala in terms of area, followed by Tamil Nadu, Karnataka, Andhra Pradesh and Odisha (Table 4).

Table 4. Statewise area, production and productivity of coconut for the year 2015-2016

	States /Union territories	Area ('000/ha)	Production (Million nuts)	Produ-ctivity (Nuts/ha)
1	Kerala	770.62	7429.39	9641
2	Tamil Nadu	459.74	6171.06	13423
3	Karnataka	526.38	5128.84	9744
4	Andhra Pradesh	103.95	1427.46	13732
5	West Bengal	29.51	373.58	12658
6	Odisha	50.91	328.38	6451
7	Gujarat	22.81	312.68	13706
8	Maharashtra	22.75	271.24	9775
9	Bihar	14.9	141.38	9489
10	Assam	19.73	132.59	6720
11	Chhattisgarh	1.85	30.54	16508
12	Tripura	7.2	29.51	4097
13	Nagaland	0.33	2.67	8091
14	Others	52.8	388.13	7351
	All India	**2088.47**	**22167.45**	**10614**

Source: Horticulture Division, Dept. of Agriculture and Cooperation, Ministry of Agriculture and Farmers Welfare, Government of India.

Banana : India is the world's largest banana producer with an annual output of 24.8 million tonnes followed by China, Philippines, Ecuador and Brazil. India accounts for 22 per cent of the global banana production. It is cultivated in India in an area of 830.5 thousand ha and total production is around 29,779.91 thousand tons. Main banana growing states are Tamil Nadu, Maharashtra, Gujarat, Andhra Pradesh and Karnataka (Table 5). Apart from providing textiles, banana fibre production provides employment opportunities to thousands of poor people in India.

Mesta : Mesta is common word used for both *Hibiscus cannabinus and H. sabdariffa* which produces good fibre of commerce. *Hibiscus cannabinus* is known by various names in India such as Bimli, Deccan hemp, Gogu, Channa, Ambadi, Gongkura, Sunkura, and Sunbeeja etc. while, H. *sabdariffa* is known as roselle, java jute, Thai jute, Pusa hemp, Tengrapat, Lalambadi, Chukair, Yerragogu, Palechi and Pundibeeja etc. Besides India, the mesta is grown mainly in Argentina, China, Cuba, Egypt, Hewti, Guatamala, Italy, Iran, Indonesia, Mozambique, North Africa, New Guina, Peru, Spain, South Africa, Southern Part of Zimbabwe, Thailand, U.S.A and Russia.

India had to lose about 80 per cent of total jute production area at the time of

Table 5. Statewise area and production of banana fibre for the year 2015-2016

State/UT's	2015-2016	
	Area (000' ha)	Production (000 T)
Andaman Nicobar	1.6	14.9
Andhra Pradesh	80.6	2819.6
Arunachal Pradesh	5.4	13.3
Assam	53.4	805.2
Bihar	31.5	1435.3
Chhattisgarh	11.5	296.9
Goa	2.3	25.1
Gujarat	61.9	3779.8
Himachal Pradesh	0.1	0.3
Jharkhand	2.9	58
Karnataka	104.4	2132.3
Kerala	51.3	406.2
Madhya Pradesh	33	1459.8
Maharashtra	85	5200
Manipur	4	33.7
Meghalaya	7	82.8
Mizoram	8.7	207.7
Nagaland	6.3	62.7
Orissa	24.7	400.4
Pondicherry	0.5	17.1
Punjab	0.1	5.8
Sikkim	1.6	3.2
Tamil Nadu	113.7	4980.9
Tripura	7.5	105.6
Uttar Pradesh	30.4	1138.6
West Bengal	41	982.2
Total	**770.3**	**26469.5**

Source: Department of Agriculture and Cooperation (Horticulture Division)

partition of the country during 1947. The jute crop needs a specific set of climatic conditions, therefore, the cultivation of jute could not be extended beyond the states of West Bengal, Assam, Bihar, Orissa, and parts of U.P. and Tripura. As a result the production of jute fell below the requirement of mills. Mesta can, however, be grown even in those areas where jute is not grown under wider climatic and soil conditions with much less care. This helped the country to expand more area under mesta. At present mesta is grown in an area of more than 26 lakh ha with a production of more than 12 lakh bales.

Pineapple : Pineapple (*Ananas comosus*) is an important fruit of India. Pineapple is cultivated in an area of 89 thousand ha and total production is 1,415.00 thousand tonness. It is abundantly grown in almost entire North East region, West Bengal, Kerala, Karnataka, Bihar, Goa and Maharashtra states. The area under pineapple cultivation in India increased by 35 per cent from 57 thousand ha in 1991-1992 to 77 thousand ha in 2001-2002 whereas the production increased by 54 per cent from 8 lakh tonnes to 12 lakh tonnes. Recent statistics shows around 90,000 ha area under this crop, 15.27 lakh tonnes annual production and 15.3 tonnes /ha productivity. The different pineapple producing states in India along with its production, area and yield is shown in Table 7.

Fibre crops of north east India : The north eastern region of India covering nearly 262,379 km^2 area has been divided into two biogeographic zones Eastern Himalaya and North East India, based on floristic composition, the naturalness of the flora and the local climate (Rodgers and Panwar 1988). The northeast region of India comprising of the states of Arunachal Pradesh, Assam, Meghalaya, Manipur, Tripura, Mizoram, Nagaland and Sikkim can be physiographically categorized into the Eastern Himalayas, Northeast hills (Patkai Naga Hills and Lushai Hills) and the Brahmaputra and Barak valley plains. The economic structure of

Table 6. Shows the statewise normal (average of 2006-2007 to 2010-2011) area, production and yield of mesta.

State/UTs	Area(000 ha)		Production(000 bales)		Yield
	Actual	(%) share to all India	Actual	(%) share to all India	(kg/ha)
Andhra Pradesh	40.8	34.2	351.2	45.3	1549
Assam	5.1	4.3	24.8	3.2	875
Bihar	18.1	15.2	164.1	21.2	1632
Chhattisgarh	1.4	1.2	2.8	0.4	360
Jharkhand	0.6	0.5	2.8	0.4	840
Karnataka	1.2	1.0	1.0	0.1	150
Madhya Pradesh	0.7	0.6	1.6	0.2	411
Maharashtra	19.2	16.1	29.2	3.8	274
Meghalaya	4.3	3.6	19.3	2.5	808
Nagaland	0.0	0.0	0.0	0.0	0
Orissa	19.5	16.3	87.9	11.3	811
Tamilnadu	0.0	0.0	0.0	0.0	0
Tripura	0.9	0.8	6.3	0.8	1260
Uttar Pradesh	0.0	0.0	0.0	0.0	0
West Bengal	7.3	6.1	83.4	10.8	2056
Others	0.3	0.3	0.6	0.1	360
All India	**119.4**	**100**	**775.0**	**100**	**1168**

(Sources: Status of Raw Jute in India, 2014)

the states of northeast India is dominated by agriculture and allied activities. But the land under cultivation in the region is only 16 per cent of its total geographical area. It varies from 2.5 per cent in Arunachal Pradesh to 7.2 per cent in Manipur, 9.4 per cent in Meghalaya, 4 per cent in Mizoram, 15 per cent in Nagaland, 36 per cent in Tripura and 45 per cent in Assam.

Table 7. Statewise area, production and productivity of pineapple for the year 2012-2014

Year	2012-2013			2013-2014		
States	Area	Prodduction	Yield	Area	Production	Yield
West Bengal	10.50	310.00	29.5	10.70	316.00	29.5
Assam	16.24	268.82	16.6	16.54	288.60	17.4
Tripura	11.84	165.01	13.9	11.59	162.26	14.0
Karnataka	2.70	169.30	6.7	2.72	160.31	58.9
Nagaland	9	85.00	9.4	9.50	142.50	15.0
Manipur	13.06	124.14	9.5	13.70	136.31	9.9
Meghalaya	10.82	109.39	10.1	11.31	117.77	10.4
Bihar	5.13	139.22	27.1	4.16	113.91	27.4
Arunachal Pradesh	12.28	67.58	5.5	12.78	69.61	5.4
Others	5.07	59.27	11.7	8.34	156.61	18.8
TOTAL	**105.2**	**1570.6**	**14.8**	**109.88**	**1736.74**	**15.8**

Source: All India 2013-2014 (final Estimates), department of Agriculture and Cooperation.
Area in '000 ha, Production in '000 tonnes and productivity = t/ha

North eastern region has been identified by the National Bureau of Plant Genetic Resources (NBPGR), India, as rich wild relatives of different crop plants. It is the centre of origin of citrus fruits. The region is rich in medicinal and aromatic plants, fibres and dye yielding plant and many other rare and endangered species. About 76 per cent of cultivated area is under food grains, 5 per cent under oilseeds and 3 per cent under fibre crops. The north eastern states have more than 60 per cent of their geographical area under forest cover, a minimum suggested coverage for the hill states in the country (Chatterjee *et al.,* 2006).

With 3 per cent of the area under fibre crops, the most common fibre crops in the region include jute, cotton, ramie and mesta. While other fibres that can be extracted from fruits such as banana stem and pineapple leaves are also found in the region. The production, area cultivated and yield of different fibre crops is summarized in Table 8 from different sources for the year 2006-2015. Jute plays a considerable role in the economy of the region, more particularly in Assam which is the largest producer in the region. Some wild types of jute also prevail in the eastern Himalayas. Jute is also distributed in parts of Arunachal Pradesh, Tripura and the Garo Hills of Meghalaya.

Ramie another important fibre yielding is the strongest known vegetable fibre. In many parts of northeast India, it is found in wild state as a naturally occurring plant. Ramie was first collected from Goalpara in Assam. The genus Boehmeria has more than 100 species. About 45 species are reported to occur in India, of which 19 species have been reported from northeast India (Kanjilal *et al.,* 1940) including Meghalaya, Assam, Arunachal Pradesh, Manipur and Sikkim. Despite the unique characteristics of ramie, it is still a minor fibre crop in world trade mainly because of problem emanating from production and processing (Sarma, 1995).

Cotton (*Gossyium sp.*) in northeast India is found mainly in Assam and Meghalaya. Meghalaya has a near monopoly of cotton grown exclusively in Garo hills areas where they are confined in jhum fields with other crops as an element in mixed culture. The yield is comparable to the Indian average around 200 bales per hectare. For Meghalaya, it is a cash crop supplementing the tribal economy. In the state of Tripura, maximum quantity of cotton production is obtained from the Chamanu block of north Tripura district.

Coconut is one of the most popular crop grown for a long time especially in Assam state and in recent times in others northeast states. The area and production which were 11,000 ha and 60 million nuts, respectively, during 1985–1986, have now increased to 40,000 ha and about 178 million nuts, in the north eastern region. The cultivation which was confined to Assam, Tripura and to some extent in Manipur, has now spread to states like Nagaland, Mizoram, Arunachal Pradesh and Meghalaya due to efforts made by Coconut Development Board.

Pineapple is the second most important fruit crop of the north eastern region of India both in terms of area under plantation and production. Its area of cultivation is estimated to be about 20,126 ha with an annual production of 1, 67,518 tons. Assam stands first in production and has the largest area under pineapple cultivation. It is followed by Manipur, Arunachal Pradesh, Tripura, Meghalaya and Nagaland.

Banana is also grown in the north eastern belts of India. In Arunachal Pradesh, the production of banana forms about 5.9 per cent of total fruit production in the state. The production is 0.02 mt from an area of 0.006 ha having productivity of 3.02 mt/ha. While in Assam, it is one of the major producers of banana and accounts for 2.9 per cent of total production of banana in the country. The production of banana in the state is 0.86 mt from an area of 0.05 m ha having productivity of 16.9 mt/ha. In Manipur, Meghalaya, Mizoram, Nagaland and Tripura, banana forms about 18.0, 24.8, 41, 26.7 and 17.1 per cent respectively of the total production of fruits in the state.

Machinery for extraction and processing of different fibre plants : Vegetable fibres are biodegradable, annually renewable, non-carcinogenic and therefore health friendly. Traditionally, jute and jute like mesta are being used for packaging as sacking, hessian, bags and soil savers besides being used as carpet backing, jute scrims, tarpaulins, canvas, tar felts, etc. There are other diversified uses too as technical textiles, geo textiles, agro textiles and handicrafts. Other allied vegetable fibres like ramie, sisal, flax, pineapple leaf fibre, coir, etc. are also used in single form or in union with jute.

Jute : Traditionally, defoliated long plant stems are jacked in submerged water in small bundles up to 20 days or 3 weeks. Alternatively, only the ribbons of green stem are retted in comparatively low water and for fewer days. In the third method, ribbons are chemically treated to accelerate retting. The National Institute of Research on Jute and Allied Fibre Technology (NIRJAFT) ribboners are both manual (Fig. 6) and power operated (Fig. 7), which peel out the green ribbon like green bark from the defoliated stem by keeping the woody stick intact. In manual ribboning, simple country devices could be improvised for stripping the green bark from single plant. For this, a vertical pole, bamboo hooks and bicycle hub can well be used for extracting the green ribbon by manual operation. The capacity of a manual ribboner is 150 kg of green ribbon while that of power unit is 1,500 kg/day. The power ribboner developed by NIRJAFT peels off the green barks in the form of ribbons by compression in pairs of rollers. The Central Research Institute for Jute and Allied Fibre (CRIJAF) power decorticator strikes the stems by rotating blades and removes the green ribbon by breaking the stick into pieces, while the manual one produces whole stick (Fig 8) (Anonymous, 2005).

Cotton : After bolls of cotton are picked by hand or by mechanical picker-harvester from matured plants, they are ginned with the help of either saw or roller gins to separate the 15-60 mm discrete fibres from lints. Plant debris and foreign matters are removed by cleaner from ginned cotton, and the clean cotton characteristically of good spinability with aspect ratio of 1,300 is processed through a series of machines in the entire spinning lines like opening and cleaning in blow room, carding, drawing, roving and spinning to manufacture yarn as fine as 120^s Ne to as coarse as 20^s Ne[5].

Table 8. Area, production and yield of different fibre crops in northeast state of India

States	Cotton			Jute			Ramie			Mesta			Pineapple			Banana			Coconut		
	P	A	Y	P	A	Y	P	A	Y	P	A	Y	P	A	Y	P	A	Y	P	A	Y
Arunachal Pradesh	-	-	-	-	-	-	-	-	-	-	-	-	69.61	12.8	5.4	14.9	1.6	-	-	-	-
Assam	-	-	-	55.8	65.09	-	0.15	0.1	1520	28.3	4.3	1182	288.6	16.5	17.4	805.2	53.4	-	132.59	19.73	6720
Manipur	-	-	-	-	-	-	-	-	-	-	-	-	136.3	13.7	9.9	33.7	4	-	-	-	-
Meghalaya	7738	7.2	182	35.3	3.9	1601	-	-	-	20.2	4.4	821	117.7	11.3	10.4	82.8	7	-	-	-	-
Mizoram	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	207.7	8.7	-	-	-	-
Nagaland	5700	3	343	-	-	-	-	-	-	-	-	-	142.5	9.5	15.0	62.7	6.3	-	2.67	0.33	8091
Sikkim	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.2	1.6	-	-	-	-
Tripura	1395	0.9	1.4	5.4	0.6	8.35	-	-	-	7.0	0.8	8.20	162.3	11.6	14.0	105.6	7.5	-	29.51	7.2	4097

Note: A – Area is in 000 ha, P – Production of cotton in bales of 180 kg, P – Production of Jute, Ramie, Mesta, Pineapple, and Banana in 000 tonnes, P – Production of coconut in million nuts and Y – Yield in kg/ha for cotton, jute, mesta, ramie and banana. Y – Yield in t/ha for pineapple, Y – Yield in nuts/ha for coconut.

Pineapple : The pineapple leaf fibre (PALF) can be obtained from green leaves by peeling and scrutching; by scrapping followed by retting in water and by mechanical decortication. A handy mechanical scratcher is run by paddle operation for disintegration of impervious layer on the leaf surface. The power operated (Fig. 9) uses rotary cylinder mounted with rasp bars to scratch out green matter thus turning out 1,500 kg of green fibre/day (Anonymous, 2005). Some of the machinery developed for sisal decortication can also decorticate pineapple leaves by making appropriate adjustments.

Sisal : The raspador decorticator of 1.20 m in diameter and 225 mm in width has been scaled down with modifications (Fig. 10) followed by 5 hp design with capacity of 60-75 kg of green fibre. Washing the fibre is done by repeatedly dipping the hanks in a series of concrete tanks filled with water

Banana : A low cost, user friendly device for extracting fibres from the psuedostem of banana has been developed. It can extract 15-20 kg fibres from the banana wastes in a day as compared to 500 g a day through the laborious manual process. The machine consists of a rigid frame on which the roller rotates. The roller is made of horizontal bars with blunt edges, and it is driven by a one hp single phase electric motor. For feeding the banana psuedostems, adjustable guiding rollers are provided. The machine reduces the drudgery, and provides a clean working environment for the labourers. It increases the fibre production fifty times (Sudhakar *et al.,* 2003). The machine extracted fibre is of superior quality in terms of length, softness, strength and colour.

Flax : Retted and sun dried flax is scutched to break the woody stick into pieces and thus separate the fibre reed in a scutching machine (Fig. 12) (Anonymous, 2002). As a first step, butting is done to make the root ends of the wide and cured bundles of straw even. The shive is broken and removed from the fibre bundles with a minimum of fibre waste, leaving the bundles clean and undamaged. Besides, there is a host of other machinery developed for fibre extraction, but all operate on essentially the same principle *i.e.* straw passes between fluted rollers which break shive in a great many places throughout its length.

Coir : Coir dehusking machine is used to separate the husk from the coir fibres. The husks are removed and put through a machine composed of a pair of corrugated iron rollers. These rollers are known as breakers which crush them. These semi opened coir fibre is further fed to the coir extractor (Fig. 13) for thorough opening and cleaning of coir fibres. The longer and stronger ones are washed, cleaned and dried. There are other methods of extraction of coir fibre by decorticating dry husks. All the processes yield basically three types of fibre depending on the methods of extraction viz. mat fibre (longest fibre), bristle fibre and mattress fibre.

Processing of plant fibres : Spinning systems of different plant fibres are shown (Fig. 18). Jute, mesta and sun hemp can be processed

Fig. 6. Manual ribboner for jute

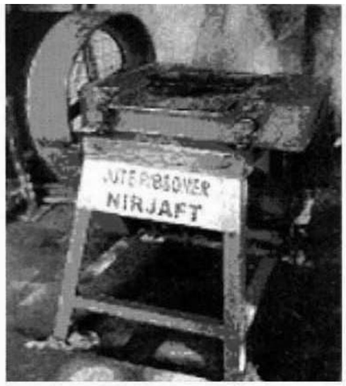

Fig. 7. Power ribboner for jute

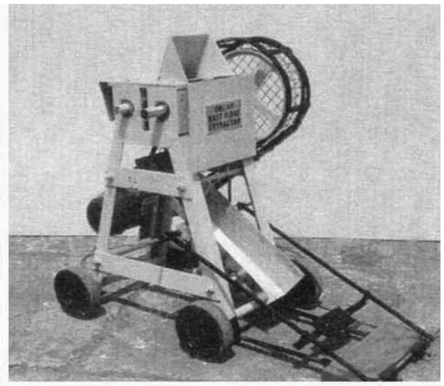

Fig. 8. Jute decorticator

Fig. 9. Pineapple leaf fibre extractor

Fig. 10. Sisal decorticator

Fig. 11. Banana fibre extractor

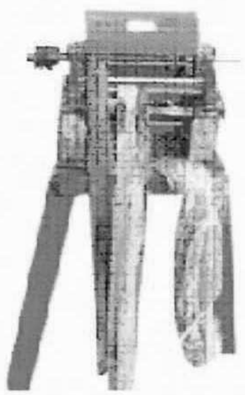

Fig. 12. Flax scutcher

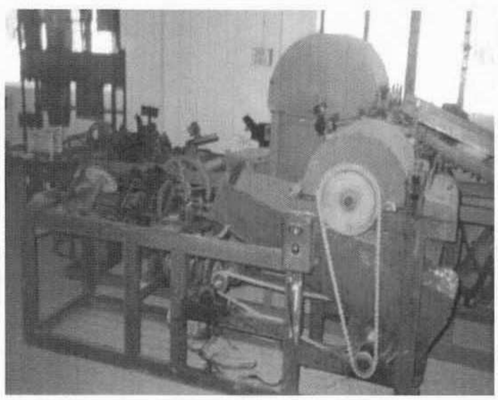

Fig. 13. Coir fibre extractor

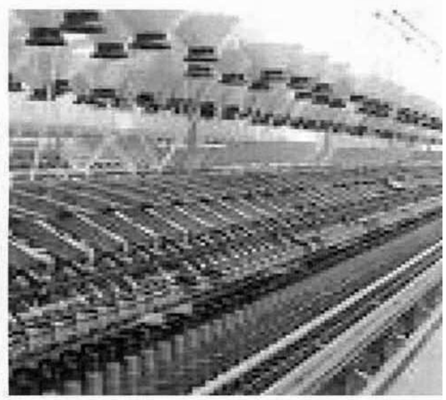

Fig. 14. Cotton spinning machine

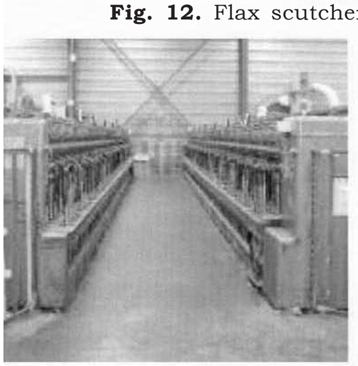

Fig. 15. Flax wet spinning machine

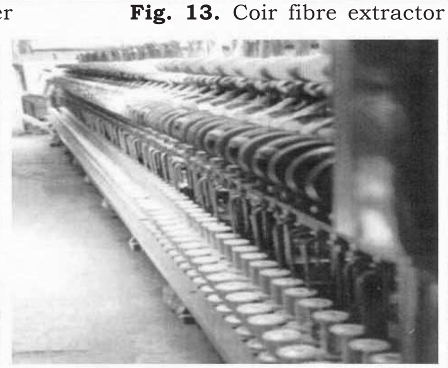

Fig. 16. Jute spinning machine

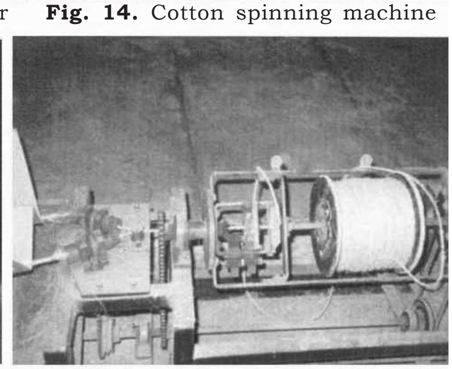

Fig. 17. Coir rope winding machine

in jute system because of their near similarity in fibre structure and physico mechanical properties. Jute being a coarse fibre compared to cotton, the processing machinery starting from fibre to fabric formation is mechanical, much robust and heavy duty. Cotton as a finer fibre requires very mild and intensive opening than jute. Due to mesh like structure, jute fibre unlike cotton requires a very high amount (shear strength < breaking strength) of opening force to de mesh or split the jute reeds. It has been found that the average jute fibre length in the yarn stage is around 200 mm (Anonymous 1999). Because of this higher staple length of jute fibre in comparison to cotton, the roller settings in the yarn processing machinery (drawing to spinning) are wider than those of the cotton yarn spinning machinery. Thus the machinery for cotton spinning system is not suitable for jute spinning system and vice versa. However, the flax (2.5-6 tex) and ramie (0.4-0.8 tex) which are also bast fibres having discrete filament structure much finer than jute (1.3-4 tex) but coarser than cotton (0.1-0.3 tex) can be processed in flax system (different from jute system). In the present scenario, the cost of ramie and flax is much higher and therefore they have limited usage in garments rather than in packaging (Anonymous, 1998). On the other hand, pineapple (2.5-6 tex) is much finer than sisal (16-35 tex). At present, sisal fibre is popular as ropes and scrubbers. The commercial use of pineapple in India is unknown. Because of its low L/B ratio (95) and high rigidity (150-250 $dyn.cm^2$), coir is not spinnable but pliable into rope (coir system). It cannot, therefore, be processed on jute, flax or cotton systems. In contrast, PALF has been tried successfully on jute, cotton, flax and semi-worsted spinning systems. Besides, the other systems for fibre processing like wool, worsted and silk (as animal fibres) are not suitable for the processing of most plant fibres and hence out of the context. The process flowcharts of some plant fibres are also shown for better understanding.

Cotton system : The series of standard machines required to process coarse cotton are bale openers, carding, drawing, speed frame, spinning frames (Fig.14), winding machines for spun yarn followed by assembly winding and plying machine for ply yarn. Further, these yarns are processed through series of weaving preparatory and weaving loom machines to give the final shape of woven fabric. After harvesting and drying, the cotton balls are fed to cotton ginning unit to separate fibre from the seeds. The compressed cotton in the form of bale is opened in the blow room using a series of machinery, usually 3-5 depending on the trash or foreign particles embedded in the cotton. Then the carding process is initiated where fibre to fibre separation and further cleaning take place. The output of carding in the form of sliver is fed to drawing frame and roving frame for gradual improvement of fineness of the fibre mass prior to spinning. Spinning produces coarse yarn known as carded yarn. For fine yarn spinning, additional process of combing is used which yields combed yarn.

Flax system : Flax in India is primarily used for oil and not for fibre; however, it has a good potential for sacking used for packaging. As flax fibres are long single entities, their machineries are somewhat different from jute machinery. The machinery for flax are hackling, carding, drawing, and spinning for yarn preparation (Fig. 15).

Jute system : Prior to mid-1850s, raw jute was being used for hand-made ropes. As a matter of fact, jute processing followed wool and flax since 1850s and continued till 1970s in roving system and then sliver replaced round roving prior to spinning. Later on full scale spinning system was developed. They comprised of softener, both breaker and finisher cards, drawing and roving frames and spinning, plying, winding frames in order to obtain yarn (Fig. 16). To prepare fabrics in weaving machine, warping, sizing and weaving machines are needed. Half a dozen of industries are engaged in making these series of machines in the country. Retted jute reeds are harsh and are bound together.

Coir system : Coir being very coarse and harsh is extensively used in villages for weaving mat of cots. Basically, they are also used for tying bamboo and wooden rafts in homes, scaffolding and temporary structures. Therefore, the machines in processing coir into ropes are coconut dehusker, beater for retted coir, coir opener, coir drawing (for sliver preparation) and rope spinning-cum-winding machine (Fig. 17).

Potential growth of fibre crops in north east India : The north eastern Region (NER) of India comprising of eight states *viz.,* Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura representing an area of over 261000 km^2, by virtue of its geographic location and richness in bio-diversity, well supported by complimentary climatic factors, more particularly high rainfall for luxuriant phyto biomass (both above and below ground) in the form of forests and allied sources of vegetation is a unique place in India (Chatterjee *et al.,* 2006). Nearly 15.7 per cent of geographical area (GA) is under cultivation; forest cover (open and dense) in the region varies from 40.2 per cent (Assam) to 72.99 per cent (Arunachal Pradesh) (NRSC, 2011). Area under shifting cultivation is 2.88 per cent (0.754 Mha). Grasslands occupy 6.06 per cent GA while wastelands occupy 6.22 per cent of GA. The region has 4.53 per cent area under waterbodies. Different areas under different land uses is shown in the pie chart below (Fig. 19).

Around 3 per cent of the cultivated area of the region contributes in the fibre crop production which can either be utilized in the region for value addition if proper mechanization and processing are available or is exported to other places of India. The common fibre crops that are grown within the region include cotton, jute, ramie and mesta. Apart from these fibre crops, horticultural produce such as banana stem and pineapple leaves have find its way into fibre production and it is used in textile making and packaging of agricultural produce as mentioned.

Cotton is chiefly grown in the Garo Hills of Meghalaya. The State also produces three main fibre crops such as jute and mesta. These have been the traditional cash crops of the Garo Hills Region. Both the area under the cultivation of fibre crops and their production has shown a decreasing trend, which indicates that these crops are gradually losing their popularity. This has been attributed to the unremunerative prices received by farmers for these crops and as such the farmers are cultivating these crops with minimum effort and inputs. There was a sharp decline in the area of cultivation of about 10,164 ha since the 1970-1971. There was about 50 per cent reduction in the area on jute which shows a dramatic decline during the period of 1970 to 1976. However, the area under jute crop for the year 2006-2007 was reported at 3967 ha and the production of jute during that period was reported at 35,304 bales of 180 kg each. Mesta on the other hand has decreased from 7,000 ha in 1975-1976 to 4,425 ha in 2006-2007. The production of mesta also decreased from 25,200 bales (180 kg each) in 1975-1976 to 20,178 in 2006-2007. The decrease in the area under mesta and the production of mesta, though not as sharp as jute and cotton, is nevertheless visible.

In the state of Assam, which is primarily an agrarian economy with 74 per cent of its population engaged in agriculture and allied activities. As per 2001 census, 53 per cent of total work force are engaged in agricultural activities. But during the period 2000-2005, the overall scenario of agriculture is not praiseworthy. There is a decrease in the production of fibre crops such as cotton and jute in the year 2004-2005. However its contribution to Indian economy nevertheless affected and in the year 2014-2015, the state stands as the second largest producer of jute.

Many factors can be attributed to the decrease in the area and production of fibre crops from these region, the main ones being lack of suitable high yielding varieties, lack of improved crop management practices and standardization of production techniques, weak geographical links and poor infrastructure facilities which makes the northeast Indian states slow in catching up agricultural development. In this circumstance, agricultural sector needs prioritization of development perspectives for enhancing the adoption of recommended technologies through extension programmes, input supply, support of financial institutions and marketing functionaries. More crucially, the research and development programmes must address the problem of generation of need-based location specific technologies for the specific agro ecological situations.

However the potential of the growth of these fibre crops such as cotton, ramie, jute and mesta can be enhanced by introducing them in jhum fields where the land are kept barren for a particular period of time after which it is reuse again for cultivation. The farmers in the Garo Hills have adopted this strategy in cultivating cotton crops in jhum fields along with other crops as mixed culture. As can be seen from the Fig. 19, about 19 per cent of the area in north east India comes under shifting cultivation and wasteland. This area could therefore be utilized for the growth of crops like jute and ramie where the roots are deeply penetrated enhancing soil conservation by reducing the soil erosion problems in the region.

Another aspect is the emphasizing on the use of other fibre rich horticultural produce such as pineapple and banana. Coir which is obtained from coconut are also used in rope making and twines are produced in different regions of north east. Emphasis can be given to such products of the region in order to enhance its potential in both area of cultivation as well as the production so as to raise the economy of the farmers as well as of the region.

Pineapple production in the north east

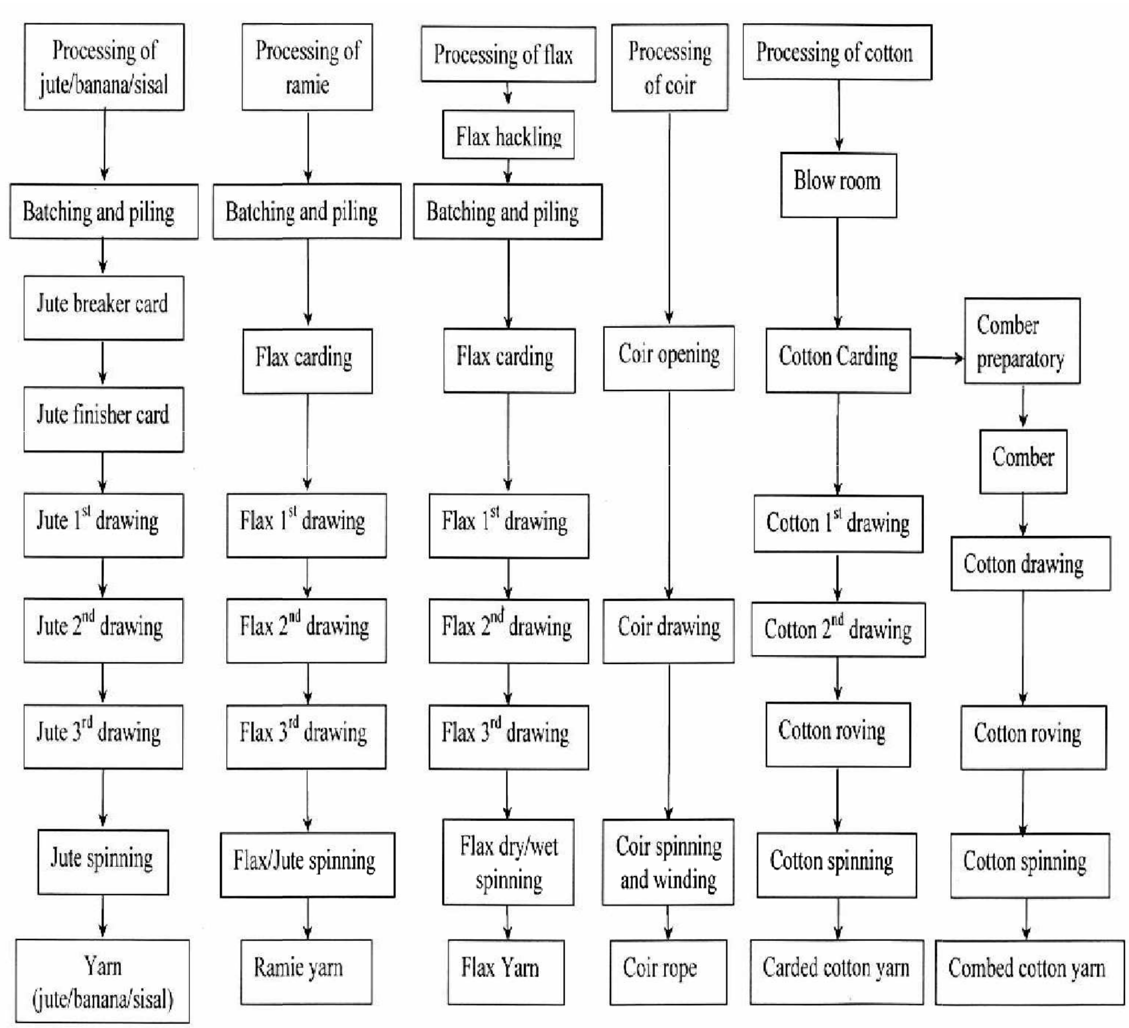

Fig. 18. Process flow chart of some plant fibres

of India ranges from as low as 8 metric tons/ha in some locations to as much as 23 metric tons/ ha. Production level of this range demonstrates the sheer potential of north east India on the world market. Assam and Tripura ranks second and fifth respectively in the production of pineapples with other region as well contributing to the highest producer of pineapple in the country. Assam accounts for about 15.42 per cent of the country's total production of pineapple. The production of pineapple in Assam for the period 1991-1992 to 2010-2011 ranges from 161103 metric tonnes to 220699 metric tonnes. Tripura accounts for 9.6 per cent of the country's total production and between 2005-2006 and 2009-2010, pineapple production in Tripura increased from 1.06 lakh metric tonnes to 1.17 lakh metric tonnes. Both these statistics of production shows an increase trend thereby giving more hope in its potential within the state.

In terms of banana production Assam ranks as the ninth position within the country with a production of 837021 tonnes for the year 2012-2013. There has been an increase in its

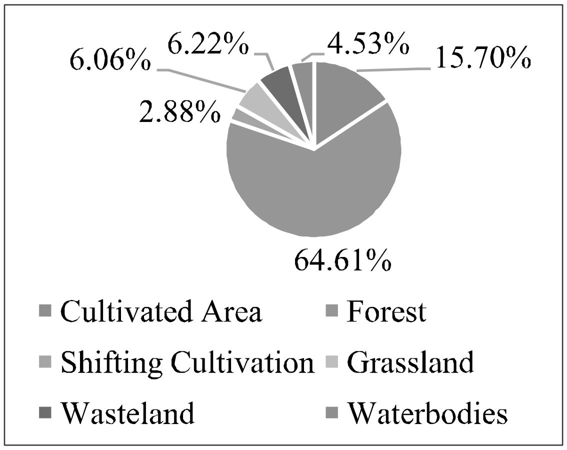

Fig. 19. Distribution of different areas under different land utilization

production from the year 2003-2004 with a production of 594645 tonnes to the year 2012-2013. Mizoram stands as the second highest after Assam in northeast in the production of banana with an average yield of annual banana production of the state from 2009-2013 was 112501 metric tonnes from an average area of 9832.50 ha. Apart from these two states, banana has the potential of growing in other regions of north east as can be seen in Table 8 with different levels of production.

Coconut is found in the states of Assam, Nagaland and Tripura. However efforts are made by the Coconut Development Board (CDB) to extent the areas of coconut cultivation to other regions of north east. This include an area of 50,000 ha in Meghalaya and 40,000 ha each in Arunachal Pradesh and Assam which shows a great potential in the region. Assam which is the only state in north east having more area in coconut cultivation with an area of about 20000 ha, the state’s annual coconut productivity is over 9,125 nuts/ha as against the national average (of 8,303 nuts in one ha).

As can be seen, either the potential of the fibre crops such as cotton, ramie, jute and mesta can be increased by introducing and encouraging its growth in areas of jhum mixed with other crops or by emphasizing more on to the other benefits that can be obtained from the horticultural produce. Both these activities can bring about the enhancement of its productivity in terms of its export potential as well as the economy and employment to the farmers and to the people of the region.

CONCLUSIONS

In the modern phases of development, owing to their importance and their diverse utilization in industries and mills, fibre crops plays an important role due its comfort, availability, biodegradable, environmental friendly in nature. Indigenous traditional knowledge on various resources of fiber yielding plants is very essential for rural based development and provided proper precautionary measures are considered for sustainability, conservation and value based selection of use pattern. As a whole systematic approaches with scientific attitude would help the conservation of economically important plant as well as indigenous knowledge base available in north East India since it does have a potential in enhancing its utilization.

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Promotion of Ramie fibre crop in *Jhum* fallow area of Wokha district in Nagaland - A new initiative

SANTOSH KUMAR BAISHYA, SANJAY KUMAR RAY, BENDANGLA IMSONG, MEGOKHONO MEYASE AND MHALO TUNGOE

Krishi Vigyan Kendra Wokha, ICAR Research Complex for NEH Region, Nagaland Centre, Longsachung, Wokha, Nagaland-797111
**E-mail : santosh_baishya@rediffmail.com*

ABSTRACT : Ramie (*Boehmeria nivea* L.) is considered as the oldest and valuable textile fibre crops. It is being recognized for its strongest and longest natural fibre having manifold uses of it. The present study was undertaken to assess the performance and potential productive capacity of ramie (variety-*Hazarika*) under the *jhum* fallow system of Wokha district in Nagaland, in order to enhance the overall farm income of the tribal *jhumias*. The study was conducted in 2 villages covering an area of 6 ha under the frontline demonstration (FLD) programme of KVK, Wokha during the year 2014-2017. Before execution of the FLD, training cum demonstration programme was conducted on the package of practices of ramie cultivation and method demonstration of ramie fibre extraction was imparted to the selected farmers. A total of 3,60,000 numbers of ramie plantlets was provided to cover an area of 6 ha. A ramie fibre extraction machine was made available to the ramie growers on community basis. Market linkage/intelligence service was also rendered from the KVK. The result of the demonstration was very encouraging as it performed well under poor management condition and the yield of fibre was ranged from 16.21 to 18.15 q/ha/year. The average cost of ramie cultivation during the study period was Rs. 18,500/ha. The economic analysis of ramie cultivation revealed an average net annual income of Rs. 39,918 /ha with a B: C ratio of 3.16:1. Moreover, after seeing the success of ramie cultivation in *jhum* fallow, a total of 5 new farmers have taken up ramie cultivation to cover an area 3 ha. Finally, it could be concluded that fibre crop production through the introduction of ramie is not only a viable income generating option for *jhumias* but also it helps to manage *jhum* fallow land in a sustainable manner.

Key words : Fibre, frontline demonstration, Jhum fallow, Ramie, sustainable

Ramie (*Boehmeria nivea* L.) is considered as the oldest and valuable textile fibre crop, which is classified as an underutilized fibre. It is one of the strongest natural fibres having rich in cellulose content. Despite of the high potential and unique quality of fibre, ramie has received comparatively less prominence in the world due to various techno-economical reasons. China is the biggest producer of ramie followed by Brazil and Phillippines (Jose *et al.,* 2017). In

India, a very few areas of north Bengal and Assam are cultivating ramie and therefore, a huge scope is existing for expansion of area for ramie cultivation particularly in north eastern region of India.

The cultivation practice of north eastern hill (NEH) region including Nagaland is largely dominated by *jhum* or shifting farming system. The process of *jhum* farming involves cutting and burning of forest and finally land left as abundant only after 1-3 years of cultivation for regeneration of soil fertility, which forced them to select a new forest site to repeat the same process.. Presently, the system is characterized by low productivity and low income associated with numbers of inherent problems such as soil erosion, loss of nutrients and biodiversity. Of late, such problems accentuating due to reduction of *jhum* cycle to 3-5 years as compared to 10-15 years in the past. Now, the system is becoming an unsustainable and non-profitable and failure in providing food and livelihood security (Mantel *et al.,* 2006). In spite of several limitations and environmental implications, huge numbers of tribal farmers are still involved in this system. At present, nearly 4.43 lakh tribal families is associated with *jhum* cultivation to earn their livelihood and a large proportion of land (3,86,900 ha.) is estimated to be brought under *jhum* cultivation in the North East region every year (Patiram and Verma, 2001; Choudhury and Sundriyal, 2003). Likewise, 1.9 lakh tribal families are still practicing *jhum* cultivation covering an area of 1.24 lakh ha of Nagaland (ICAR, 2015). Therefore, complete eradication of this method of cultivation is practically not possible.

Around 3 million hectares of land in the region have come under different types of soil erosion hazards as a consequence of *jhum* cultivation (Mandal, 2011). Kushwaha and Ramakrishnan (1987) suggested some viable alternative *jhum* fallow management strategies by involving banana and/or pineapple plantation in the *jhum* fallow system. Arunachalam and Arunachalam (2002) recommended that the utilization of bamboos in eco-restoration is a viable option for managing *'jhum'* fallow system. Tawnenga and Tripathi (1996) also hypothesized that if second year cropping in *jhum* fields is essentially introduced, the dependence of the shifting cultivators on the forest could be reduced to almost one half. Whatever possible alternative *jhum* fallow management suggestions were made by the researchers, most of them are not practically adopted by the tribal *jhumias*. Hence, an appropriate post *jhum* management strategy is the paramount importance to be promoted in *jhum* areas to sustain the livelihood of tribal people. Under this circumstance, cultivation of ramie crop could be a viable intervention for the *jhum* fallow system because of its perennial surviving ability, extensive life span, 4-6 times annual harvesting and adaptive capability in wide range of soil and agro climatic conditions. Keeping the above facts in view, a frontline demonstration (FLD) programme was conducted to promote the ramie fibre crop cultivation through a cluster approach in *jhum* fallow areas of Wokha district in Nagaland to find out the potential productive capacity of ramie, to assess the economic benefits of ramie cultivation and changes in soil fertility status and crop performance.

MATERIALS AND METHODS

Study area : The study was initiated in the year 2014-15 at two different villages of Wokha district. The Humtso and Yithum village was selected because of the diverse ecological situation representing the whole district. The location is situated in between $26^0$05’037" N to $26^0$06’437" N latitude and $94^0$12’110" E to $94^0$12’980" E longitude and 527 to 1125 m above the mean sea level.

Soil status : Soils of the site were clay loam in texture. According to rating limits of soil test values (Muhr *et al.* 1965; Soltanpour and Schwab, 1977), soil pH (4.22) was extremely acidic in nature, high in soil organic carbon (2.42%) content, low in available nitrogen (177.21 kg/ha) content, very low in available phosphorus (12.0 kg/ha) content and very high in soil available potassium (256.48 kg/ha) content respectively.

Ramie production technology details : Frontline demonstration (FLD) on improved ramie cultivation technology was conducted by KVK, Wokha, Nagaland during the year 2014-2015 in undulating *jhum* fallow, covering an area of 6 ha involving 9 numbers of jhum farmers. Before implementation of the FLD, a training programme was organized on production technology of ramie cultivation. In total 3,60,000 numbers of ramie plantlets (variety: Hazarika) was provided to cover the targeted area. The full package of agronomic practices was followed with special emphasis on soil and water conservation measures, fertilization based on initial soil nutrient status, maintenance of adequate spacing (30 x 60 cm) and planting across the slopes, intercultural operations (weeding, spraying, etc.) and timely harvesting, which are the major production constraints in hill areas. At the harvesting stage of crop, hands on training cum demonstration programme on ramie fibre extraction were also conducted for 30 farmers using ramie fibre extraction machine at the FLD site.

Estimation of yield and fibre production : Ramie rhizome yield data was collected from the each demonstrated farmer fields through random plot cutting method in three replications at each and every harvesting stage of the year. After that, fibre was extracted from the cane and data of raw fibre production were also recorded. The fibre production conversion ratio from cane to fibre was also estimated during the period of crop harvest.

Economic analysis of FLD on ramie : Cost of cultivation of ramie crops, including cost of farm inputs such as fertilizers, pesticides and hiring of additional labour during planting, weeding and post harvesting operations. The family labour and cost of plantlets were not taken into consideration in the present study. The gross and net returns were worked out accordingly by taking cost of cultivation and raw fibre yield per hectare.

RESULTS AND DISCUSSION

Crop performance and productivity : In the present study the cultivation of ramie was found to be a successful technological intervention in the *jhum* fallow area. It was

Table 1. Year and season wise ramie cane yield

Year	Value	Fresh ramie cane yield (kg/ha) in different cuttings				Fresh cane yield (kg/ha/annum)
		1st	2nd	3rd	4th	
2015-2016	**Mean**	**4008.67±148**	**4497.00±216**	**4378.33±153**	**4526.67±205**	**17,410.67**
	Range	3859-4155	4250-4652	4211-4512	4300-4700	16,620-17,813
2016-2017	**Mean**	**4467.33±216**	**4953.33±61**	**4802.67±115**	**5187.33±146.5**	**19,410.67**
	Range	4230-4652	4890-5012	4698-4925	5085-5355	19,295-19,552

noticed that the planting time of ramie during the month of February March was ideal and the crop was harvested in four times of the year successfully. The annual ramie crop cane (ramie stem) yield was recorded to be 17410.67 kg/ha and 19410.67 kg/ha (Table 1) after the 1st year and 2nd year of planting respectively. Similarly, fibre yield was 1621 kg/ha in 1st year and 1815.33 kg/ha (Table 2) in 2nd year. Relatively higher cane and fibre yield was noticed in 2nd years of harvest. The higher yield in 2nd year might be due to better root establishment that helps to absorb adequate water and nutrients from both the surface and sub surface soils.

Further, it was recorded that the mean cane (ramie stem) yield in each cuttings (harvest) were ranged from 4008.67 to 4526.67 kg/ha and 4467.33 to 5187.33 kg/ha (Table 1) in 1st and 2nd year after planting respectively. Likewise, mean raw fibre yield in each cuttings were also ranged from 382.33 to 428.33 kg/ha and 411.33 to 475.67 kg/ha (Table 2) in 1st year and 2nd year respectively. The highest quantity of cane harvest was recorded in 4th cuttings followed by 2nd cuttings and 3rd cuttings and the lowest harvest was in the 1st cuttings in both the cultivating years. The cane yield was recorded highest in the 4th cuttings irrespective of the years which might be due to favourable temperature and rainfall distribution during the growing period that creates optimum soil and crop growth environment for better performance as compared to the other growing seasons.

The fibre content in ramie cane ranged from 9.1 to 9.5 per cent (Fig. 1) in the 1st year of harvest, whereas in 2nd year these ratios was altered considerably with values ranged from 8.6 to10.4 per cent (Fig. 2). Relatively higher percentage of fibre indicated that the better quality of harvest. However, in both the year moderately less harvest was obtained in 1st cutting but the superior quality of fibre was achieved.

Table 2 Year and season-wise ramie fibre yield

Year	Value	Ramie fibre yield (kg/ha) in different cuttings				Raw fibre yield (kg/ha/annum)
		1st	2nd	3rd	4th	
2015-2016	**Mean**	**382.33±13.57**	**410.67±4.51**	**399.67±11.06**	**428.33±6.51**	**1621±14.00**
	Range	368-395	406-415	388-410	422-435	1611-1637
2016-2017	**Mean**	**411.33±10.5**	**465.67±12.89**	**462.67±8.02**	**475.67±10.07**	**1815.33±13.43**
	Range	401-422	455-480	455-471	465-485	1800-1825

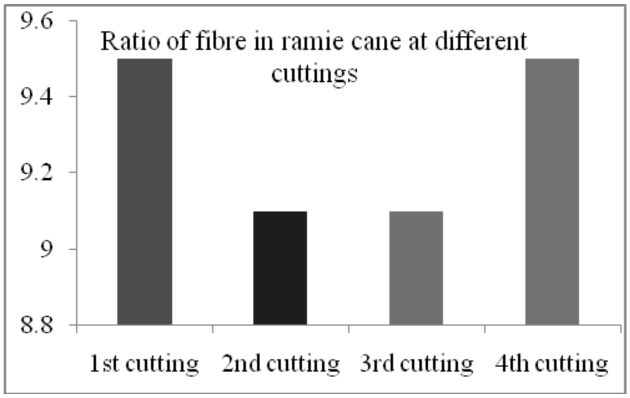

Fig.1 Ratio of fibre in ramie cane in 1st year of cuttings

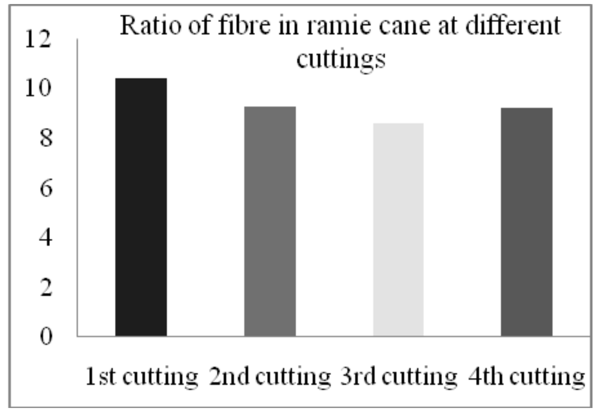

Fig.2 Ratio of fibre in ramie cane in 2nd year of cuttings

Table 3 Economic analysis of ramie cultivation

Year	Raw fibre production (kg/ha)	Cost of cultivation (Rs.)	Gross returns (Rs.)	Net returns (Rs.)	B:C ratio
2015-2016	1621.00	21,300	55,114	33,814	2.59:1
2016-2017	1815.33	15,700	61,721.2	46,021	3.93:1
Mean	**1718.17**	**18,500**	**58,417.6**	**39,918**	**3.16:1**

Economic analysis : The cost of ramie cultivation was Rs. 21,300 and Rs. 15,700/ha for 1st and 2nd year, respectively (Table 3). The highest expenditure was involved in 1st year of cultivation which was due to additional manpower involvement for planting of ramie plantlets. The gross returns was found higher in 2nd year (Rs. 61,721/-) than the 1st year (Rs. 55,114/-). This might be attributed to the higher annual production obtained in 2nd year. The two years net revenue varied widely from Rs. 33,814/- (1st year) to Rs. 46,021/-(2nd year) per/ha (Table 3) with average net income of Rs. 39,918/-. The higher net revenue was calculated in 2nd year due to the less cultivation cost and higher fibre production. The average B: C ratio was recorded as 3.16:1 from two years of ramie cultivation.

Changes in soil health status : The results indicated that the continuous cultivation of ramie in *jhum* fallow plays an important role to maintain the soil fertility status to some extent as compared to the uncultivated *jhum* fallow system. The result showed that soil pH increased significantly (4.52) from its initial soil pH value of 4.22 after two years of planting (data not shown). Implementation of a proper soil and water conservation measures and use of weed biomass as mulching materials also helped to increase soil organic carbon and residual available N content by 0.74 to 12.2 per cent. The residual phosphorus and potassium marginally decreased by 8.2 to 21.6 per cent from their initial soil P and K value of 12 kg/ha and 256.48 kg/ha, respectively.

CONCLUSION

From the present study, it could be

inferred that the cultivation of ramie fibre crop could be a viable technological intervention for management of *jhum* fallow areas leading to an income generating avenue for the *jhumias*.

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Impact of Poly mulching in reducing the infestation of pink bollworm on cotton crop

M.S.KAIRON*

Former Director, ICAR-Central Institute for Cotton Research, Nagpur and Presently President KVSS Sakarla, Tah.Parseoni, Dist. Nagpur

**E-mail : miansinghkairon@gmail.com*

With the large scale adoption of Bt cotton , bollworms were expected to develop resistance sooner or later. The moophagous (Feed on single type of food source) Pink bollworm. *Pectinophora gossypiella* was reported by Monsanto in ICAR-IARI New Delhi to have developed resistance to cry 1Ac in 2010. Pink bollworm started appearing on BG II ,consequently damaging proportion over the past 2-3 years specially in Gujarat and Maharashtra, and it was confirmed that it has developed resistance to cry 1Ac and cry 2Ab.

More over bollworm that develop resistance to cry1Ac and cry2 Ab are likely to adopt to new coming toxins very easily in a very short time as reported by ICAR-CICR Nagpur.Now it has become uncertain that pink bollworm will be controlled with *Bt* cotton. To-day it is the pink bollworm and tomorrow it may be American bollworm and as a result it has become a big question mark as what will be the future of the cotton with *Bt* resistant bollworms.

It has become very much essential for the policy makers and the cotton scientists to come with new strategies/technologies intervention laden with eco friendly environmentally suitable for controlling the bollworm to ensure long term sustainability of cotton production systems, with pink bollworm resistance to *Bt* cotton. Once again cotton farming is entering in to a stage of dangerous situation.

We have to find out the new technologies/strategies to sustain the progress of cotton production by using integrated approach of cultivating cotton like plastic mulching, cultural practices, which can keep down number of pink bollworm carry over between cotton crop, maintainence of host free period during off season is a must to ensure pink bollworm free during the next coming season. Therefore effective methods of prevention of pink bollworm damage include post-harvest, off season and pre planting action,allowing cattle grazing over green bolls on the plant at the end of the crop season, timely growth termination to maintain close season, clean up destruction of cotton stubbles immediate to harvest avoiding stacking of cotton stalks for fuel purpose to over long periods and summer deploying to expose the pupae of surviving larvae.

Plastic mulching have come into use to its inherent advantage of efficient moisture conservation, weed control and maintainence of soil temperature for faster mineralization.

MATERIALS AND METHODS

The field experiment was conducted on

the impact of poly mulch in reducing the infectation of pink bollworm on the cotton crop during 2016 and at 2017 Dr. M. S. Kairon Research Foundation, Nagpur. Ankur 3025 was used with a plot size of 20x10m (Main treatment) replicated thrice. The experiement was sown on 12-6-2016 and 8-7-2017 during 2016 and in the next year *i.e.* 2017 the experiments were sown in 13-6-2017 and 7-7-2017 with six treatments (sub treatments) i.e.

Sub Treatments

T1- Polythene sheet 30 micron black colour

T2-Polythene sheet 30 micron silver lining

T3- Chemical/ weed control

T4-Farmers package of practices

T5-No weeding- Zero level

T6-Complete weed removal manually

On raised bed of one meterwidth was made with water channels on all around the bed. The plant to plant distance was 30cm.The basal fertilizers (25%N, 25% K and 50% P) was given alongwith FYM, before spreading the poly film on the raised bed. The poly ethylene film 30 micron roll was placed before the raised bed, the sowing lines were marked on the polythene sheets. The remaining dose of fertilizers was given on 3 equal splits after 45,90 and 120DAS . In the irrigation channel intercrop green gram was sown and harvested after 60DAS. Polythene sheets were intact after the cotton harvest. The following observation were recorded plant growth parameters like plant height alongwith yield contributing characters like boll/plant, boll weight, seed cotton yield/ha, pink bollworm and jassid infestation.

Details of Treatments:

Variety: Ankur 3028

Main treatment

Plot size: 20x10m ———Replication:3

Date of sowing:

First year – 12/6/2016 and 8/7/2016

Second year - 13/6/2017 and 7/7/2017

Total treatment – 2 x6 =12

RESULTS AND DISCUSSION

Now it has been observed and recorded the data at Dr.M.S.Kairon Research Foundation during 2016-2017 in collaboration with Bajaj Polymin, Nagpur, in relation to pink bollworm attack on cotton crop planted with plastic mulching.

As poly mulch blocks successful completion of pupae stage which largely happens in soil crevices and plant debris. Plant debris on poly sheets would have conditions largely unfavourable for successful adult emergence of pink bollworm. The generation of pink bollworm are curtained due to their effect in mulch fields. Similarly, sucking pests, reflection and canopy micro-climate due to poly mulch deters for sap feeders from feeding/shelter and oviposition as well as the plant leaves of the poly mulch crop are thicker and attracts lesser incidence of sucking pests. The poly mulched plants are sturdy and the pest like stem weevil attacks could not break the cotton plants even through galls found in the stems.

Reflective mulches helps in reduction of virus diseases . The higher co_2 assimilatiion and increased cropproductiion efficiency resulting to increase the cotton production by 50-80 per cent higher and found cleaner produce and no soil is splashed to the produce during heavy down pour and or irrigation.

Table 1. Yield and yield contributing character and pest population effective by different treatments during 2016 (Average of two years)

Treatment	Yield (kg/ha)	Boll no.	Boll weight (g/boll)	Pink bollworm/ 20 green bolls	Jassid nyph/20 leaves	Plant height (cm)
D1xT1	4170	63.50	4.4	0.50	1.9	150.2
D1xT2	4115	61.75	4.5	0.00	1.5	152.4
D1xT3	2565	43.0	4.4	2.50	4.0	146.0
D1xT4	2240	40.5	4.4	4.00	3.6	138.0
D1xT5	820	12.75	4.1	10.00	9.0	120.0

Table 2. Yield and yield contributing character and pest population effective by different treatments during 2017 (Average of two years)

Treatment	Yield (kg/ha)	Boll no.	Boll weight (g/boll)	Pink bollworm/ 20 green bolls	Jassid nyph/20 leaves	Plant height (cm)
D2xT1	3700	61.00	4.4	1.00	1.7	148.4
D2xT2	3850	59.00	4.5	0.00	0.5	151.0
D2xT3	1700	45.50	4.3	1.00	3.8	140.0
D2xT4	1600	37.50	4.2	11.00	4.0	130.0
D2xT5	500	12.50	4.1	13.50	8.8	105.0
D2xT6	1650	38.50	4.0	8.50	7.0	130.0
	CD@ 130 kg/ha	NS	NS			

The poly mulching has significantly increased the yield over the other treatments (Table 1 and 2) .The poly mulching both black and silver colour are *at par* to each other. The main effect which was observed in relation to pest population especially to pink bollworm was remarkably very low in both the years and the jassid population was also low.

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Present status and holistic approach for the management of pink bollworm in cotton

S.G.HANCHINAL, G. AKSHATA, A.G. SREENIVAS AND M.BHEEMANNA
Department of Entomology, University of Agriculture Science, Raichur-584104
**E-mail : shanchinal@gmail.com*

ABSTRACT : The pink bollworm is back with a vengeance in *Bt* cotton across the India. This insect was a serious concern for cotton in India about 15 years ago in non *Bt* cotton. During lost 2 to 3 years damage to cotton bolls by pink bollworm and yield-losses were observed in *Bt* cotton in many regions of Gujarat and some parts of AP, Telangana, Maharashtra and Karnataka. PBW larval survival on BG II was recorded significantly higher during 2012, 2013 and 2014 mainly in Amreli and Bhavnagar districts in Saurashtra, while the damage ranged between 0-80 per cent on BG II in Bharuch. Pink bollworm had started to evolve resistance to the *Bt* toxin Cry1Ac in 2008 as it was confirmed with insect populations collected from Amreli district in Gujarat. Management of insect pests through synthetic insecticides was practiced and was a boon in the advent era of green revolution. Sole reliance on insecticides, particularly pyrethroids has caused an imbalance in the agroecosystem creating resistance and resurgence problems, warranting alternate control measures. Though the value of IPM in sustainable agriculture has been well recognized, much intense action is desired at field level. The slow progress in adopting IPM by cotton growers and raising demand for chemical pesticides is the issue of great concern. Hence a suitable technology for the cotton farmers in various agro climatic regions has to be adapted to all states.

Pink bollworm, *Pectinophora gossypiella* (Saunders), was a serious pest in non *Bt* cotton era. After introduction of *Bt* cotton hybrids in 2002, the pest was under control. Later it started developing resistance to cry proteins and damaging to *Bt* cotton in India.

World over, historically pink bollworm has become economically the most destructive insect pest of cotton. After hatching, the larvae are found in the flower, feeding on the anthers, pollens by living in a sort of web. Such flowers are characteristically twisted in the form of rosette. Later the larvae bore into the bolls, burrow through the lint penetrating deep into immature seeds. When one seed is destroyed, larvae then tunnel and enters through the developing lint and migrates to another seed and similarly to locules. The affected bolls rot and shed, while, those retained on plants open prematurely resulting in stained immature fibre (Agarwal *et al.,* 1984), causing 80 per cent reduction in seed cotton yield and quality of lint (Henneberry *et al.*, 1978). In north India, pink bollworm is considered as a key pest of cotton, causing a total crop failure in Punjab and Sindh during 1905, 1906 and 1911 (Khan and Rao, 1960). In peninsular region, Narayanan (1962) reported that 75 to 100 per cent bolls are liable to be damaged by pink bollworm in Karnataka. The pink bollworm under unprotected condition has been known to cause 2.81 to 61.87 per cent loss in seed cotton yield, 3.44 to 37.83 per cent loss in germination, 2.12 to 47.13 per cent loss in oil content and 10.66 to 59.15 per cent loss in normal opening of bolls (Patil, 2003).

Until 2008, *Bt* cotton was very effective in controlling all the three bollworm species. However, resistance monitoring reports published by Monsanto and IARI (Indian Agricultural Research Institute, New Delhi) showed that the pink bollworm had started to evolve resistance to the *Bt*-toxin Cry1Ac in 2008 as was confirmed with insect populations collected from Amreli district in Gujarat. Data published in 2011 by Monsanto and IARI showed that resistance was significantly higher at 44 fold resistance for insects derived in 2008 from Amreli than for any of the other field populations tested from four locations in India. This was the first confirmed bollworm resistance to *Bt* cotton in India.

Santhosh *et al.,* (2009) studied the impact of *Bt* cotton on PBW infestation and the results revealed that *Bt* cotton registered significantly lower number of larvae (3.35 larvae/30 bolls) as compared to non *Bt* cotton (10.03/30 bolls). In Vadodara and Kheda districts, the infestation of PBW was found up to 94 per cent and 27 per cent, irrespective of the *Bt* cotton varieties (Anonymous, 2014). PBW larval survival on BG-II was recorded significantly higher during 2012, 2013 and 2014 mainly in Amreli and Bhavnagar districts in Saurashtra, while the damage ranged between 0-80 per cent on BG II in Bharuch, Vadodara, Anand, Bhavnagar, Amreli, Junagadh, Rajkot, Surendranagar and Ahmedabad districts (Kranthi, 2015). The infestation of PBW was observed up to 100 per cent in Vadodara and 14.05 per cent incidence in Kheda district (Anonymous, 2016).

Survey was conducted to record the field infestation of pink bollworm on *Bt* cotton in major cotton growing areas of Karnataka during 2015-2016. The survey revealed that the presence of pink bollworm in all hybrids of *Bt* cotton and survival of pink colour later instar larvae on bolls in all locations. The maximum mean green boll damage were recorded in Raichur taluka (67.80%) followed by Shahpur taluka (42%) in Yadagir district.

Extensive research has resulted in a broad array of monitoring, biological control, cultural, behavioural, genetic, mating disruption ,sterile insect technique, splat technique and host plant resistance methods that can serve as a base for the formulation of integrated PBW management systems. The life history characteristics of the PBW, in particular the high mobility of adults, indicate the need for combinations of selected integrated pest management (IPM) components implemented over large geographical areas.

Biology and ecology of pink bollworm : The female can lays around 125 eggs on the tender leaves, squares, flowers or green bolls. Young larvae emerge after 3-5 days (in optimum conditions), entering the cotton bolls shortly after emergence where they feed internally within the pod, making a small hole to the exterior to allow air to penetrate. Larvae feed on squares, flowers and bolls, including the seeds within bolls. They web the cotton flower petals, imparting a characteristic 'rosette' appearance. Feeding within the boll results in malformation, rotting, premature or partial boll opening, reduction in fiber length and overall reduced quality of the cotton crop due to staining of the lint (Ingram, 1995).

Carryover of pest : Mallah *et al.* (2000) reported that population of PBW remained in left over standing cotton throughout the year. According to Attique *et al.,* (2001)*,* 35 per cent larvae survived in the lower part of the heap in the left over bolls of cotton stalks kept horizontally. The seed cotton carried to market yards acts as a source for the pest to spread. In the absence of cotton, or as a genetically pre-disposed condition, the pink bollworm undergoes hibernation for 6-8 months, until the next season (Kranthi, 2015).

Seasonal abundance of pink bollworm : Korat and Lingappa (1996) reported that larval activity of PBW on tender bolls began in mid November and continued till harvest of the crop. Sangareddy and Patil (1997) at Raichur reported that incidence of PBW commenced from October onwards which gradually increased and reached to a peak during February and declined thereafter. Venilla *et al.,* (2007) at Nagpur studied seasonal abundance of PBW for five years and reported maximum population during 27th week of crop emergence in 2001, while comparatively lower population was observed in subsequent years. Significantly lower number of pink bollworm larvae and green boll damage were recorded in *Bt* cotton hybrid compared to non-*Bt* cotton hybrid (Nadaf and Goud, 2007).

Diapause in pink bollworm : Fourth instar larvae of the pink bollworm may undergo a facultative diapause at the end of the larval feeding period. Diapause larvae are heavier, have a slower rate of heart beat, and consume oxygen at about one-sixth the rate of non-diapause individuals. In addition, the diapause condition is accompanied by an atrophy of the male gonads and an increase in fat content of both sexes. Diapause in the pink bollworm is primarily under the control of the photoperiod.

Laboratory and field studies conducted at Brownsville, Tex., indicated that diapause in the pink bollworm (*Pectinophora gossypiella* (Saunders) was controlled primarily by photoperiod, with boll age and temperature exerting a secondary effect. Photoperiods progressively increasing from 12 to 16 hours and a constant photoperiod of 14 hours favored the development of non diapause larvae, whereas decreasing photoperiods and constant ones above and below 14 hours were effective in inducing larvae to enter diapause.

Development of resistance to pink bollworm (*Pectinophora gossypiella)* : Pink bollworm resistance to Cry1Ac was confirmed in four districts in Gujarat-Amreli, Bhavnagar, Junagarh and Rajkot in 2009 and 2010. Pink bollworm larval survival on BG II was recorded significantly higher in 2012, 2013 and 2014 mainly in Amreli and Bhavnagar districts in Saurashtra. Pink bollworm survival on all the *Bt* cotton hybrids in different parts of karnataka, Andhra Pradesh and Telangana during 2015 and 2016 (Kranthi, 2015).

Reasons for pink bollworm occurrence on Bollgard II : Cultivation of long duration hybrids that erve as continuous hosts of the pink bollworm in different parts of the country. Large number of hybrids with varying flowering and fruiting periods that, provide continuous food for the bollworms in an overlapping manner. Long term storage of raw cotton in ginning mills and market yards that serve as a source of pink bollworms to the ensuing crop. Early (April-May) sown crop stars flowering that coincide with the minor seasonal pink bollworm that occurs in June-July. Pink boll worm populations from Gujarat developed resistance to Cry1Ac and Cry2Ab together. Therefore the larvae are able to survive on BG II. The segregating seeds in bolls of F 1 hybrid plants accelerate resistance development. Non compliance of refugia(non *Bt* cotton). Squares, flowers and developing seeds in young bolls have less *Bt* toxin expression. Extending the crop beyond November. In many fields, extended the crop up to April May provided continuous availability of cotton all through the year (Kranthi, 2015).

Holistic approach for the management of pink bollworm : Conventional insecticides have not provided a long-term solution to the pink bollworm problem (Henneberry, 1986). Considerable amounts of basic biological and ecological information have been accumulated and applied in developing PBW control programs. No single control method is completely satisfactory. The possibility of combining a number of methods into a single control system appears to be the most promising approach (Henneberry *et al.,* 1980).

Cultural control : Late planting of crops has been used as a cultural control method where the end of diapause is triggered by day length. Larvae that emerge before the crop is ready then have no food supply (Frisbie *et al.*, 1989). While planning for the next season selection of varieties with early maturity, drying of seeds under sun for 6-8 hours and sowing of acid delinted seeds are effective and economical to prevent the carryover of pink bollworm to the next cotton season.

Physical control: Cent per cent mortality was observed when seeds were exposed for 20 min at 48.9 ^{0}C temperature. (Atwal and Singh, 1969).

Botanicals: Borkar and Sarode (2011) reported that application of botanicals, NSKE (5%), azadirachtin 1500 ppm and neem oil (1%) proved to be the most effective. *Neem* oil at 1.5 and 2 per cent and neem seed water extract at 2 and 3 per cent resulted into significantly lower damage than control (Rashid *et al.,* 2012).

Biological control agents : PBW were effectively controlled by *Rogas* and *Apanteles spp.* (Anonymous, 1979). *Chelonus blackburni* was effective as uni parental egg larval parasite (Jackson *et al.*, 1979). *Apanteles angaleti* was effective parasitoid of PBW (Singh *et al.*, 1988). Malik (2001) reported that total parasitization of pink bollworm eggs by *Trichogramma bactrae* in two replications was 19.56 and 26.84 per cent, respectively. *Trichogramma evinces* efficiently parasitized PBW pbw eggs under field condition (Saad *et al.*, 2012).

Chemical control: Lamdacyhalothrin @0.5ml/1 or Decamethrin 2.8EC @0.5ml/1 or Cypermethrin10EC @ 0.5ml or Profenophos 50EC @ 2ml/1 or Thiodicarb 75WP @1g/1 are effective in controlling pink bollworm. Beta-Cyfluthrin (24.11%), spinosad (25.33%) and indoxacarb (26.43%) were promising for control of PBW (Gopalswamy *et al.*, 2000).

Pheromonal control : Nandihalli and Patil (1993) recommended that nine traps/ac were optimum for mass trapping the PBW moths. Korat *et al.*, (1994) reported that the number of moths trapped/trap/night were 9.60 and 10.47 in check and 5.75 and 7.44 in insecticidal treated block during 1989-1990 and 1990-1991, respectively. Application of PB rope LLT in cotton @ 150/ha caused effective mating disruption of PBW (Anonymous, 2007).

Pheromone trap catches of pink bollworm (PBW) *Pectinophora gossypiella* (Saunders) moths and incidence in bolls increased steadily over the years. The peak trap catches of PBW was noticed from November to February during cropping season over ten years period. Mean trap catches of PBW was 56.12, 48.04, 44.50 and 26.26 moths/ trap during November, December, January and February, respectively. PBW, *Pectinophora gossypiella* (Saunders) incidence is increasing considerably late in the cotton season under irrigated conditions which needs immediate management strategy (Patil *et al.*, 2007).

Mating disruption technique : Behavioural insect control by mating disruption with sex pheromone was suggested by Knipling and McGuire (1966).

Area-wide, timely application of commercial formulations of gossyplure in the Parker Valley of Arizona, demonstrated the feasibility of suppressing PBW infestations to a near zero level in four years, and conceptualized the prospect of eradication (El-Lissy *et al.*, 1993, Staten *et al.*, 1995, and Antilla *et al.*, 1996).

Patil *et al.,* 2001-02 found out the effective dosage of Pb Rope ◊L against pink bollworm management in 100 ha farmer fields at village, Raichur , Karnataka, India. They have concluded that PB Rope◊ L at 200 dispensers / ha application at first pin square stage (35- 40 DAS) effectively checked pink bollworm incidence and increased seed cotton yield under irrigated ecosystem.

Suppressing resistance to transgenic *Bt* cotton using sterile insect technique (SIT) : Sterile insect technique (SIT) is one of the eco friendly pest management technique and it can be included in IPM with other pest management technique for pest suppression. SIT works in principle against pests with recessive or dominant inheritance of resistance. During a large scale, four year field deployment of this strategy in Arizona, resistance of pink bollworm to *Bt* cotton did not increase. A multitactic eradication program that included the release of sterile moths reduced pink bollworm abundance by >99 per cent, while eliminating insecticide sprays againt this pest (Tabashnik *et al.,* (2013). For non *Bt* cotton @ 4400/ha/week. For *Bt* Cotton @380/ha/week reduced the pest population effectively.

Efficacy of pink bollworm eradication programme by sterile insect technique : The Pink Bollworm Program is probably the most successful and longest running yet least known area wide biological control programs in the world. For 34 years, program activities have successfully prevented incipient infestations of pink bollworm (PBW) from becoming established in the cotton growing areas of the San Joaquin Valley. The pink bollworm program uses an integrated pest control approach relying on trapping, sterile release, crop destruction infestations below economic impact levels. The program does not use pesticides, but rather uses sterile PBW moths to overwhelm these infestations.

SPLAT (Specialized Pheromone and Lure Application Technology) : Novel formulations of Semiochemicals. Unlike traditional pheromone dispensers , the application of SPLAT can be tailored by the user to best match the pest distribution and density in the field. Using a fixed amount of SPLAT/area, one can choose to either use a high density of small point sources, thus maximizing the mating disruption effect, or decrease the point source density while increasing its size, thus increasing the longevity of the application.

SPLAT PBW over stimulates males with a sex pheromone to disrupt the mating cycle, deterring males from mating with female moths. For best results, use SPLAT when populations are dense to help deter mating activity(ISCA).

CONCLUSION

Pink bollworm once again reached major pest status in *Bt* cotton in India. is a major problem in India, primarily because of long duration varieties and absence of any potent control measures. The simplest and most potent way to overcome the problem is to take up timely sowing and cultivate early maturing varieties of about 150 days duration. All other management strategies such as pheromone traps, PB ropel, botanicals, SIT, bioagents and insecticides alone and with integration can be effective tool for control of PBW. Holistic approach for the the management of PBW an opportunity to Indian Researchers to augment the power of *Bt* resistance management.

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Integrating infochemicals for the management of pink bollworm in cotton

P.R. BADARIPRASAD*, A.G. SREENIVAS AND S. G. HANCHINAL
Department of Entomology, University of Agricultural Sciences, Raichur - 584 104
**E-mail : bads2001@rediffmail.com*

Pink bollworm (PBW) *Pectinophora gossypiella* (Saunders) has been economically the most destructive insect pest of cotton and causes maximum seed cotton loss in quantity and quality. In Karnataka, PBW is emerging as a serious pest and its activity is observed for a brief period from January to till the end of the season in April. In the recent past, the pest has been frequently noticed from early flowering.

PBW has been the most enigmatic in the context of *Bt* cotton because of its biology. PBW is known to feed and multiply only on conventional non GM cotton (non*Bt*). Considering that *Bt* cotton covered >95 per cent of total cotton acreage (~11 million ha) in 2015, PBW has evidently come under increasing selection pressure to evolve resistance to *Bt* protein(s) produced in tissues of *Bt* cotton plants. Secondly, even as an alternative control method, conventional insecticides have limited efficacy on PBW due to the internal feeding habit of the larvae within the developing cotton boll.

Unusually high levels of pink bollworm (PBW) infestation and crop damage were experienced in the fields of the dual *Bt* gene cotton (Bollgard II®) technology, a genetically modified cotton which produces two *Bt* insecticides (Cry1Ac and Cry2Ab) to combat cotton bollworms, in Gujarat, Madhya Pradesh, Maharashtra, Karnataka and Andhra Pradesh during *kharif,* 2015 (Kranthi, 2015), and in the early part of the 2016 season in Saurashtra (Gujarat) and Haveri (Karnataka). These incidences caused great concerns in the cotton trade chain because of the impact on cotton output and reduced market price of PBW damaged cotton, and equally among the scientific fraternity because it indicated that PBW, which had been well managed by *Bt* traits in cotton in the past, was now capable of feeding on Bollgard II crop. A study by the Central Institute for Cotton Research had indicated that the unusual damage by PBW to Bollgard II in 2015 could be due to resistance evolution by the insect to the dual *Bt* gene cotton, which had provided excellent protection against all bollworms since its introduction in 2006. Field-resistance to the single *Bt* gene cotton (Cry1Ac) in PBW populations from Gujarat was reported in 2010 (Dhurua and Gujar, 2011).

Hummel *et al.,* (1973) identified a 1:1 mixture of the (*Z,Z*) and (*Z,E*) isomers of hexadeca 7,11 dienyl acetate as the sex pheromone of the pink bollworm(PBW) and named it "gossyplure". Shorey *et al.,* (1976) initiated research to determine the efficacy and mechanism(s) of mating disruption for PBW using gossyplure which resulted in the first US Environmental Protection Agency (EPA) registered mating disruption product in 1978 (Brooks *et al.,* 1979).

Since that time, scientists and entrepreneurs have turned their attention to mating disruption as a "biorational" approach to insect pest management.

A new alternative to pesticides successful globally is mating disruption or attract and kill techniques using Semiochemicals. (Carde´ and Minks, 1995) and till date none have been registered in India. These two techniques usually become the key elements in integrated pest management (IPM) programs when available. However, globally there are very few mating disruption products developed globally. Sex pheromone can be used for mating disruption which is a pheromone mediated control strategy used on lepidopterous insects (moths) that prevents the mating and reproduction of adult pests. Since the worm or larva is the stage that damages fruit, prevention of this stage is the goal in any pest management program. This control strategy requires the use of dispensers which provide a sustained release of the pheromone for a long time interval. These dispensers are placed throughout the field so as to saturate the area with the pheromone scent. Male insects normally cue in on a plume of pheromone emitted by an unmated female. By saturating an area with the same scent, males are prevented from locating the females and mating never takes place. There are more than 250 pests affecting various crops and matting disruption program for these pests have been largely unviable due to high cost of pheromone synthesis and its use limited to monitoring.

A number of commercially available formulations containing the synthetic female sex pheromone (Gossyplure) of *P.gossypiella*, have been used widely as a prophylactic spray for mating disruption and mass trapping to control the pink bollworm in the developed world (Staten *et al.,* 1987; Moawad *et al.,* 1991; Chritchley *et al.*, 1991).

A variety of strategies have been employed, including applications of hollow fibers, chopped laminate flakes, sprayable microencapsulated pheromone, twist-tie ropes or laminate membrane dispensers.

The effective use of mating disruption could not only lead to reduced insecticide usage, but it has also been identified as a strong tool in managing insecticide resistance. Insecticides are valuable and important tools for modern agricultural production, so any methods to delay the onset of resistance are beneficial. Appropriate rotation of mating disruption strategy in an IPM program can reduce the need for insecticide treatments, thus reducing the insecticide selection pressure for insect pests resulting in delayed evolution of resistance to insecticides applied in the field.

Other benefits of pheromone-based mating disruption can include preserving insect natural enemies and reducing health risks to the farm workers.

The extent of insect control programs that use pheromones and the area treated has increased considerably during recent years. However, intensive research focusing on insect behavior, effective pheromone formulation characteristics and suitable application techniques is required for its successful deployment for certain insect species. At least for the present, various studies have indicated that control of certain insect pests is not yet possible by using present mating disruption techniques and/or pheromone formulations.

However, because of some difficulties with high pest populations, such programs should not be viewed as standalone strategies, but rather as one tactic within a suite of IPM options (Welter *et al.,* 2005).

Perhaps the greatest challenges lie with understanding the mechanisms of mating disruption systems for different target species and dispensers, which will allow the design of better applications and protocols. Finally, the implementation of mating disruption may require a shift in the scale at which growers, pest management consultants, extension specialists and university researchers approach management systems, given that overall program performance is strongly correlated with large-scale, multigrower implementation efforts.

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Impact of climate change in exacerbation of insect pest problems in cotton

K. K. DAHIYA, R. S. JAGLAN AND ARUN JANU*

Department of Entomology, CCS Haryana Agricultural University, Hisar – 125004

**E-mail : januhau@gmail.com*

Agriculture is extremely vulnerable to climate change. Higher temperatures will eventually reduce yields and increase the prevalence of pests and diseases. The term global change embraces a range of natural and anthropogenic environmental changes. According to Intergovernmental Panel on Climate Change (IPCC), it is defined as "Change in climate over time, either due to natural variability or as a result of human activity". Most of the warming observed over the last 50 years is attributable to human activities. The global mean surface temperature is predicted to increase by 1.4 to 5.8°C from 1990 to 2100. If temperatures rise by about 2°C over the next 100 years, negative effects of global warming would begin to extend to most regions of the world (IPCC, 2001). Such changes in climate and weather could profoundly affect the status of insect pests of crops. These may arise not only as a result of direct effects on the distribution and abundance of pest populations but also indirect effects on the pests' host plants, competitors and natural enemies (Porter *et al.*, 1991). Some pests which are already present but only occur in small areas, or at low densities may be able to exploit the changing conditions by spreading more widely and reaching damaging population densities (Bale *et al.*, 2002). Keeping these facts in view, the topic on the impact of climate change on insects is discussed here.

Impact of climate change on Insect and pests : Climatic factors like temperature and precipitation in particular, have a very strong influence on the behaviour, distribution, development, reproduction and survival of insect pests, as the insects being *poikilotherms*. Researchers found that the numbers of leaf eating insects are likely to surge as a result of rising levels of CO_2 (Connor, 2008). These effect could either be direct, through the influence of weather on the insects' physiology and behavior (Merrill *et al.*, 2008) or may be mediated by host plants, competitors or natural enemies. Climate change related factors like rise in temperature, changes in precipitation patterns, milder and shorter winters, rise of sea levels and increased incidence of weather events can directly influence insects by affecting their rate of development, reproduction, distribution, migration and adaption. In addition, indirect effects can occur through the influence of climate on the insect's host plants, natural enemies and interspecific interaction with other insects. The impacts include changes in phenology, distribution and community composition of ecosystem that finally leads to extinction of species (Walther *et al.*, 2002). As insects represent huge numbers of taxa and individuals, with their short generation times, high mobility and high reproductive rates, they will respond more quickly to climate changes than long lived organisms, like higher plants and mammals (Menéndez, 2007). Infact, insects may be the first predictors of climate change. Milder and shorter winters will results in early start by the pest under warm weather condition breeding. Other changes include expanded pest ranges, disruption of synchrony between pests and natural enemies and increased frequency of pest outbreaks and upheavals (Parmesan, 2007)

Rising temperature and insect pest population : A key factor regulating the life history pattern of insect pest is temperature. Because insects are *poikilothermic* (cold blooded) organisms, the temperature of their bodies is approximately the same as that of the environment. Therefore, the developmental rates of their life stages are strongly dependent on temperature. Almost all the insects will be affected to some degrees by changes in temperature and there may be multiple effects upon insect life histories. With every degree rise in global temperature, the life cycle of insect will be shorter. The quicker the life cycle, the higher will be the population of pests. In temperate regions, most insects have their growth period during the warmer part of the year because of which, species whose niche space is defined by climatic regime, will respond more predictably to climate change while those in which the niche is limited by other abiotic and biotic factors, will be less predictable. The general prediction is that if global temperatures increase, the species will shift their geographical ranges closer to the poles or to higher elevations and increase their population size (Harrington *et al.*, 2001).

The increase in temperature associated with climatic change, would impact crop pest insect populations in several complex ways like (a) extension of geographical range (b) increased over-wintering (c) changes in population growth rate (d) increased number of generations (e) extension of development season (f) changes in crop pest synchrony (g) changes in interspecific interactions (h) increased risks of invasions by migrant pests and (i) introduction of alternative hosts and over-wintering hosts. But all these effects of temperature on insectslargely overwhelm the effects of other environmental factors (Bale *et al.*, 2002).

With the increase in mean temperature by ~0.6°C over the past century and projected increases in the future (IPCC, 2001), climate change has been shown to have effects on ecosystems worldwide (Walther *et al.*, 2002). Temperature increases already have caused changes in species diversity and distribution. It will alter the distribution of many species in different taxa (Hickling *et al.*, 2005).It has been recognized that global warming affects the individual species and communities in the form of range shifts and extinctions (Battisti, 2004). Depending on the development strategy of an insect species, temperature can exert different effects. Temperature can impact insect physiology and development directly or indirectly through the physiology or existence of hosts. Some insects take several years to complete one life cycle. These insects (cicadas, arctic moths) will tend to moderate temperature variability over the course of their life history. Some crop pests are "stop and go" developers in relation to temperature, so they develop more rapidly during periods with suitable temperatures. It has been estimated that with a 2°C temperature increase, insects might experience one to five additional life cycles per season (Yamamura and Kiritani, 1998). Warming could decrease the occurrence of severe cold events, which could in turn expand the over-wintering area for insect pests (Patterson *et al.*, 1999). In-season effects of warming include the potential for increased levels of feeding and growth, including the possibility of additional generations in a given year. There is also the prospect of new pests, which may become much more important as a result of increased temperature due to global warming.

Elevated global temperatures were found to create favourable conditions for the survival and reproduction of many insect pests such as the cotton sap-sucking pest's*viz.* whiteflies, thrips, aphids, mealybug, etc. Among various sap sucking pests the whitefly, *Bemisia tabaci* B biotype causes serious yield losses to cotton, vegetable and ornamental crops not just as a direct pest but also a vector of the cotton leaf curl virus in India and Pakistan. Elevated temperatures can have serious effects on increasing populations of the whitefly and the cotton leaf curl disease.

Elevated carbon dioxide and insect pest population : One of the most studied aspects of climate change is the effect of increasing concentrations of CO_2 on plants. Plants consist primarily of carbon and elevated CO_2 levels allow them to grow more rapidly because they can assimilate carbon more quickly. Greenhouse growers have known this for decades and add CO_2 to encourage plant growth. Similarly, because CO_2 increases the photosynthetic rates of most crop plants, scientists initially thought that increasing CO_2 would be a solution for the world's food supply (LaMarche *et al.*, 1984). In addition to enhanced growth, many crop plants become more drought tolerantdue to CO_2 enrichment. This is because the openings in the leaves (stomata) thatlet CO_2 in also let water vapor out and if there is high CO_2 concentration in the vicinity of leaf then the stomata need not open as much. It was suggested that under conditions of elevated CO_2, plants will produce better yields even when conditions are harsh. Unfortunately, this optimistic prediction has not proven accurate. One reason for this is that insects also eat more when plants are grown under elevated levels of CO_2 to compensate their low nutritional quality.

A rise in CO_2 generally increases the carbon to nitrogen ratio of plant tissues thereby reducing the nutritional quality for protein limited insects diluting the nitrogen content of the tissues (Coviella *et al.*, 1999). The expected reactions from herbivores to the increase in carbon to nitrogen ratio are compensatory feeding, concentrations of defensive chemicals in plants and competition between pest species. Insects may accelerate their food intake to compensate for reduced leaf nitrogen content, although this is not always the case (Knepp *et al.*, 2005). However, the response of plants to increased CO_2 varies among species.

Increased carbon to nitrogen ratios in plant tissue may slow insect development and increase the length of life stages vulnerable to attack by parasitoids. Phytophagous insects may also develop adaptations to overcome higher carbon to nitrogen ratios. However, other insect speciesseem unable to compensate the lower nutritional quality of the plants by increasingthe efficiency of nutrient utilization (Brooks and Whitekar, 1999). The experimentsat CICR showed that the leaf eating caterpillar *Spodoptera litura* consumed 30 per cent more leaves of cotton plants under elevated CO_2 compared to control plants. Further the insect laid more eggs after feeding on the CO_2 exposed plants.

Rising temperature and carbon dioxide on host insect interaction : The capacity of an herbivore insect to complete its development dependson the adaptation to both, the environmental conditions and the host plant. Thechanged temperature, which promotes the expansion of insect's range, may alsoinvolve a new association between an herbivore and its host. The large outbreaks observed in the expansion areas on the newhosts may be explained either by the high susceptibility of the hosts or by theinability of natural enemies to locate the moth larvae on an unusual hosts or environment (Stastny *et al.*, 2006).

The effects of a modified atmosphere on herbivore insects could also involve the third trophic level, *i.e.*, their parasitoids and predators. A delay in the developmental time of the herbivores after exposure to high CO_2, can increasethe probability of parasitism and predation as well. Dury *et al.* (1998) showed that an increase in temperature by 3°C might lead to the same effect as that of an increase in CO_2 (decreased nitrogen and increase in condensed tannins) on oak leaves. However, an increase in temperature may enhance the feeding of theherbivore and thus compensate for the negative effects of a lower food quality.

The response of herbivore insects to increased CO_2 may also differ among the feeding guilds (Bezemer and Jones, 1998). Defoliators are generally expected to increase leaf consumption by about 30 per cent, but leaf miners show a much lower rate. Phloem-sucking insects appear to take the greater advantage from increased CO_2, as they grow bigger in a shorter time. Elevated CO_2 increased the susceptibility of soybean to invasive insects by down-regulating the expression of genes related with hormonal defense, which down regulate important anti digestive defenses against beetles. Soybean respond to insect attack by producing defense compounds that inhibit digestive enzymes (proteinases) in the gut of insects, thereby reducing their performance and crop damage. The productions of these anti digestive compounds are regulated in plants by the hormone jasmonic acid. However, elevated CO_2 levels disrupt this equilibrium in plant-insect interactions and benefit the herbivore.

Precipitation and pest population : There are few scientific evidences on the effect of precipitation on insect pest population and their growth. Some insects are sensitive to precipitation and are killed or removed from crops by heavy rains. In some northeastern US states, this consideration is important when choosing management options for onion thrips (Reiners and Petzoldt, 2005). However, some insects that over-winter in soil, suchas cranberry fruit worm and other cranberry insect pests, flooding the soil has been used as a control measure (Vincent *et al.*, 2003). It is predicted that more frequent and intense precipitation events forecasted during climate may change have negative impacts on these insect pest population. Similar to temperature, precipitation changes can impact insect pest predators, parasites and diseasesresulting in a complex dynamic manner. Fungal pathogens of insects are favored by high humidity and their incidence would increase by climate changes thatlengthen periods of high humidity and reduced by those that result in drier conditions.

Pest management under climate change scenario: Weather based pest forewarning systems are decision support tools that help growers to assess the risk of outbreaks of economically damaging crop pests at present and future climate change scenario. Using information about weather, crop, and/or insects, warning systems advice growers or other crop managers when they need to take an action usually to apply an insecticidal spray to prevent pest outbreaks and avoid economic losses. Pest warning systems are key elements of Integrated Pest Management (IPM) efforts to reduce excessive use of chemical pesticides. There are several potential incentives for growers to adopt pest warning systems. By substituting risk assessment based spray timing for traditional calendar based pesticide spraying, growers can reduce spray frequency, limiting the health and environmental hazards of pesticide use while presenting an environmentally friendly image to customers. The five components of an IPM programme are prevention, monitoring, correct disease and pest diagnosis, development and use of acceptable thresholds, and optimum selection of management tools. The management strategies available include genetic control, cultural control, biological control, and chemical control. What management strategy is most relevant depends impart on the particular pest. Pest management strategy coupled with weather based pest forewarning system forms the 'Expert System' or 'Decision Support System' for pest management. Need for these systems will be felt increasingly in the future.

CONCLUSIONS

The greatest challenge facing humanity in the coming century will be thenecessity to double our global food production to meet the booming increase in population by using less land area, water, soil nutrients, droughts from globalwarming and increasing insect damage to crops as insect migration expands. Understanding how these rapid anthropogenic changes in climate and atmosphericchemistry will affect the 'goods and services' provided by native and agriculturalecosystems, is one of the greatest scientific challenges of our time. Conversely, there are some indications that the interrelated effects of climate on plant and direct influence on natural enemies can make the overall effects difficult to predictand it is considered that not all climate change scenarios will be detrimental.

There are many interactions and it is extremely difficult to predict theimpact of climate change on insect pests in the future, but we may expect anincrease of certain primary pests as well as secondary pests and invasive species. It has been assumed that global warming will increase the prevalence of insect pests in many agro-ecosystems, but just to identify the problem is not enough,we need to find some solutions. IPM methods provide enough flexibility by whichwe will be able to deal with many of the pests. But reducing the amount of globalwarming is desirable. Global warming is one of the problems caused by humanactivities and can also be minimized by human activities. By acting now, we canmitigate the problem and will not have to face the doomsday forecasts of melting icecaps, flooded seacoasts, and species extinctions.

In India, the government's agenda includes three main strategies. First, through international negotiations, gaining access to technology, funding and energy transfer to adapt to climate change. Secondly, through adaptation policies, such as implementation of the national action plan, which has eight core national missions running. The third strategy is to conduct research on climate change through a network of institutions. In addition, the private sector may also plays a major role through financing, development and deployment of technologiessuitable for mitigating and adaptation to climate change.

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Insecticidal toxin genes from entomopathogenic nematodes potential alternate to *Bt* genes

NANDINI GOKTE NARKHEDKAR*
Crop Protection Division, Central Institute for Cotton Research, Nagpur -
**E-mail : nnarkhedkar@rediffmail.com*

Insect pests particularly bollworms viz. American bollworm *Helicoverpa armigera*, Pink Bollworm *Pectinophora gossypiella* and spotted bollworm *Earias* spp., are the bane of all four species of cotton (*Gossypium arboreum*, *G. herbaceum*, *G. hirsutum* and *G. barbadense*) cultivated in India causing considerable losses in quality and yield. In India, cotton is grown under both rainfed and irrigated conditions as almost monoculture with almost nil crop rotation. This causes perpetuation and carry over of the insect pests from one season to another which in turn necessitates consumption of large amount of pesticides in their management. Chemical management of bollworms has inherent risk of human toxicity apart from environmental pollution and contamination of perennial sources of water, toxicity to mammalians and aquaculture. Introduction of *Bt* cotton was the technological breakthrough which provided inherent protection to cotton against bollworms. However in recent years there has been reports of break down of resistance particularly against pink bollworms making it necessary to find alternatives to *Bt* toxins .

Entomopathogenic nematodes (EPNs), in recent years , have been recognized as potential bio-agent in IPM system especially for management of insects in cryptic and soil habitat (Gaugler and Kaya, 1990; Georgis and Hague, 1991). The relatively rapid death of the insect host (24-48 h), wide host range, nontoxicity to mammals, amenability to mass production protocols and host finding ability of these nematodes has generated great interest in their use as component of Integrated Pest Management protocols. EPN of the families Heterorhabditidae and Steinernematidae are symbiotically associated with two bacteria *Photorhabdus* and *Xenorhabdus,* respectively . Insecticidal effect of EPN are derived to a great extent from the bacterial symbionts of EPN.

Work on entomopathogenic nematodes was initiated in India at Commonwealth Institute of Biological Control, Bangalore as early as 1966 when Rao and Manjunath (1966) explored possibilities of use of DD136 strain of *Steinernema carpocapsae* for management of insect pests of rice, sugarcane and apple. This group and other workers studied various aspects as efficacy of nematode in laboratory and field trial, life cycle of nematode and compatibility with insecticides and fertilizers (Singh and Bardhan, 1974). However, all this work was done with introduced EPN species. It is well recognized fact that indigenous bioagents native to particularly ecosystem show maximum efficacy as biocontrol entities. However little work was done on isolation of indigenous isolates and using them for insect pest management. With lull on this front for several years, there has been revival of interest in last five years. Two nematode species, *Heterorhabditis indica* and *Steinernema thermophilum* have been described from India. (Poinar *et al.*,1992; Ganguly and Singh,2000).

There are two genera of Entomopathogenic nematodes *viz. Heterorhabditis* and *Steinernema spp.* The life cycle includes an egg stage, four juvenile stages and adult stages. Third juvenile stage is called infective juvenile and is the only free living stage. This stage can survive in soil and can search, locate and infect insect hosts. Insects infected with Entomopathogenic nematode are typically characterized by flaccid appearance with characteristic change of color to yellow, brown or orange in *Steinernematid* infection while *Heterorhabditis* infected insects appear brownish red to brick red that faintly luminescence in the dark. Normal life cycle is completed in 3-7 days. Infective juveniles start emerging from infected host in 6-11 days for Steinernematids and 12-14 days for Heterorhabditids. (Gaugler and Kaya, 1990)

Infective juveniles locate their hosts by means of two strategies. 'ambushing ' and 'cruising'.

Ambushing- Nematodes that use this strategy remain stationary and locate host insects by direct contact. An ambusher searches by standing on its tail so that most of its body is in the air, referred to as 'nictation' The nictating nematodes attached to and attacks passing insect hosts. Highly mobile insect pest are controlled effectively by this. Ambusher species include- *Steinernema carpocapsae*.

Cruising : These are highly mobile and locate their hosts by sensing carbon dioxide or other volatiles released by the host These are effective against sedentary and slow moving insect species. Cruiser species are *Heterorhabditis bacteriophora* and *S. glaseri*.

The nematodes belonging to *Steinernema* penetrate insects through natural body openings as mouth, anus and spiracles while nematodes belonging to *Heterorhabditis* can also directly puncture cuticle due to presence of tooth in mouth region. EPN are symbiotically associated with a bacterium species (*Photorhabdus luminescens* and *Xenorhabdus* spp.) which live within nematode's gut. Once inside the body cavity of insects, these bacteria are released. These bacteria multiply quickly. Insect kill is achieved due to toxin produced by both nematode and the bacterium. When host contents have been consumed, the infective juveniles armed with bacteria emerge from empty shell of insect and move into the soil to search for new host. Gene isolated from these bacteria are now attracting attention for developing next generation transgenics.

Bacterial symbionts of EPN- Source for insecticidal genes : *Photorhabdus luminescens* symbiont of *Heterorhabditis spp.* is gram negative, photoluminescent bacteria with two recorded species. *Photorhabdus luminescens* and *P. temperata* are associated with nematodes. Third species *P.asymbiotica* has been isolated from human wounds, however molecular data suggests that this species is distinct from other two. *Photorhabdus* bacteria is known to undergo phase variation. It exists in two phases. Phase I is toxin producing and is associated with infective nematode juveniles and also isolated from haemocoel of newly infected insect host. Phase II is poor producer of toxins and this phase occurs in old bacterial cultures. Pathogenicity of the bacterium is due to presence of pathogenicity island which code for a toxins, enzymes, bacteriocins and antibiotics. Four pathogenicity island have been identified (), and three of them code for toxins while fourth one codes for type III secretion system. A large number of toxins are produced by *Photorhabdus* spp. which can be categorised as Tcs (Toxin complexes), Photorhabdus insect related genes (PIR proteins), toxins that make caterpillar floppy (Mcf) toxins and Photorhabdus virulence cassettes (PVC). (Rodou *et al.*,2010).

Toxin complexes (Tc toxins) : Toxin complexes (Tc toxins) are high molecular weight insecticidal toxins with multiple subunits.. Four such complexes Tca, Tcb, Tcc and Tcd are found on different loci. Two genes tca and tcc encode for several open reading frames and thus several components are produced/locus while other two tcb and tcd have single ORF. Tc toxins have been shown to demonstrate both oral and intrahaemocoelic toxicity against large number of insect pests. Tc like genes have been identified in other bacteria as *Serratia entomophila* also. (Rodou *et al.*,2010).

From *Photorhabdus luminescens* associated with heat tolerant isolate of *Heterorhabduis indica* four genes TccC, tccA, tcaC and Tcc1c gave been cloned . TccC and tcac showed oral toxicity and caused cessation in feeding and reduction in larval weight of *H. armigera* . (Unpublished).

Photorhabdus insect related (PIR) toxins : Photorhabdus Insect related (PIR) toxins act as binary proteins and both proteins *Pir A* and *Pir B* are necessary for injectable but not oral toxicity,. These proteins show similarity to endotoxins of *Bacillus thuringiensis* . *Pir B* shows high homology with the N terminal region of pore forming domain of cry2A insecticidal toxin. (Rodou *et al.*,2010).

Makes caterpillar floppy’ toxins : ‘Makes Caterpillar floppy’ Toxins *Mcf1* and *Mcf2* exhibit intrahaemocoelic toxicity and are encoded by PAI II. *Mcf1* causes apoptosis in the midgut producing classic floppy phonotype. *Mcf2* shows similarity to type III secreted protein of plant pathogen *Psuudomonas syringae.* Both the toxins allow bacteria to survive inside the inset and promotes death of host insect. (Rodou *et al.*,2010).

Photorhabdus virulence cassettes (PVC) : In *Photorhabdus* multiple copies of these genes have been recognised and each of these encode for 15-20 proteins which destroy insect haemocytes. PVCs also show homology to antifeeding genes in *Serratia entomophila* and encode proteins resembling types of bacteriocins (Rodou *et al.*, 2010)

Insecticidal toxin genes from Xenorhabdus : Four genes on a genomic fragment from *Xenorhabdus nematophilus* were shown to be involved in insecticidal activity towards three commercially important insect species. (Sergeant *et al.,* 2003) . The combined four genes (*xptA1*, *xptA2*, *xptB1*, and *xptC1*), in *E. coli*, showed activity towards *Pieris* *brassicae*, *Pieris rapae*, and *Heliothis virescens*. The genes *xptA1*, *xptB1*, and *xptC1* were involved in expressing activity towards *P. rapae* and *P. brassicae*, while the genes *xptA2*, *xptB1*, and *xptC1* were needed for activity towards *H. virescens*. Individual gene activity was less and the two three gene product combinations interact with each other to produce good insecticidal activity.

Sheets *et al.,*2011 purified a native toxin complex (toxin complex 1) from Xenorhabdus nematophilus. The toxin complex is composed of three different proteins, XptA2, XptB1, and XptC1, representing products from class A, B, and C toxin complex genes, respectively. Recombinant XptA2 and co-produced recombinant XptB1 and XptC1 bind together with a 4:1:1 stoichiometry. XptA2 forms a tetramer of <"1,120 kDa that bound to solubilized insect brush border membranes and induced pore formation in black lipid membranes. Co expressed XptB1 and XptC1 form a tight 1:1 binary complex where XptC1 is C-terminally truncated, resulting in a 77-kDa protein. . XptA2 had only modest oral toxicity against lepidopteran insects but as a complex with co-produced XptB1 and XptC1 had high levels of insecticidal activity. Sheets *et al*, 2011 also demonstrated that addition of co-expressed class B (TcdB2) and class C (TccC3) proteins from *Photorhabdus luminescens* to the Xenorhabdus XptA2 protein resulted in formation of a hybrid toxin complex protein with the same 4:1:1 stoichiometry as the native *Xenorhabdus* toxin complex 1. This hybrid toxin complex, like the native toxin complex, was found to be highly active against insects.

Brown *et al.*, 2006 identified a novel 42-kDa protein from *Xenorhabdus nematophila* that was lethal to the larvae of insects such as *Galleria mellonella* and *Helicoverpa armigera* when it was injected at doses of 30 to 40 ng/g larvae. The toxin gene txp40 was identified in another 59 strains of *Xenorhabdus* and *Photorhabdus*, indicating that it is both highly conserved and widespread among these bacteria. Histological data from *H. armigera* larvae into which the toxin was injected suggested that the primary site of action of the toxin is the midgut, although some damage to the fat body was also observed.

At CICR, Nagpur gene similar to *Xenorhabdus* Xpt1 has been cloned and was found to have oral toxicity against *H.armigera*.

Both EPNs and their associated bacteria and toxins when injected into the insect hemocoel are well known for their ability to kill insects . However for their potential as biocontrol agent, toxin genes with oral toxicity are desired. Many of the insecticidal genes from *Photorhabdus* and *Xenorhabdus* are known to have oral toxicity and thus have potential for their use as alternate to *Bt* toxin in development of transgenic cotton.

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Changing scenario of diseases in *Gossypium* spp in north zone since sixty years

B.L CHOPRA*

Former Senior Pathologist Cotton, Punjab Agricultural University,, Ludhiana - 141 004

**E-mail : ruminchopra@gmail.com*

Cotton is one of the commercial fibre crop in India. India is an important cotton growing country with largest area under its cultivation in the world and second as producer, consumer and exporter to China. In India cotton growing is divided in three zones *i.e.* north zone (Punjab, Haryana and Rajasthan), Central zone (Madhya Pradesh, Gujarat and Maharashtra), south zone (Andhra Pradesh, Telangana, Tamil Nadu and Karnatka). These three zones have different agroclimatic conditions and variable availability of irrigation facilities which further leads to different disease situation in cotton crop.

In India, more than 25 diseases caused by either biotic or abiotic factors has been reported from various cotton growing states. Out of these, 19 have been reported from north zone.

A. Major diseases caused by biotic factors: The diseases caused by pathogenic organisms can further be divided into three groups:

1. **Soil and root diseases :**
    - Seedling mortality
    - Pre and post emergence damping off
    - Root rot
    - Wilt
2. **Foliar diseases:**

Major	**Minor**
• Bacterial blight	• Helminthosporium blight
• Leaf curl	• Cercospora leaf spot
• Alternaria leaf spot	• Grey mildew
• Myrothecium leaf spot	• Anthracnose

3. Boll rot complex : Caused by bacterial and fungal organisms associated with pest attack.

B. Diseases caused by abiotic factors :

- New Wilt/para wilt
- Reddening of leaves
- *Tirak* or stress opening of bolls
- Stress due to drought/water logging
- Effect alkaline/saline soils
- Deficiency due to N, P, K, Mg and other elements

It is estimated that cumulative losses caused by diseases in cotton vary from 5 to 13 per cent. However, losses due to any individual disease may go to the extent of 50 to 80 per cent. The diseases cause reduction in the yield of seed cotton and deteriorate quality of lint fibre by effecting parameters *i.e.* fibre length, strength, fineness and maturity coefficient. Diseases can directly or indirectly effect the yield of seed cotton by following ways.

1. Reduction in plant stand : Diseases caused by soil and seed borne pathogens i.e. seedling mortality, root rot and wilts reduces the number of plants. The organisms of these diseases cause rotting of roots or cause necrosis at collar region of the plant and disturb the movement of water and other nutrients by affecting the xylem and phloem system. These diseases are generally localized in patches where the soil is either sick or infected with pathogens of these diseases. However, in case of wilt caused by *Fusarium oxysporum* pv. *vasinfectum* produces fusaric acid and fusarin, which induces the formation of tyloses in xylem vessels which there by restrict the movement of water and other nutrients to help in causing the primary symptoms of wilt.

2. Reduction in photosynthetic area of leaves : Foliar diseases *i.e.* bacterial blight and fungal leaf spots initially cause chlorotic region which later on becomes necrotic and finally the death of foliage tissues. In some cases *i.e.* Alternaria leaf spot, some kind of toxic substance *i.e.* alternaric acid is produced. Similarly *Cercospora* produces cercosporin and *Aspergillus niger* and *A. flavus* produces aflatoxin. All these chemicals counter with physiological system of the plant by inhibiting chlorophyll synthesis to cause yellowing of the leaf tissue and reduce the photosynthetic area of the leaves**.**

3. Boll rot complex: Few fungal and bacterial pathogens cause nectrotic spots on the surface of bolls in association with insect-pests *i.e.* bollworms, red cotton bug and caterpillars which pre-disposes the surface tissues and help the pathogen to cause necrotic lesions. Later on, infection move deep to the developing fibre and seed. From the surface, it seems that very little portion of boll is infected but when cut open the boll, whole of the locule and even in some cases, developing fibre and seed in adjoining locules is also rotted. Thus by this way, boll rot infection directly effect the yield of seed cotton and deteriorate quality of lint fibre.

Disease situation in relation to change in varietal scenario of *Gossypium* spp.: Cotton disease scenario has shown a continuous change during past seventy years since independence. With partition of the country in 1947, major medium and long staple cotton growing area *i.e.* about 82 per cent including Multan, Lyallpur, Bhawalnagar, Sargodha and Jhang went to Pakistan. Partition hit hard the cotton status of Indian Punjab as only 18 per cent, that also mainly under *desi* cotton came to its share. Moreover, best suited canal irrigated area with high fertile loamy texture soil with pH ranging 7.5 to 8.0 left with Pakistan. Area with poor fertility having sandy to sandy loam soils and high pH ranging from 8.0 to 8.7 with saline reaction remained with India. These soils were practically unfit for cotton cultivation and need serious efforts for further improvement.

The situation further aggravated by the fact that all the cotton improvement programme concentrated in area remained with Pakistan. Since major cotton growing areas remained with Pakistan, most of the spinning mills and allied industry left in Indian Punjab, and it needed serious efforts to provide raw materials to run these industrial units.

Further, LSS and 4F varieties of American cotton having long growing period *i.e.* 270-280 days and susceptibility to diseases and insect pests were only available for general cultivation by the farmers of southern and western districts of Punjab.

All these reasons became the limiting factors for further spread of area under cotton. Since the sowing of wheat after picking of seed cotton of LSS variety was not possible, a new variety *i.e.* 320 F comparatively less susceptible to angular leaf spot, anthracnose and *Tirak* (bad opening of bolls) was developed through selection from LSS. But due to early initiation of flowers and boll formation, incidence of jassid and boll rot particulary when late rains occur, became the limiting factor for its acceptance by the farmers. With further improvement in 320 F, another variety J 34 was developed at Agriculture Farm, Jalandhar in 1966. This variety was comparatively more tolerant to diseases than previous version. Since J 34 was earlier in maturity by about two months than LSS, it made the way for successful cultivation of wheat crop and also increased the area under American cotton in central districts of Punjab. With span of two years, area under American cotton reached to 5.12 lac/ha.

With start of All India Coordinated Cotton Improvement Project in mid 70s, the work on production and protection technologies was taken up at main and sub centres of SAUs and CICR Regional Station Sirsa in north zone. During mid 80s, major changes in disease situation was observed(Table 1). Following factors either individually or in combination seems to be responsible for this change.

1. Development and release of new varieties : With start of AICCIP, coordinated efforts were made to strengthen the breeding programme to develop high yielding varieties of cotton resistant to attack of diseases and insect pests. As a result, within short period few varieties of American cotton *i.e.* J 205 and F 414, RST 9, RS 8 and H 14 of American cotton and G 27, LD 133 and 231R of *desi* cotton were released for general cultivation to the farmers of north zone

However, release of these varieties made conspicuous impact on the presence, development and spread of cotton diseases in north zone. Helminthosporium blight, anthracnose and '*Tirak*' were practically wiped out. Myrothecium leaf spot (new record from Punjab) became one of the serious problems specially where synthetic pyrethroids were used regularly. Previously, angular leaf spot, one of the phase of bacterial blight was prevalent, but during this period other phases *i.e.* black arm and vein blight also became prominent. Moreover, in boll rot complex *Xanthomonas*

Table 1. Major and minor diseases of cotton in northern zone from 1950 to 1980

1950-65		1965-80	
Major	Minor	Major	Minor
Helminthosporium blight	Boll rot	Bacterial blight	Cercospora leaf spot
Anthracnose	Cercospora leaf spot	Boll rot	Grey mildew
Angular leaf spot	Alternatia leaf spot	Seedling mortality	Root rot
Seedling mortality		Alternaria leaf spot	
Fusarium wilt		Myrothecium leaf spot	
Root rot		Fusarium wilt	
Tirak			
Reddening of leaves			

campestris pv *malvacearum* found to be dominating among all the organisms recorded.

2. Mechanization of farm operations : Introduction of tractors and other field implements *i.e.* furrow turning plough, disc cultivator and others facilitated the operations *i.e.* deep tillage, drill sowing, hoeing and spray of pesticides. All these operations along with sured and timely irrigation greatly effected the growth and multiplication of soil borne pathogens. Deep tillage and inverter ploughing helped in decreasing the intensity of diseases caused by *Colletotrichum, Phytophthora, Pythium* and *Ascochyta* spp.

3. Availability of inorganic fertilizers: Availability of nitrogenous and phosphatic fertilizers during 70s also contributed upto some extent in changing disease situation, particularly caused by soil pathogens. Addition of these fertilizers increased fertility of soil, thus making conditions more congenial for vegetative growth and multiplication of soil inhabitants *i.e. Rhizoctonia* spp and *Fusarium* spp. Application of higher doses of nitrogen (Urea and DAP) may lead to more vegetative growth and dense plant canopy, thus restricting the penetration of air and light and creating more favourable conditions for the development and spread of diseases *i.e.* boll rot, bacterial blight, Alternaria and Myrothecium leaf spots.

4. Crop intensity : All these factors discussed here made direct or indirect impact in increasing the crop intensity. Earlier, farmers were generally sowing one crop. In that case, if the field is kept fallow during *kharif*, the temperature of upper layer specially in sandy and sandy loam soils reached to the extent of 50-55°C during May-June. This high temperature will kill thermophobic organism completely, whereas it will restrict the growth and development of thermophyllic organisms including pathogens of some of the diseases. Further, this high temperature may even kill resting and dormant bodies/spores of fungal pathogens. However, with possibility of two crops in a year, survival of pathogen became more viable for their presence throughout the year. Double cropping in association with other factors, made the conditions more congenial for transmission, development and spread of diseases.

5. Application of pesticides : During 70's, number of new fungicides, insecticides and nematicides were launched in cotton crop. Biological and toxicological studies indicated that some of these chemicals at lower concentrations may act as growth regulators and thus increase the vegetative growth by making microclimatic conditions more congenial for initial infection and spread of pathogens of foliar diseases. Some insecticides particularly synthetic pyrithroides, if sprayed continuously for control of bollworms, may lead to more attack of *Myrothecium* and *Cecospora* leaf spots. Punjab Agricultural University has given note of caution in Package of Practices for *kharif* crops for not to spray synthetic pyrithroides continuously. It will be better to spray alternatively with other recommended insecticides belongs to carbamate and organophosphate groups.

In last decade of 20th century, drastic changes in disease situation occurred with reporting of leaf curl. The disease caused by geminivirus and transmitted by whitefly (*Bemisia tabaci*) was first reported in 1994 on variety F846 and Pakistani *Narma* from Panjkosi village in Abohar (Ferozpur distt.). Later on, in same season it was also observed in 1z, 5z, Khatlabana and Kalian villages of Sriganganagar (Rajasthan) and in some fields in Faridkot and Bathinda districts of Punjab.

It is expected that the disease came through veruliferous whitefly from cotton grown in border area of Pakistan, since upto that time, it was well established in cotton belt including Multan, Sahiwal, Bhawalnagar and Jhang. By 1996-1997, CLCuD was well established in major cotton grouping area of north zone. Incidence varied from 5 per cent (HS 6 and LH1556) to 90 per cent (Pakistani *Narma*). Almost all varieties and hybrids released before 1995 for general cultivation in north zone were susceptible to CLCuD with varying degree of intensity. Thereby, it became the limiting factor for cultivation of *hirsutium* cottons, since *arboreum* cottons were practically immune to this disease. Renewed coordinated efforts were concentrated by the scientists of State Agricultural Universities and ICAR institutes for development of tolerant varieties and hybrids to this disease.

Table 2. Leaf curl resistant or tolerant varieties/ hybrids released in north zone

Variety	Year	Release From
LH 1556	1995	PAU, Ludhiana
LH 2108	2013	PAU, Ludhiana
F 1861	2002	PAU, RS, Faridkot
F 2164	2012	PAU, RS, Faridkot
H 1117	2002	CCS HAU, Hisar
RS 2013	2002	ARS.Sriganganagar
CSH 3129	2017	CICR RS Sirsa
CSH 3075	2017	CICR RS Sirsa
CICR *Bt* 6	2017	CICR RS Sirsa
Hybrids :		
LHH 144	1998	PAU, Ludhiana
Ankur 651	2002	PAU, Ludhiana
White Gold	2002	PAU, Ludhiana
FHH 141	2012	PAU, RS, Faridkot
HHH 223	2002	CCS HAU, Hisar
CSHH 198	2005	CICR RS Sirsa
CSHH 238	2007	CICR RS Sirsa
CSHH 243	2008	CICR RS Sirsa
CSGH 1862	2008	CICR RS Sirsa

Number of varieties and inter *hirsutum* hybrids developed by State Agricultural Universities and CICR, Regional Station, Sirsa were released for general cultivation to the farmers of north zone listed in Table 2. Beside these, large number of transgenic *Bt* cotton hybrids were also developed by the private seed producing companies, which are being accepted by the farmers of Punjab, Haryana and Rajasthan for general cultivation.

Alongwith development of resistant varieties and hybrids to leaf curl, efforts were also made for the estimation of losses and epidemiological studies including development of disease map, production equation in relation to agroclimatic conditions and identification of alternate and collateral hosts which helped in the management of CLCuD. But on the other hand release of large number of *Bt* hybrids and underscript material brought by the farmers from other states alongwith breakdown of resistance due to development of recombinants and emergence of more virulent strains of CLCuV, leaf curl became a cause of major concern and need to be tackled by more coordinated approach by cotton scientists of northern zone.

The development of high yielding varieties/hybrids resistant to diseases alongwith chemical, biological and cultural

Table 3. Major and minor diseases of cotton in northern zone from 1980 to 2017

1980-1995		1995-2017	
Major	Minor	Major	Minor
Leaf curl	Root rot	Leaf curl	Root rot
Bacterial blight	Boll rot	Bacterial blight	Boll rot
Seedling mortality		Alternaria leaf spot	Myrothecium leaf spot
Alternaria leaf spot		Fusarium wilt	Cercospora leaf spot
Fusarium wilt			

management and epidemiological studies in relation to congenial climatic conditions made a conspicuous impact on the development and spread of various fungal,bacterial and viral diseases. If compare the Table 1 which reveals that Helminthosporium blight, anthracnose, reddening of leaves and '*Tirak*' which were more prevalent during 1950-65 completely disappear in present time (Table 3). Another, conspicuous observation indicates that during 1965-80 the boll rot, seedling mortality and Myrothecium leaf spot listed in major group came in minor category (Table 3).

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Implications of induced systemic acquired resistance against cotton diseases

P. S. SEKHON* AND RITU RAJ
Department of Plant Pathology, Punjab Agricultural University, Ludhiana - 141 004
**E-mail : pssekhon-pbg@pau.edu*

Cotton (*Gossypium hirsutum* L.) is also known as "white gold" is the most important fibre crop in the world. Grown in countries on five continents, cotton is a major crop in each of the five top producing countries including China, USA, the countries of the former Soviet Union, Pakistan and India (Hillocks 1992). It substantially, adds to export revenue and gross domestic product (GDP) of the country. India is the only country in the world where all the cultivated species of genus *Gossypium* namely, *G. arboreum, G. herbaceum*, *G. hirsutum* and *G. barbadense* and their compatible inter specific hybrids are gown.

Cotton crop production is constrained by many abiotic and biotic factors. Among the biotic factors, various viral, fungal and bacterial diseases are known, namely cotton leaf curl disease, Alternaria leaf spot, Myrothecium leaf spots, wilt, root rot, mildew and tropical rust. Time to time, all these diseases have greatly affected cotton cultivation. Most plant protection methods currently applied in crop plants use toxic chemicals against pathogen and pest, which are noxious to the environment, have narrow spectrum of defense, ensure shortly lasting protection and are economically costly (Kuc 2001). On cotton, injudicious and continuous application of conventional pesticides has resulted in development of varying level of resistance (Ahmad *et al.,* 2002).

Induced resistance exploiting natural defense machinery of plant could be used as an alternative, non conventional and eco-friendly approach for plant protection (Heil 2001, Edreva 2004). Plants are known to defend themselves from pathogen infection through a wide variety of mechanisms that can be either local, systemic, constitutive or inducible (Dixon 1986; Ryals *et al.,* 1994). One particular inducible systemic response, is systemic acquired resistance (SAR). SAR refers to a distinct signal transduction pathway that plays an important role in the ability of plants to defend themselves against pathogens. Induced chemical defense *i.e* SAR, being based on the expression of latent genetic information present in the plant, is not under lied by genomic alternation (mutation, introgression of foreign genetic material), thus enhancing its bio safety. It can be stimulated by range of biotic, and abiotic factors. Abiotic factors include elicitors like synthetic harmless chemicals. The application of chemical inducers of resistance is an exciting perspective to supplement the classical chemical means of biochemical change and disease control by providing both effective and ecosafe plant protection.

The practical application of chemicals as resistance inducers is mainly based on their systemic effect, *i.e* on SAR expression in plants. Different chemicals have been reported to induce SAR such as Salicylic acid (SA), SA analogues (2,6 Dichorisonicotinic acid (INA), Benzothiodiazol (BTH), â-aminobutyric acid (BABA), Acibenzolar-S-methyl (ASM)), Jasmonic acid (JA), Methyl jasmonates (MeJA), Para amino benzoic acid (PABA), 2 chloroethylphosphonic acid, Hydrogen peroxide, Oligosaccharides (Chitosan) polyacrylic acid, SiO_2, *etc*. Chemically-induced SAR was found to be effective against various organisms, namely *Tobacco mosaic virus*, *Peronospora tabacina*, *Cercospora nicotianae, Phytophthora parasitica* var. *nicotianae, Pseudomonas syringae* (Schneider *et al.,* 1996, Kuc 2001). An important feature of SAR is the low specificity, since SAR can be induced by structurally unrelated compound (eg. â-aminobutyric acid, 2,6-dichliroisonicotinic acid or phosphate) or unrelated pathogens (fungi, bacteria, virus). It is based on the activation of the plant's own defense system with the aid of low molecular weight synthetic molecules, thus providing resistance against a wide range of microbial pathogens. These compounds act as signals that stimulate the synthesis of natural products like phytoalexins and PR-proteins that control pest and pathogen attack (Benhamou and Theriault 1992, Ebel and Cosio 1994). SAR activates large number of genes coding for PR-proteins *viz.,* â-glucanase (PR-2), Chitinase (PR-3), hevein like protein (PR-4), thaumatin like and osmotin-like protein (PR-5) and various other proteins under stress condition (Ward *et al.,* 1991, Enkerli *et al.,* 1993). The PR proteins are coded by the host plant but induced specifically in pathological and related condition against infection by fungi, bacteria and viruses.

Worldwide, there are many reports conferring the usefulness of synthetic chemical elicitors using SAR in managing various plant diseases. Ghoshroy *et al.,* (1998), Chivasa *et al.,* (1997), Anfoka (2006), Dong and Beer (2000), Ahn *et al.,* (2005), Mayers *et al.,* (2005), Faheed and Mahmoud (2006) and Mandal *et al.,* (2008) had successfully used chemicals such as cadmium, Salicylic acid, 2,6-dichloroisonicotinic acid, antimycin A, riboflavin, vitamin B1, chitosan, benzo-(1,2,3)-thiadizole-7-carbothioic-S-methyl ester (acibenzolar-S-methyl), kinetin and ozone to induce plant resistance against *Tobacco mosaic virus*, *Potato virus X*, *Cucumber mosaic virus*, *Tobacco necrotic virus, Tomato spotted wilt virus.*

Application of these SAR chemicals, which mimic the function of the pathogen in induction of systemic acquired resistance, can be explored specifically in managing various cotton diseases like viral diseases (Cotton leaf curl disease), fungal diseases like Alternaria and Myrothecium leaf spot, grey mildew and Verticillium wilts, root rot. There are various reports, where attempts were made in successfully managing these pathogens in other crops and in cotton as well. Thus, providing a safe alternative against the management of different diseases.

SAR against viruses : It is said that SAR operates against localized virus infection by limiting cell to cell spread of virus, through a mechanism involving an accelerated hypersensitive reaction without preventing virus replication (Pennazio and Roggero 1998). Huijsduijnen *et al.,* (1986) sighted that spraying tobacco plants with salicylic acid induces both the synthesis of PR proteins and resistance to viruses. They reported that spraying Samsun NN tobacco with salicylic acid induced the production of PR-1 mRNAs and inhibited the systemic multiplication of alfalfa mosaic virus (A1MV) by 90 per cent. They also reported the induction of PR proteins in bean and cowpea plants which reduced the production of local lesions by 75 per cent in A1MV-infected bean plants by inhibiting the replication of A1MV in cowpea protoplasts by upto 99 per cent.

Feng *et al.,* (2014) revealed that exogenous application of SA, JA and SA + JA yielded a significant reduction in the levels of viral RNA per plant. They concluded that SA and JA in combination act as strong activators of systemically induced defense in tobacco leaves against TMV whereas silencing of SA or JA biosynthetic and signaling genes in *Nicotiana benthamiana* plants increased susceptibility to TMV. Siegrist *et al.,* (2000) revealed that foliar application of BABA resulted in SAR activation in tobacco against tobacco mosaic virus. BABA-induced cell death was associated with the rapid generation of superoxide, hydrogen peroxide and the expression of PR-1a. A preliminary study conducted by Madhusudan *et al.,* (2005) showed that pretreatment of the indicator plant (*N. glutinosa*) with the Acibenzolar-Smethyl (ASM) followed by challenged inoculation with tobamo viruses resulted in reduced number and size of local lesions (67 and 79% protection over control to TMV and ToMV inoculation, respectively). Mandal *et al.,* (2008) reported the activation of SAR by ASM in flue-cured tobacco against TSWV. ASM was reported to have restricted virus replication and movement. Expression of the PR protein gene, PR 3, and different classes of PR proteins such as PR 1, PR 3, and PR 5 were detected at 2 days post ASM treatment which inversely correlated with the reduction in the number of local lesions caused by TSWV. A study was conducted to check the response of different cotton cultivars namely RS 921, LH 2076, PIL 8, Ankur 3028 BGII and a *desi* cotton variety LD 694 to JA and salicylic acid (SA) in relation to induction of resistance against CLCuD under which it was reported that 150 μM concentration of JA and 200 μM SA concentration were most effective in maximum protein induction (Fig 1) and providing defense against cotton leaf curl disease. JA was found to be more effective than SA in maximum protein induction and defense against CLCuD (Ritu raj *et al.,* 2015).

To mitigate the ZYMV infection, SA was exogenously applied at different concentration *viz.*, 0.01, 0.1, 1 and 10mM for the induction of resistance in cucumber plants. Thereby, resulting increase in the phenolic and protein contents as compared to control. Virus multiplication appeared to be inhibited at 10mM concentration of SA. This study showed that exogenously applied SA could offer a good source for the management of ZYMV by inducing resistance in cucumber (Umar *et al.,* 2016). Ong and Cruz (2016) evaluated the effect of SA treatment on the severity of leaf curl disease of tomato (*Solanum lycopersicum* L.) under screen house conditions. Healthy seedlings of susceptible tomato variety, Apollo White were treated by spraying with 50, 250 or 500μM SA at 5, 10 or 15 days before inoculation. All the treatments were effective in reducing the severity of the disease but the effect was more consistent with 50μM SA. Plants treated with 50μM SA had reduced amount of disease (AUDPC values), lower symptom severity score and lower disease index (DI) than the untreated control.

A study was conducted in which chemical elicitors; SA, 2,6- INA, BTH and BABA were applied at 250 and 500µM concentrations by seed priming, foliar spray and soil drench on three cotton cultivars *viz.,* F1378 (susceptible), LH2076 (moderately resistant) and FDK124 (immune). Activities of the three pathogenesis related (PR) protein enzymes, chitinase (PR 3), â-1,3glucanse (PR 2) and peroxidase (PR 9) was estimated. All the four elicitors resulted increase in the activities of the three enzymes with respect to their respective controls. Foliar spray caused higher induction in activities of chitinase, â-1,3-glucanase, and peroxidase at 500µM concentration of the four tested elicitors. INA and SA were more effective against CLCuD. The higher enzyme activities, increased band intensities in protein profiling and decreased disease incidence and disease index in susceptible cultivar in comparison to controls suggested that these chemical elicitors can be tried as protective regime against CLCuD (Kumari 2016).

SAR against fungal pathogens : It is reported that application of these SAR chemicals has provided protection against *Alternaria* sp., *Fusarium* sp., *Rhizoctonia* sp. in various other crops. Exogenously applied MeJA was reported to impart protection against *A. brassicicola* in *Arabidopsis* by the induction of PDF1.2 PR 3 and PR 4 gene (Thomma *et al.,* 1998). Kolowski *et al.,* (1999) conducted experiments which showed that jasmonates were effective in inducing local and systemic protection against *P. ultimum* in Norway spruce. Chandra *et al.,* (2001) showed that in cowpea foliar spray of salicylic acid resulted in reduction in root rot disease caused by *R. solani* by enhancing the production of proteins.

Work done by Walters *et al.,* (2002) proved that treatment of barley (cv. Golen promise) seedlings with MeJA imparts systemic protection against powdery mildew caused by *Blumeria graminis* f.sp. *hordei.* ASM increased the activity of â-1, 3 glucanase (defense enzyme) against early blight (*A. solani*) and powdery mildew (*E. cichoracearum*) in potato plants (Bokshi *et al.,*., 2003). Graham *et al.,* (2003) showed in their studies that application of JA and MeJA in soybean resulted in the expression of different PR genes, which resulted in induction of resistance against *P.sojae*. Tian *et al.,* (2005) demonstrated that pear fruits treated with various elicitors like SA, oxalic acid, calcium chloride etc significantly enhanced defence-related enzymes activities such as â,1-3 glucanase, phenylalanine ammonia lyase, peroxidase, and polyphenol oxidase activity, and reduced the disease incidence of *A. alternata*. The early increased expression of the lignin peroxidase gene has been reported in cucumber plants that are ASM protected against *C. orbiculare* highlights the role of lignin in the resistance mechanism (Deepak *et al.,*, 2006).

Sharma *et al.,* (2008) found that activities of various defense related enzymes got enhanced with the application of SA which provided resistance against Alternaria blight caused by *A. brassicae*. SA foliar application induced resistance in potato against black scurf and stem canker caused by *R. solani* (Khalil *et al.,* 2008). Kone *et al.,* (2009) studied in greenhouse that SA applied as soil drench or foliar spray at 25 or 50µg/ml significantly reduced severity of disease caused by *P. capsici*, compared with control.

Vimala *et al.,* (2009) reported induction of resistance against *E. cichoracearum* in okra with the foliar application of SA which resulted in the induction of increased enzymatic activity. Kamal *et al.,* (2009) tested BTH, SA against cotton root rot disease caused by *F. oxysporum* and *P. debarynum* .They observed significant disease reduction of 78 per cent. The induction of resistance against powdery mildew in wheat with MeJA treatment. The induced resistance was positively correlated with the induced expression of defense related genes like PR 2, PR 3, PR 5, PR 10 and Ta-JA2 which encode â,1-3 glucanase, chitinase, thaumatin-like proteins, peroxidase etc. BABA and SA at 0, 250, 500 and 1000 µg/ml, BTH at 0, 0.3, 0.6 and 1mM and IAA at 0, 25, 50 and 100 µg/ml were applied as foliar spray on wheat proved effective against yellow rust of wheat (Fayadh *et al.,* 2013). Under a detailed study conducted by Astha *et al.,* (2017) exogenous foliar sprays of different SAR compounds (SA, JA and Bion (BTH @ 50µM, 250µM, 500µM,1000µM and BABA of 20 mM, 30mM, 50 mM, 100mM were tested for inducing resistance in potato against late blight and in muskmelon against downy mildew. SA, JA and Bion @ 500 µM, and BABA @ 50 mM provided good control of disease. SA gave 81.28 per cent disease control followed by JA with 76.23 per cent; Bion and BABA were *at par* with each other and gave 74 per cent disease control *wrt.* control and recommended spray schedule of fungicides was reported to provide 93 per cent disease control, which was at par with disease control given by salicylic acid and BABA spray schedules in combination with other contact fungicides. Further, the electrophoretic protein profiling of treated potato and muskmelon plants confirmed induction of PR proteins ranging from 15- 75 kDa along with some other proteins. These inducers stimulated enzymatic activities *i.e.* â-1,3 glucanase, POD, PPO, PAL from 26 to 99 per cent which indicated induced resistance in treated plants as compared to control.

All these studies sight a healthy possibility in exploring these chemicals in managing various fungal diseases of cotton.

SAR against bacterial pathogens : ASM application was found effective in controlling bacterial black spot of mango, caused by *Xanthomonas campestris* pv. *mangiferae indicae* (Cole 1999). Buonaurio *et al.,* (2002) reported that application of ASM on pepper plants resulted in the Induction of systemic acquired resistance against bacterial spot disease caused by *X. campestris* pv. *vesicatoria*. Rice plants pretreated with ASM, significantly reduced the leaf blight infection caused by *X. oryzae* pv. *oryzae*. (Babu *et al.,*. 2003). A study was undertaken by (Subbiah and Bhaskaran 2005) to evolve a management practice for bacterial blight of cotton caused by *X. axonopodis* pv. *malvacearum* by induced systemic resistance using elicitors (salicylic acid, benzoic acid, dipotassium phosphate, napthalene acetic acid, glycine, hydrogen peroxide, oxalic acid, copper sulphate and indole acetic acid) biotic (Phylloplane micro organisms and bacterial endophytes) and abiotic elicitors. Among the tested chemicals, salicylic acid @ 250 ppm controlled the disease by increasing the biochemical constituents (total sugars, reducing sugars, non reducing sugars, protein, phenol, activities of phenylalanine ammonia lyase, polyphenol oxidase, peroxidase and catalase) in treated plants. Boro *et al.,* (2011) reported that seed and leaf treatment with ASM act as potent inducer of resistance in passion fruit plants against bacterial leaf spot caused by *X. axonopodis* pv. *passiflorae*. ASM conferred a protection up to 70 per cent at the concentration of 12.5 µg a.i./ml. Song *et al.,* (2013) reported that Para amino benzoic acid (PABA) elicited induced resistance against *X. axonopodis* pv. *vesicatoria* in *Capsicum annuum* by the priming of pathogenesis related 4 gene.

Application of these SAR chemicals was found to enhance the activity of PR proteins and of various other proteins as well which in turn resulted in providing protection against various diseases. All these studies sight a healthy possibility in exploring these chemicals in managing various diseases of cotton in a biologically safe manner. SAR inducing chemicals thus, can provide us with novel benefits to our existing strategies of disease control.

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Distribution, loss assessment and management of root knot nematodes parasitizing cotton in India

K.K. VERMA*
Department of Nematology, CCS Haryana Agricultural University, Hisar-125001
**E-mail: kkv1959@gmail.com*

ABSRACT : Cotton, popularly known as **"White Gold"**, is an important cash and commercial crop. The successful raising of this crop is hampered by the attack of number of insect pests and diseases. Amongst these, the root knot nematode is a major yield limiting factor in many countries including India. Among various species of root knot nematodes, *Meloidogyne acronea* and *Meloidogyne incognita* are known to parasitize cotton. However, *M. incognita* (Kofoid & White, 1919) Chitwood, 1949, is the only species which is of consequence to the cotton throughout world and hence worldwide in distribution especially where soils are coarsely textured. *M. acronea* has so far been found only in some areas of south Africa. The earliest report of root-knot nematode on cotton was from USA. However, in India the first report of its occurrence on cotton was by Luthra and Vasudeva (1939) from Punjab. Besides India, it has also been reported from Taiwan, Pakistan, Egypt, USSR, Brazil, south Africa, USA, China, Kenya and from many other countries. In India, this nematode has been reported from New Delhi, Tamil Nadu, Maharashtra, Karnataka, Andhra Pradesh, Gujarat, Punjab and Haryana.

The annual yield losses due to phytoparasitic nematodes on worldwide basis are reported to be 10.7 per cent. Later on, the yield suppression ranged from 18.0-47.3 and 8.5-35.0 per cent in 2002 and 2003, respectively, from US and 17.0 per cent alone in Brazil. The avoidable losses under field conditions in Haryana ranged from 16.8 to 20.0 per cent due to root knot nematode.

Nematode management strategies employed are chemical, cultural, biological, use of host plant resistance and integrated management. The chemicals which mainly belong to carbamates (aldicarb and carbofuran) and organophosphates (phorate, phenamiphos etc.) are applied in the form of soil or seed treatments. The non-chemical cultural methods include deep summer ploughing, organic manures *viz.,* neem cake, poultry manure, FYM etc., crop rotations with wheat, barley, corn and soybean. Various bio-agents like *Paecilomyces lilacinus*, arbuscular mycorrizal fungi and rhizospheric bacteria have been investigated and found effective. Resistant sources such as the cotton variety Auburn 623, Fa LSS and Arkot 9111 have been found to possess a high level of tolerance.

Despite the fact that a lot of information has been generated on cotton nematology, the areas to be covered for futuristic approaches may be intensive surveys on nematodes of *Bt* cotton, screening of transgenic plants to nematodes,

identifications of resistance genes and studies on integrated nematode management.

Cotton is a major fiber crop of global importance and has high commercial value. It is grown in temperate and tropical regions of more than 70 countries and is grown in all types of soil except pure sand, saline and water logged soils. Specific areas of its production include India, China, US, Pakistan, Uzbekistan, Egypt, Turkey, Australia, Greece etc. Cotton, popularly known as “White Gold” is an important crop in world agriculture and is used by about 75 per cent of world’s population for textile purposes because its fiber is used universally as a textile raw material. In India, it is important cash and commercial crop valued for its fiber and vegetable oil and thus earning valuable foreign exchange by providing employment to millions of people, hence plays a significant role in national economy. Cultivation of cotton has been considered as an index of the progress of civilization of mankind due to the reasons that cotton is made into more diverse products than any other fiber crop vizly, in addition to clothing, cotton cake is a rich source of high quality protein for stock feed.

India continued to maintain the largest area under cotton and is second largest producer of cotton next to china. India also sustained the position of being the second largest consumer and exporter of cotton. In India, the major cotton growing states are Punjab, Haryana, Maharashtra, Madhya Pradesh, Gujarat, Tamil Nadu, Karnataka etc. and the area under cotton cultivation during 2016-2017 was 10.5 million hectares with production around 35.1 million bales of 170 kg. As regards cotton production, Gujarat is the leading cotton producing state with 91.8 lakh bales. The state of Haryana had cotton in an area of 4.98 lakh hectares with production of 17.0 lakh bales during 2016-2017 (All India Coordinated Cotton Improvement Project-Annual Report, 2016-2017).

The cultivation of cotton falls into three main groups *viz.,*, Egyptian or American Egyptian type, the long staple cotton, *i.e., Gossypium barbadense* (allotetraploid), American and African upland medium staple cotton, *i.e., G. hirsutum* (allotetraploid) and Asiatic old world short staple cotton, *i.e., G. arboreum* (diploid) and *G. herbaceum* (diploid). *G. hirsutum* accounts for over 80 per cent of global cotton production. But, during past few years, it has been observed that traditional cotton cultivation of non *Bt* has given way to cultivation of *Bt* cotton hybrids.

The successful raising of this crop is hampered by the attack of number of insect pests and diseases. During recent past, phytoparasitic nematodes, which not only cause diseases by themselves directly but also aggravate the disease caused by fungi, have assumed significance in limiting the production of cotton in many cotton growing areas of the country. Because cotton is grown as a cash crop, it is often grown in monoculture system that favours the development of a nematode community that is dominated by one or a few species of plant parasitic nematodes. Among these parasites, the root knot nematode, *Meloidogyne* spp is a major yield limiting factor in many countries including India. Among various species of root knot nematodes, *M. incognita* (Kofoid and White, 1919) Chitwood, 1949, is the prominant species which parasitize the cotton throughout India.

The pathogenicity of *M.incognita* on cotton revealed that there was significant decrease in plant growth characters at and above one j_2/g soil in non *Bt* cotton (Rai and Jain, 1989) and *Bt* cotton (Chawla, 2015). Further, the reproduction factor of *M. incognita* infecting cotton under different soil textures showed maximum value under sandy soil while clay and clay loam soils were least favoured in American (Verma, 1997) as well as in *Bt* cotton (Chawla, 2015). Histopathological studies in cotton roots due to the feeding of *M. incognita* showed that nematode feed on xylem tissue and giant cells were formed in vascular bundles. Nematodes were observed lying parallel to stellar region forming multinucleate giant cells with dense cytoplasm (Rai and Jain,1989).

Symptoms : The foliar symptoms of root knot nematode attack on cotton are not very diagnostic. Infestation results in uneven, pale, stunted and sick crop. The general symptoms of damage include dwarfing, chlorosis and temporary wilting and a general unthrifty appearance giving the look of nutritional deficiency symptoms. High population density of the nematode at sowing can kill the plants at seedling stage. Cotton is a fairly drought resistant crop by virtue of its long tap root which may reach depths of more than one meter and any damage to this tap root can severely restrict the uptake of water and nutrients, leading to loss of vigour in rest of the plant. Root-knot nematode attack both tap and lateral roots and leads to formation of galls/knots thereby causing disruption in meristematic zone, which may lead to slowing down or even complete cessation of tap root growth depending upon the initial nematode population in the soil. However, galls on cotton are not as big and numerous as on other susceptible crops like vegetables.

Distribution: Among various species of root knot nematodes, *Meloidogyne acronea, M. incognita* and *M. javanica* are known to parasitize cotton. However, *M. incognita* (Kofoid and White, 1919) Chitwood, 1949, is the only species which is of consequences to the cotton throughout India. It is worldwide in its distribution from nearly all cotton growing areas especially where soils are coarsely textured (Starr *et al.,* 1993). *M. acronea* has so far been found only in some areas of south Africa. The earliest report of root knot nematode on cotton was from USA (Atkinson, 1989). However, in India the first report of its occurrence on cotton was by Luthra and Vasudeva (1939) from Punjab followed by Thirumalachar (1946). Besides India, it has also been reported from Taiwan (Tu *et al.*, 1972); Pakistan (Tanveer and Haq, 1975); Egypt (Ibrahim *et al.*, 1979); USSR (Khurramov, 1982); Brazil, south Africa (Wyk *et al.*, 1987); USA (Martin *et al.*, 1994); China (Yang, *et al.*, 1992), Kenya (Karuri *et al.*, 2010) and from many other countries.

As far as its distribution in India is concerned, Prasad (1960) observed this nematode on cotton at IARI, New Delhi, Abu Bucker and Seshadri (1968) reported it, attacking cotton from Tamil Nadu, Darekar *et al.* (1992) from Maharashtra, Patel (1984) from Gujarat reported *M.incognita and M.javanica* attacking cotton. Sakhuja *et al.*, (1986) reported it from Punjab in all types of cotton, Murali and Vanita Das (2014) from Andhra Pradesh. Amongest races prevalent in India, race 4 of *M. incognita* infecting cotton in Sirsa district of Haryana was reported for the first time in India and later on by others (Bajaj *et al.,* 1986; Vats *et al.,*1999; Verma and Jain, 1999). However, presence of race 3 of *M. incognita* equally capable of damaging cotton has been reported from Tamil Nadu and Karnataka (Krishnappa, 1985). The frequency of occurrence of root knot nematode (*Meloidogyne incognita* race 4) in major cotton growing areas of Haryana such as Sirsa, Fatehabad, Bhiwani and Jind was however high in *desi* and American non *Bt* varieties (Vats *et al*., 1999). The distribution of *Meloidogyne incognita* on *Bt* cotton based on per cent frequency of occurrence was 25.0 in Sirsa and Hisar followed by 24.0 in Fatehabad, 23.8 in Bhiwani and 21.2 in Jind, respectively, with an average loss of 15.4-29.3 per cent on *Bt* cotton yields at farmers' fields of Haryana at different locations (QRT Report 2007-2012, AICRP, Nematodes).

Assessment of losses : The annual yield loss in cotton due to phytoparasitic nematodes on worldwide basis is reported to be 10.7 per cent (Sasser and Freckman, 1987). Among these parasites, the root knot nematode, *Meloidogyne incognita* is a major yield limiting factor in many countries including India. A loss of 17.0 per cent in cotton has been attributed to root knot nematodes alone in Brazil (Sasser, 1979). Similarly, Davis and May, 2005, recorded the yield suppression in cotton which ranged from 18.0-47.3 per cent in 2002 and from 8.5-35 per cent in 2003 by the southern root knot nematode. In India, this nematode has also become an important parasite of cotton under Haryana conditions causing 7.63 per cent yield loss. Similarly, the avoidable losses in cotton yields due to root knot nematode (*Meloidogyne incognita*) under field conditions in Haryana ranged from 16.8 to 20.0 per cent (Jain *et al.,* 2000).

Nematode management: Among the various nematode management components, the following methods are considered to be most practicable and effective in India as well as world.

I. Chemical methods: Basically, two types of chemicals *viz.,* fumigants and non fumigants have been used. Soil fumigation with ethylene dibromide, dichloropropene dichloropropane (DD) and dibromochloropropane (DBCP) proved effective but, DBCP was most promising. However, due to their prohibitive cost, difficulty in application methods, environmental and toxic hazards, their use has been banned in most of the countries including India. Thereafter, non-fumigant (non-volatile) chemicals were begun to be used for controlling phytonematodes infecting cotton. These chemicals mainly belong to carbamates (aldicarb and carbofuran) and organophosphates (phorate, phenamiphos etc.) group. In Punjab, application of carbofuran @ 1 kg a.i./ha at sowing followed by additional dose of 2 kg a.i./ha 50 days thereafter led to 41 per cent higher cotton yield in root knot nematode affected fields (Sakhuja *et al.,* 1987). In order to use the chemical pesticides, judiciously, seed treatment with systemic nematicides has been found to be an effective proposition, which gives protection for 3-4 weeks thereby providing healthy start to the plant. Seed soaking treatment with monocrotophos or carbosulfan each @ 2000 ppm for two hours or use of *neem* based pesticides *viz.,*, Achook, Nimbicidine etc. @ 1, 2 and 4 per cent have shown promising results against *M. incognita* infecting cotton (Vats *et al.,* 1997 and

1998) or a novel nematicide, abamectin @ 100g/ 100 kg seed (Monfort *et al.,* 2006). It has been observed that carbamates like aldicarb and carbofuran gave better results than organophosphatic compounds like phorate and disulfoton in controlling nematodes attacking cotton (Kumar and Agarwal, 1985).

II. Cultural methods : Harnessing of solar energy in northern parts of India, where maximum temperature many a times, goes as high as 48°C, can help in controlling these noxious soil borne pathogens. Deep summer ploughing of nematode infested fields not only leads to disturbance and instability in nematode community but also causes mortality by exposing the nematodes to solar heat and desiccation and hence reduction in their initial population.

Azadirachta indica leaves used @ 20 g/ kg soil proved effective in terms of minimum galling (16.7/plant) compared to 118.3/plant in untreated check. Further, of the various organic manures *viz., neem* cake, poultry manure, spent compost, FYM and biogas slurry, proved best in improving growth parameters of cotton (Vats *et al.*, 1998, Verma and Jain, 2001). The crop rotations with wheat, barley and oat and also corn and soybean have shown promising results in containing the buildup of root knot nematode population (Singh *et al.*, 1998, Koenning and Edmisten, 2008).

III. Biological control: Soil application or seed treatment with the number of micro organisms have been found effective to suppress root knot nematode infestations in cotton. Various bio agents like oviparasitic fungi, *Paecilomyces lilacinus* and rhizospheric bacteria have been investigated for controlling *M. incognita* infecting cotton. *Azotobacter chroococcum* used as seed dressing treatment method in cotton in *M. incognita* infested soil (Lakshminaryanan *et al.*, 1995) and *Pseudomonas fluorescens* (Timper *et al.,* 2009) mitigated the adverse effects of nematode infection by reducing galling and egg mass production. *Gluconacetobacter diazotrophicus* srain. 35-47 (rhizobacteria) used as seed treatment, accounted for 35-47 per cent higher cotton yield in *M. incognita* infested fields (Bansal *et al.,* 2005). This practice has been included as a recommendation for adoption by the farmers in the "Package of Practices of Kharif Crops" in Haryana. Further, use of arbuscular mycorrhiza fungi (*Glomus fasciculatum*) when applied in root knot nematode infested soil was effective in increasing plant growth and reducing nematode galling and multiplication (Verma and Jain, 2004). Even a complex of *M. incognita* and root-rot fungus, *R. bataticola* was managed successfully using *Trichoderma viride* (Verma, 2011) while Verma and Nandal, 2009 observed reduction in root knot nematode population on cotton using *T. viride* and 50 kg P/ha.

IV. Host plant resistance : Quite a good number of genotypes have been screened by various workers for resistance against *M. incognita*. But, so far no promising genotypes, which could be used for transferring resistance into commercially cultivated type is yet available. However, the cotton variety Auburn 623 has been found to possess a high level of tolerance to root knot nematode races. Fa LSS and Arkot 9111 have exhibited resistance against *M. incognita* (Dube *et al.*, 1988, Bourland and Jones, 2005). As far as *Bt* cotton is concerned, high degree of susceptibility to root knot nematode has been reported in high number of hybrids screened (Verma *et al.,* 2011, Chawla, 2015, Verma *et al.*, 2015).

V. Integrated management : For the management of this nematode, Verma *et al.,* (2015) recorded highest increase in *Bt* cotton yield (39.5%) over check and significantly lowest final nematode population in treatment combination of *Gluconacetobacter diazotrophicus* strain 35-47 @ 50 ml/kg seed and carbofuran @ 1.0 kg a.i./ha as soil application followed by 29.3 per cent yield increase over check in seed treatment with carbosulfan (3.0%) w/w + soil application of carbofuran @ 1.0 kg a.i./ha. Similarly, seed dressing treatment with carbosulfan @ 3.0 per cent (w/w) alone or with soil application of sebufos @ 1.0 kg a.i./ha at sowing proved effective (Vats *et al.*, 1998). Similarly, Chawla, 2015, observed maximum growth of *Bt* cotton plants and minimum number of eggs and final nematode population in integration of soil treatment with either carbofuran or neem cake + seed coating with carbosulfan. Though the importance of *M. incognita* as yield limiting factor of cotton has received increased recognition and attention in India in the recent past, nevertheless, development of such integrated nematode management technology can lead us to a scenario where *Bt* cotton can be grown successfully as the level of susceptibility was recorded to be higher in *Bt* hybrids than non *Bt* cotton (Banu, 2009)

Futuristic approaches : Besides root knot nematodes, populations of other nematodes are also recorded from some areas. Hence, there is need to carry out intensive surveys for recording other economically important phytonematodes associated with cotton. During recent times, the cotton cultivation has boosted due to introduction of *Bt* cotton hybrids which replaced conventional non *Bt* cultivars at national and state level, so the research work involving *Bt* cotton becomes necessary as all the previous work was conducted on non *Bt* varieties. Except some preliminary work on *Bt* cotton, the systematic and in-depth research on *Bt* cotton was necessitated as now the cotton production and profitability has increased by adoption of *Bt* cotton Other points of future thrusts can be:

- Carry out studies on host parasite relationships.
- Carry out studies on nematode interactions with other co habiting microorganisms.
- Intensive survey on nematodes on *Bt* cotton in India has to be carried out.
- Screening of transgenic plants to nematodes.
- Identification of resistance genes to root knot nematodes in cotton.
- Conduct studies on INM in *Bt* and non *Bt* cotton.

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Dimensions of growth and development of cotton : A global scenario of *Bt* cotton growing countries

DEVENDRA BEERALADINNI*, PRABHULING TEVARI AND VIJAYA WALI
Department of Agricultural Economics, Univrsity of Agriculutral Sciences, Raichur-584 104
** E-mail:beeraladinnidevendra1975@gmail.com*

ABSTRACT : The study analysed the growth in area, production and productivity of cotton in major *Bt* cotton growing countries in the world. The study is based on the time series data analysed in two sub period's *viz.,* Period I (before the introduction of *Bt* cotton) and Period II (after the introduction of the *Bt* cotton) to know the changes in area, production, productivity, import, export and domestic consumption of cotton in major *Bt* cotton growing countries after the introduction of *Bt* cotton. In India there was a phenomenal increase in cotton area, production, productivity and export after the adaption of *Bt* cotton on a large scale. Introduction of *Bt* cotton helped in expansion of cotton area both in irrigated and rainfed condition which triggered the growth in Indian cotton yield, production and exports. Whereas USA, Australia, Brazil, China and Pakistan experienced decreased area under cotton cultivation after the adaption of *Bt* cotton. However, there was a significant change in productivity and export of raw cotton in Brazil, Australia, USA and India. Except Pakistan in all the five countries the cotton yields were increased in absolute terms after the introduction of *Bt* cotton. In case of Pakistan there were no significant changes in cotton sector after the adaption of *Bt* technology.

Key words: *Bt* cotton, CAGR, domestic consumption, percentage share, USA, world cotton

Cotton is one of the important commercial crop for the millions of farmers and favourite natural fibre in the world which is known as 'White gold' being in cultivation in the world for more than five thousand years. At present cotton is grown in around 60 countries out of which over a dozen countries cultivate *Bt* cotton in the world. Cotton is also one of the most traded agricultural commodities in the world. Around 120 countries are involved in raw cotton import and export trade in addition to 90 consuming countries in the world (ICAC, 2016). In addition, cotton also contributes to economic growth through raw material supply to textile industries, employment generation and trade earnings.

Globally, cotton is cultivated in an area of 29.24 million ha with a production of 136.72 million bales during 2016-2017 (USDA, 2017). *Bt* cotton for commercial cultivation in the world was first introduced in Australia and USA during 1996 fallowed by China in 1997, India in 2002, Brazil in 2005 and Pakistan during 2010 which are the major cotton growing countries in the world (Table 1). These six countries together contribute more than 72 per cent of area and nearly 80 per cent of production, 68 per cent of export and consumption of world's raw cotton (Fig.1).

Table 1. Major *Bt* cotton growing countries in the world

Sl.No	Country	Introduction of *Bt* cotton (Year)
1	Australia	1996
2	United States of America	1996
3	China	1997
4	India	2002
5	Brazil	2005
6	Pakistan	2010

Source: ISAAA, 2015

Uzbekistan and Turkey other two major cotton producing countries where *Bt* cotton for commercial cultivation is not initiated. In recent decades the trends in area, production and productivity of raw cotton across the world are increasing. Among the major cotton growing countries in the world India ranks first both in area (12.10 million ha) and production (359.07 million bales of 170 kg) fallowed by USA, China, Pakistan, Brazil, Australia, Uzbekistan and Turkey (Table 2).

There are many reasons attributed to the increased production and productivity of cotton in the world. Introduction of *Bt* cotton, increased area under irrigation, higher prices significantly increased the production and productivity of raw cotton in different countries of the world. The contribution of each of these factors towards the sources of growth is an researchable issue needs to be addressed by researchers, institutions and policy makers for enhancing growth and development of cotton globally and boost the trade at large. Off late, the trends in cotton exports in both physical and value terms in major *Bt* cotton growing countries is increasing after the introduction of *Bt* cotton. In view of these developments, a study on dimensions of growth and development of cotton in major *Bt* cotton growing countries in the world before and after the introduction of *Bt* cotton is initiated.

Table 2. Area and production of cotton in major cotton growing countries of the world during 2017

Sl. No.	Country	Area (Lakh ha)	Production (Lakh bales of 170 kg each)
1	India	115.00	359.07
2	China	30.50	307.78
3	United States of America	46.05	246.44
4	Pakistan	28.50	119.26
5	Brazil	10.00	89.77
6	Australia	4.50	61.56
7	Uzbekistan	11.80	47.45
8	Turkey	4.85	46.16

Source: www.indexmundi.com

MATERIALS AND METHODS

The study is based on secondary data compiled from official websites of various national and international organisations. The data pertains to area, production, productivity, import, export and domestic consumption of cotton in major *Bt* cotton growing countries in the world were collected from www.indexmundi.com, portal that gathers facts and statistics from muliple sources, www.fas.usda.gov of United State Department of Agriculture, www.cottonaustralia.com.au, www.cotcorp.gov.in of Cotton Corporation of India Ltd., Ministry of Textiles and www.aiccip.cicr.org.in of All India Co ordinated Cotton Improvement Project. The time series

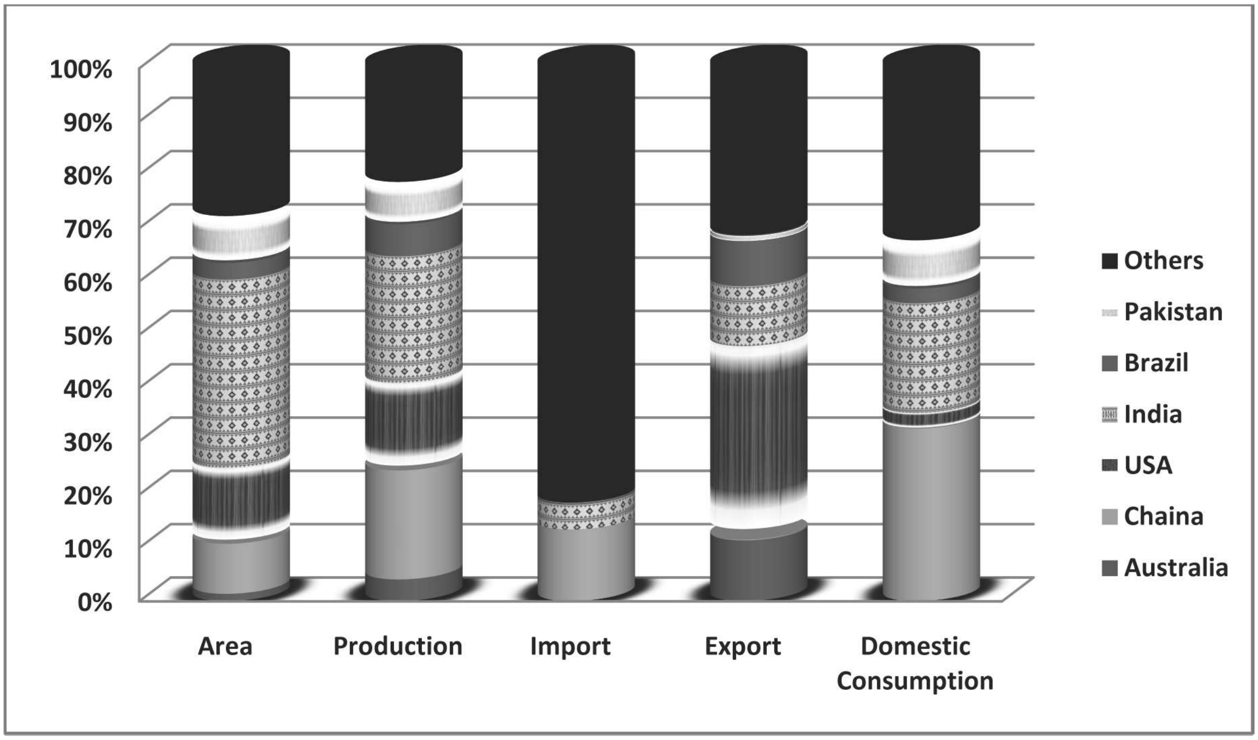

Fig. 1. Current share of major Bt cotton growing countries in the world cotton (2017)

data for the period from 1976 to 2017 were collected and analysed between two periods *viz.,* period I (before the introduction of *Bt* cotton) and Period II (after the introduction of the *Bt* cotton) for major *Bt* cotton growing countries in the world.

The compound Annual Growth Rate (CAGR) of area, production, productivity, import, export and domestic consumption in selected *Bt* cotton growing countries was computed for two sub periods *i.e.,* Period I (before the introductions of *Bt* cotton) and Period II (after the introduction of *Bt* cotton). However the duration of Period I and Period II is different for each country based on which year the *Bt* cotton was introduced in that country. In Australia and USA *Bt* cotton was introduced during 1996, hence the duration of Period I is 21 years from 1976 to 1996 and the duration of Period II is also 21 years from 1997 to 2017. Similarly in China, *Bt* cotton was introduced during 2001, hence the data for first period is taken from 1984 to 2001 and for the Period II it is from 2002 to 2017. In Brazil *Bt* cotton was introduced during 2005, hence the data for Period I was from 1992 to 2005 and Period II from 2006 to 2017 of 13 years duration. In case of India the data for Period I was taken from 1986 to 2002 and Period II 2003 to 2017 of duration 16 years each as *Bt* cotton for commercial cultivation was introduced during 2002. In case of Pakistan *Bt* cotton was introduced during 2010 accordingly Period I is from 2002 to 2010 and Period II is from 2011 to 2017.

Triennium averages were worked out to even out the inter-year fluctuations in data. The

Compound Annual Growth Rate (CAGR) was worked out using the semi-log growth model. The country wise CAGR of area, production, productivity import, export and domestic consumption of cotton was computed using the exponential growth functions of the form.

$Y = ABtV^t$

Where, Y_t = Dependent variable for which growth rate is estimated

A = Intercept indicating Y in the base period (t = 0)

B = Regression coefficient (1 + g) and

g = CGR

T_i = Time period (i = 1 to 10)

V_t = Random error

The growth equation was converted into the logarithmic form in order to facilitate the use of Ordinary Least Square for estimation of parameters.

RESULTS AND DISCUSSION

Growth in area, production and productivity of cotton in major *Bt* cotton cultivating countries in the world : The CAGR of area, production, productivity, import, export and domestic consumption of world was analysed in two periods. Period I was from 1986 to 2002 and Period II was from 2003 to 2017 (Table 3). During the Period I there was negative growth in world cotton import and export and positive growth in production and domestic consumption, whereas world cotton area has registered a negative growth in both the periods. During Period II world cotton production, yield, import, export and domestic consumption registered a positive growth. There was a significant increase in the export growth of raw cotton in world which increased at 1.18 per cent/annum during Period II. While the world export of raw cotton was decreased at the rate of 1.59 per cent/annum during Period I.

CAGR of area, production, productivity, import, export and domestic consumption of cotton in Australia : Australia is the first country, where the commercial cultivation of *Bt* cotton was started during 1996. At present Australia is relatively a minor producer on the world scale but is the world third exporter of raw cotton after USA and India. The major production area of cotton in Australia is New South Wale and Queensland. The CAGR is calculated for two sub periods *viz.,* Period I was before the introduction of *Bt* cotton (1976 to 1996) and Period II was after the introduction of *Bt* cotton (1997 to 2017). The CAGR of cotton area in Period I has decreased from 10.73 to 1.17 per cent/annum and cotton production 12.80 to 2.48 from period I to period II. Similarly, the CAGR of cotton import, export and domestic consumption has also decreased from Period I to Period II. Whereas, the CAGR of cotton productivity has increased remarkably from 1.77 to 37.35 per cent/annum from period I to period II (Table 3 and Fig.2). In Australia over the last twenty years (after the introduction of *Bt* cotton during 1996) cotton yield has increased by 38 per cent (Cotton Australia, 2017). During 2007-2008 because of severe drought the cotton area and production was severely affected. During II Period there was a drastic reduction in area, production, import and domestic consumption of raw cotton in Australia. Whereas the export of raw cotton during Period I and Period II was positive. The remarkable increase in yield

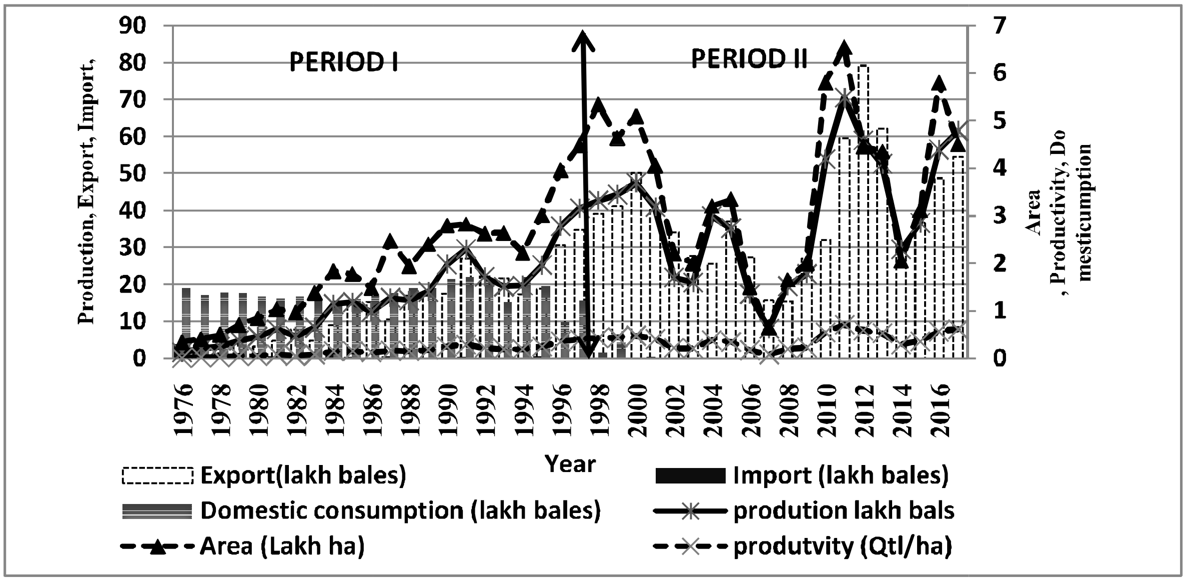

Fig. 2. Area, production, productivity, import, export and domestic consumption of cotton in Australia

during Period II can be attributed to about 77 per cent of cotton is grown in irrigated condition and 99.9 per cent of Australian cotton crop is grown with verities containing biotech traits. Off late all the Australian cotton produced is being exported to mills of South East Asia, more than 50 percent of its export to China.

CAGR of area, production, productivity, import, export and domestic consumption of cotton in USA : In United State of America *Bt* cotton was introduced for commercial cultivation during 1996. At present USA is the third largest producer of cotton after India and China and ranks first in raw cotton exports accounting for one third of global trade in raw cotton. Cotton is being produced in 17 Southern states from Virginia to California and the predominant type of cotton grown in USA is *Gossypium hirsutum.* The success of cotton production in the USA has served as a major boost for the American economy and a catalyst for improvements and innovations (Yoo-Kyoung Seock, 2013). The CAGR is calculated for two sub periods *viz.,* Period I pertaining to before the introduction of *Bt* cotton (1976 to 1996) and Period II pertaining to after the introduction of *Bt* cotton (1997 to 2017).

The CAGR of cotton area, production, import and domestic consumption was positive during the Period I and during Period II there was a negative growth. Cotton area (0.43%), production (2.42%), import (4.00%) and domestic consumption (4.12%) registered a positive growth during Period I. Whereas during Period II cotton area (-2.73%), production (-1.23%), import (-11.96%) and domestic consumption (-6.35%) registered a negative growth (Fig.3 and Table 2). However the growth in cotton productivity remained positive in both the periods. During Period I cotton productivity was increased at the rate of 13.57 per cent/annum, which was declined to 13.27 per cent/annum during Period II. There was a significant increase in export from Period I to Period II. The raw cotton export which grew at 1.10 per cent/annum in Period I was grew at 2.31 per cent/annum in Period II.

Table 3. Compound Annual Growth Rate (CAGR) of cotton area, production, productivity, import, export and domestic consumption in major *Bt* cotton growing countries (%)

Country	CAGR in Period I						CAGR in Period II					
	Area	Production	Yield	Import	Export	Consumption	Area	Production	Yield	Import	Export	Consumption
Australia	10.73***	12.80***	1.77***	-7.57	280.36***	0.91**	1.17	2.48	37.35***	-29.49	-107.30	-
USA	0.43	2.42***	13.57**	4.00	1.10**	4.12***	-2.73***	-1.23**	13.27**	-11.96***	2.31**	-6.35***
China	-1.33***	0.25	1.63**	17.09***	-17.44***	-0.07	-3.08**	-0.28	2.91**	1.11	-7.45***	0.01
India	2.24***	3.70***	1.44***	25.99***	-9.92**	4.65***	3.30***	4.51***	1.25***	5.94**	12.78**	4.12***
Brazil	-2.88	10.94***	13.99**	-15.76***	35.18**	0.32	-0.001	0.57	0.71***	-11.12**	7.30***	-3.62***
Pakistan	-0.30	-1.25	-2.50	12.87**	2.42	2.87	-2.1**	-3.92**	-0.48	16.15***	-18.60***	0.23
World	-0.22	0.86***	-	-1.63***	-1.59***	0.31**	-0.46	0.03	-	0.56	1.18***	0.10

****** and ** Significant at one and five per cent level***

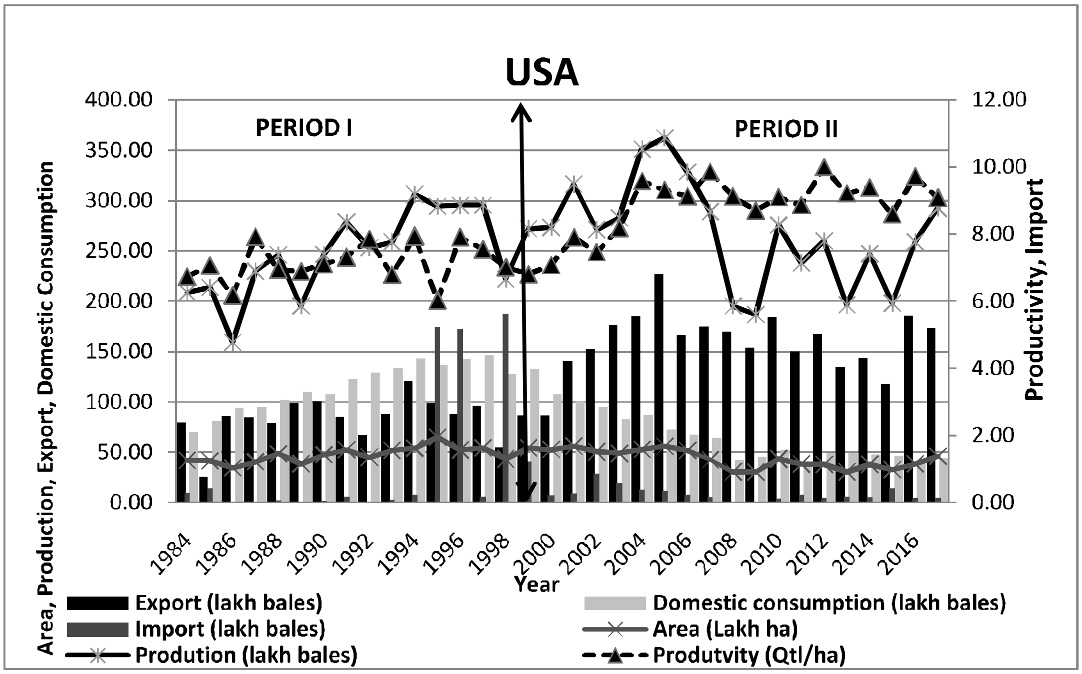

Fig. 3. Area, production, productivity, import, export and domestic consumption of cotton in USA

CAGR of area, production, productivity, import, export and domestic consumption of cotton in China : Cotton is one of the most important cash crop in China. China is one of the largest raw cotton producing and consuming country in the world, accounting for more than 20 per cent of world production and more than 32 per cent of world consumption. The major production area of cotton in China is in the Northwest inland cotton region, the Yellow river valley region and the Yangtze river valley region. *Bt* cotton was introduced in China during 1997. During Period I and Period II the CAGR of cotton area and export was negative where as remarkable growth in yield was registered from Period I (1.63%) to Period II (2.9%). The CAGR of production (-0.28%) was negative during Period I which registered a positive growth during Period I (Fig.4 and Table 2).

However domestic consumption of raw cotton increased at 0.01 per cent per annum during Period II which was negative during Period I. There was a significant increase in the raw cotton consumption in China during Period II. China has been the driving force of the world textile industry. The textile industry in China is highly dependent on the export market and China has increased its share of world textile and apparel exports in recent decades. The rate of increase in the raw cotton consumption occurred in China (Cotton Exporter's Guide, 2007). Higher disposable income, rising standard of living, population growth and urbanisation also attributed to the increased consumption of raw cotton in China.

The largest and most significant impetus to the growth of world trade in cotton was provided by a sharp increase of cotton use in China. During 2005-2006 China imports of raw cotton constituted 43 per cent of world cotton imports

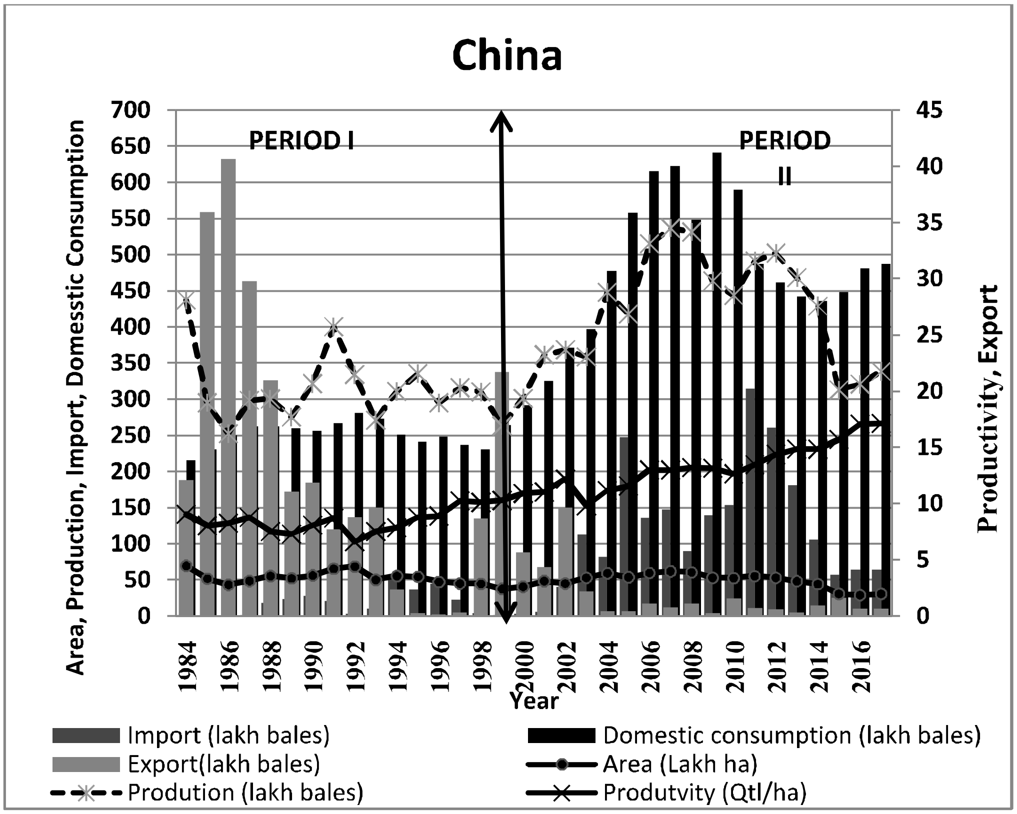

Fig.4. Area, production, productivity, import, export and domestic consumption of cotton in China

(Table 4, Cotton Export Guide, 2007). The output of Chinese cotton had been decreased from 2008 after the implementation of seed subsidy in 2007 (Yanwen Tan, 2013). In China cotton production during Period II was decreased at 0.28 per cent/ annum despite increase in the yield due to decreased cotton area and it has been reported that Chinese government policies contributed to the decade low cotton production in 2015-2016. China governments Target Price based Subsidy policy and the reduction of government support to corn producers encouraged cotton farmers as a result there was slight increase in the cotton production during 2015 (Gain report, 2017).

CAGR of area, production, productivity, import, export and domestic consumption of cotton in India : India is the major producer, exporter and consumer of raw cotton in the world accounts for more than 35 per cent of area, nearly 24 per cent of production, 11.30 per cent of export and about 20 per cent of consumption in the world. Cotton in India is grown in three distinct the Northern Zone comprising of Punjab, Haryana and Rajasthan states, Central Zone comprising of Madhya Pradesh, Gujarat and Maharashtra and the Southern Zone comprising of Karnataka, Andhra Pradesh and Tamil Nadu. The CAGR computed for two sub periods *i.e.,* Period I (1986 to 2001) and Period II (2002 to 2017). In India cotton area has increased significantly from 2.24 to 3.30 per cent per annum from Period I to Period II (Table 2 and Fig.5) . India became the top cotton producing country in the world in 2015. The CAGR of cotton production has increased remarkably from 3.70 to 4.51 per cent from Period I to II. The phenomenal increase in cotton production in India in the period 2002 to 2014 was due to the structural transformations in the cotton value chain driven by multiple factors including: the high and broad scale adaption of *Bt* cotton technology, hybridization of the cotton crop, supply good quality seeds by the private sector and the untiring efforts of cotton farmers (Bhagirath Choudhary and Kadambini Gaur, 2015). The growth in productivity has decreased but remained positive from 1.44 to 1.25 per cent from Period I to Period II. The growth in raw cotton imports was 25.99 per cent/annum during Period I whereas in Period II the import growth was 5.94 per cent/annum.

The raw cotton export registered a tremendous growth during Period II compared to Period I. During Period I raw cotton export was negative and decreased at 9.92 per cent/annum where as during Period II raw cotton exports increased at 12.78 per cent/annum. However there was a slight decrease in the domestic consumption of raw cotton from Period I to Period II. During Period I the domestic consumption was increased at 4.65 per cent/annum whereas during Period II it was increased at 4.12 per cent. This sustained

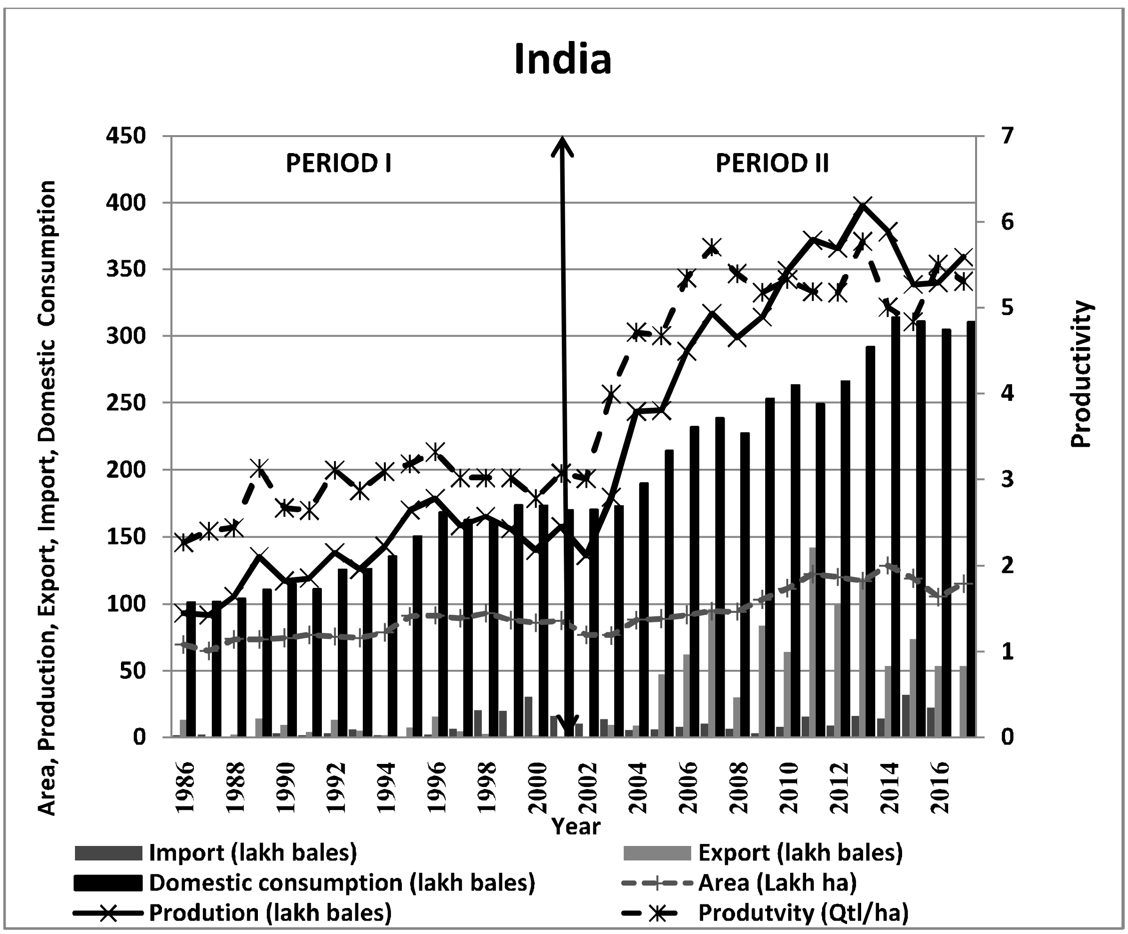

Fig. 5. Area, production, productivity, import, export and domestic consumption of cotton in India

growth in raw cotton consumption is attributed to the mushroom growth of spinning industry and its modernization. India achieved a sustained growth in cotton consumption during Xth Plan period since then domestic consumption has been increased steadily (CCI, 2017).

There was a significant increase in growth in area, production and export of raw cotton in India during Period II . It was reported that in India *Bt* technology has witnessed an impressive adaption rate and emerged as one of the faster adopted crop technologies in history of Indian agriculture. Within a decade area under *Bt* cotton has increased remarkably at the rate of 90 per cent/annum and occupied 91 per cent of total cotton area during 2011-2012 (Shivendra and Deeothi, 2016). Although the production level was sustained in 2000, the real improvement in the production level in the later year of 2000 was due to enhancement in area under cotton triggered by large scale adaption of *Bt* cotton (Sabesh, 2014).

There was a tremendous growth in domestic consumption of raw cotton during period I which grew at 4.65 per cent/annum more or less the same trend was observed during Period II. Indian has been a net cotton producer since the introduction of *Bt* cotton as production outfaced consumption and the country generated a large exportable surplus during Period II. At the same time domestic mill consumption was increased at 4.12 per cent/annum during Period II. It was the favourable textile policies that contributed in a big way for high growth of domestic cotton consumption during both the periods. In addition, Indian textile and clothing industry is largely cotton based and the cotton share in textile mill consumption is 70 per cent at the same time the manmade fibre and yarns industry has not experienced a rapid growth as the government textile policies supported for the growth of natural fibres during both the periods (Grain Report 2017).

The tremendous performance of Indian cotton during Period II was attributed to the increased area under *Bt* cotton at the rate of 3.30 per cent/annum and increased irrigated area under cotton. In addition, yield enhancement, MSP purchases of Government of India through Cotton Corporation of India, modernization of market yards and ginning mills also contributed in achieving record productivity, production, consumption and exports. The earlier studies also reported that CAGR of area, production and productivity of cotton in India had increased significantly from 2002-2003 to 2009-2010 (Puran Mal *et al.,* 2007 and Sabesh *et al.,* 2014). The significant increase in area and production of cotton in India was attributed to better returns realized by farmers due to rapid spread of *Bt* cotton (Khadi *et al.,* 2008; Elumalai and Sujata, 2011).

CAGR of area, production, productivity, import, export and domestic consumption of cotton in Brazil : Brazil is one of the leading cotton producer in the world. The main cotton producing areas of Brazil are Matto Grosso and North East where more than 95 per cent of cotton is grown in rainfed conditions that have world's highest yields. At present Brazil is the fifth largest producer, fourth largest exporter and consumer of cotton in the world. The CAGR of area, production, productivity, import, export and domestic consumption was analysed for two periods *viz.,* Period I (1992 to 2004) and Period II

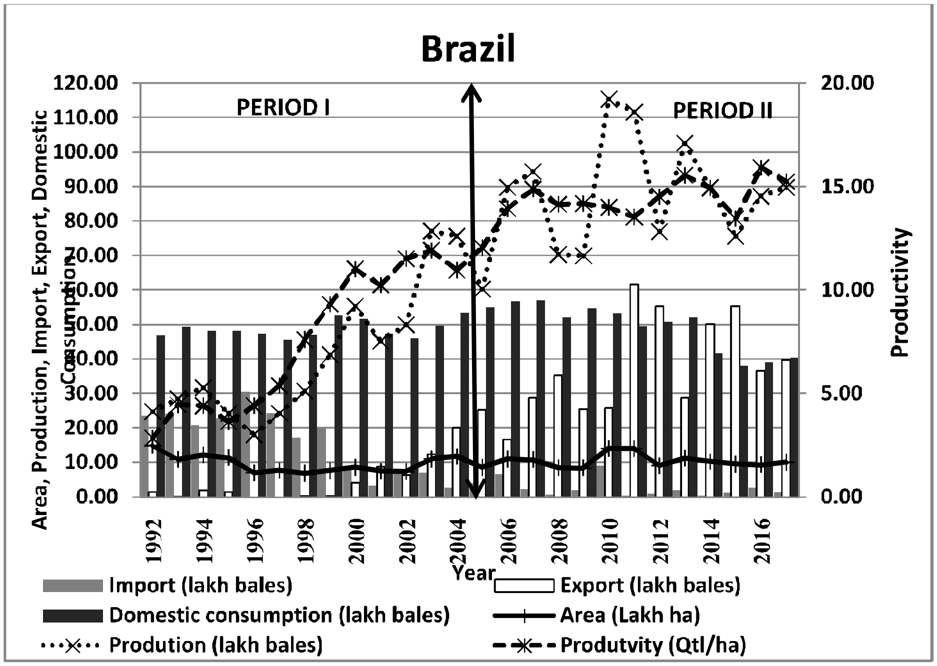

Fig. 6. Area, production, productivity, import, export and domestic consumption of cotton in Brazil

(2005 to 2017). The cotton area registered a negative growth in both the periods where as production growth was 10.94 per cent in Period I which grew at mere 0.57 per cent/annum during Period II (Table 2 and Fig.6). Cotton production in Brazil decreased rapidly in mid 1990's because of structural changes in government policy in favour of Soyaben and outbreak of cotton boll weevil.

Again during second half of the 1990's the cotton production recovered as cotton production was spread to the other areas where cotton had not previously grown (Cotton Exporters Guide, 2007). During Period I the cotton yield increased remarkably at the rate of 13.99 per cent/annum with the adaption of modern large scale farming and improved access to the inputs and due to extremely favourable climate in Brazilian new production regions. The cotton yields during Period I have surged to more than double the world average. Even though more than 90 per cent of cotton grown in rainfed condition Brazilian average yields of cotton are second only to those in Australia, where cotton produced under irrigated condition (James Kiawu, 2011). Whereas during Period II the growth in cotton yield in Brazil was mere 0.71 per cent/annum.

The growth in export was positive whereas the growth in import was negative in both the periods. The domestic consumption has decreased at 3.62 per cent/annum during Period II. Brazil at present is a net exporter of cotton and often a major source of world cotton supplier. With the open trade policies and exposure to competition and strong exchange rates caused Brazil textile industry and cotton consumption to contract. While microeconomic reforms, open trade, flexible exchange rate regime and the development of cotton varieties suitable to Brazils Cerrados area have helped Brazil become one of the world's major producer and exporter of raw cotton (James Kiawu, 2011)

CAGR of area, production, productivity, import, export and domestic consumption of cotton in Pakistan : Cotton is a major crop of Pakistan which occupies largest area after wheat. Cotton is grown in Punjab and Sindh province and livelihood of million of farmers is dependent on this crop. Pakistan occupies 4th place in cotton production in the world. *Bt* cotton was made available for commercial cultivation during 2010 (USDA GAIN Report, 2010) and in 2015 , Pakistan achieved a 93 per cent adaption rate of *Bt* cotton (James Clive, 2015). The CAGR of area, production, productivity, import, export and domestic consumption was analysed in two periods viz., Period I (2002 to 2009) and Period II (2010 to 2017).

In both the periods' cotton area, production, yield and export registered a negative growth while import and domestic consumption registered a positive growth. The raw cotton import growth during Period I was 12.87 which was increased to 16.15 per cent/annum during Period II (Table 2 and Fig.7). Pakistan is a net importer of raw cotton, primarily due to strong demand for better grades of cotton for producing export oriented quality textile products and to augment domestic supplies for processing and re-export (Grain Report, 2017). There was no significant change in growth of area, production and productivity of cotton in Pakistan from Period I to Period II.

Share of major *Bt* cotton growing countries in world cotton area, production, import, export and domestic consumption : The percentage shares of major *Bt* cotton growing countries in world cotton area, production, import, export and consumption were computed

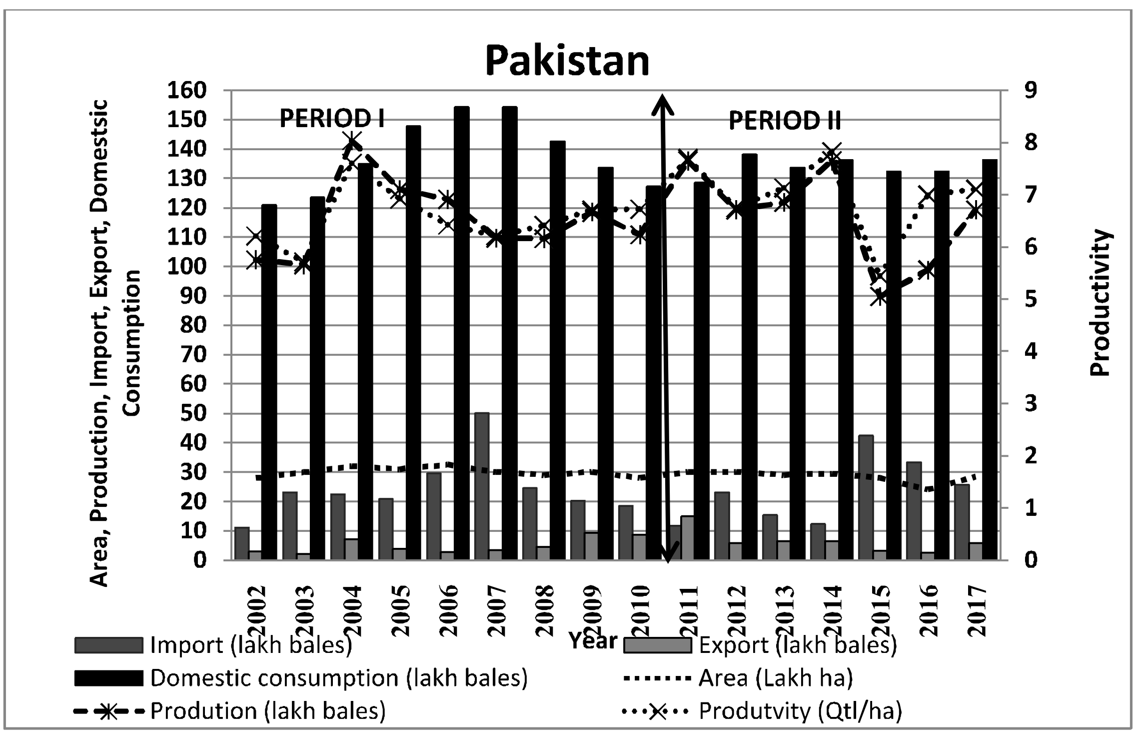

Fig. 7. Area, production, productivity, import, export and domestic consumption of cotton in Pakistan

by taking 32 years time series data from the period from 1986 to 2017 (Fig.8 and Table 5a, 5b). The actual share of China in world raw cotton production was decreased in recent years, whereas the share of cotton production remained highest for a long period of time until Indian share surpassed in 2015. The Indian raw cotton production share in world cotton production shown an increasing trend throughout the period under consideration and during 2017 its share was highest (23.87%) among major *Bt* cotton growing countries fallowed by China (20.46%), USA (16.37%), Pakistan (7.93%), Brazil (5.97%) and Australia (4.09%). In USA, Australia, India and Brazil raw cotton production in recent years picked up and their share in world cotton production also increased. While Pakistan share in world raw cotton production remained below 10 per cent throughout the period (Fig. 8a).

The area share of major *Bt* cotton growing countries in the world cotton area (Fig.8b and Table 5) revealed that India has a maximum share throughout the period and in recent decades its share was increased tremendously. Whereas the share of China, Australia, USA. Brazil and Pakistan has decreased continuously. During 2017, maximum share of world cotton area was in India (35.44%) fallowed by USA (14.19%), China (9.4%), Pakistan (8.78%), Brazil (3.08%) and Australia (1.39%).

The raw cotton export share of major *Bt* cotton growing countries (Fig.8c) in world raw cotton exports revealed that USA has the highest share throughout the period under consideration and its share was increased in recent years. Similarly, the raw cotton export share of Australia and Brazil was also increased in recent years. Whereas, the raw cotton export share of India has decreased and that of Pakistan and China remained constant at less than one per cent.

Even though the export share of USA was declined (2011-2013) due to reduced imports from China and increased competition from India (USDA, 2011), during 2017 USA has the maximum share of 36.32 per cent in world raw cotton exports, the gain in USA market share was largely attributed to supply issues in other major cotton exporting countries such as Brazil and India (National Cotton Council of America, 2017). Australia (11.43%) has the second largest share in world raw cotton exports fallowed by India (11.3%), Brazil (8.34%), Pakistan (1.21%) and China (0.13%). At present, Australia is the third largest exporter of raw cotton after USA and India, about 95 per cent of the Australian cotton is exported to China, Indonesia and Thailand as there is no base of domestic textile industry (GAIN Report, 2017).

The raw cotton import share (Fig. 8d) of major *Bt* cotton growing countries in world cotton imports revealed that China has the highest share throughout the period from 1986 to 2017. However, Chinese cotton imports reduced drastically during 2013-2014 due to Chinese government cotton support policies to procure domestic cotton at high prices (Grain Report, 2017). Among the six countries China has maximum share of 13.45 per cent during 2017 fallowed by India (4.71%), Brazil (0.27%), Pakistan (0.06%) and USA (0.03%). In all the major *Bt* cotton growing counties the import share of raw cotton in the world from 1986 to 2017 has shown decreasing trend. Over the past decade the global market for the cotton fibre and cotton based

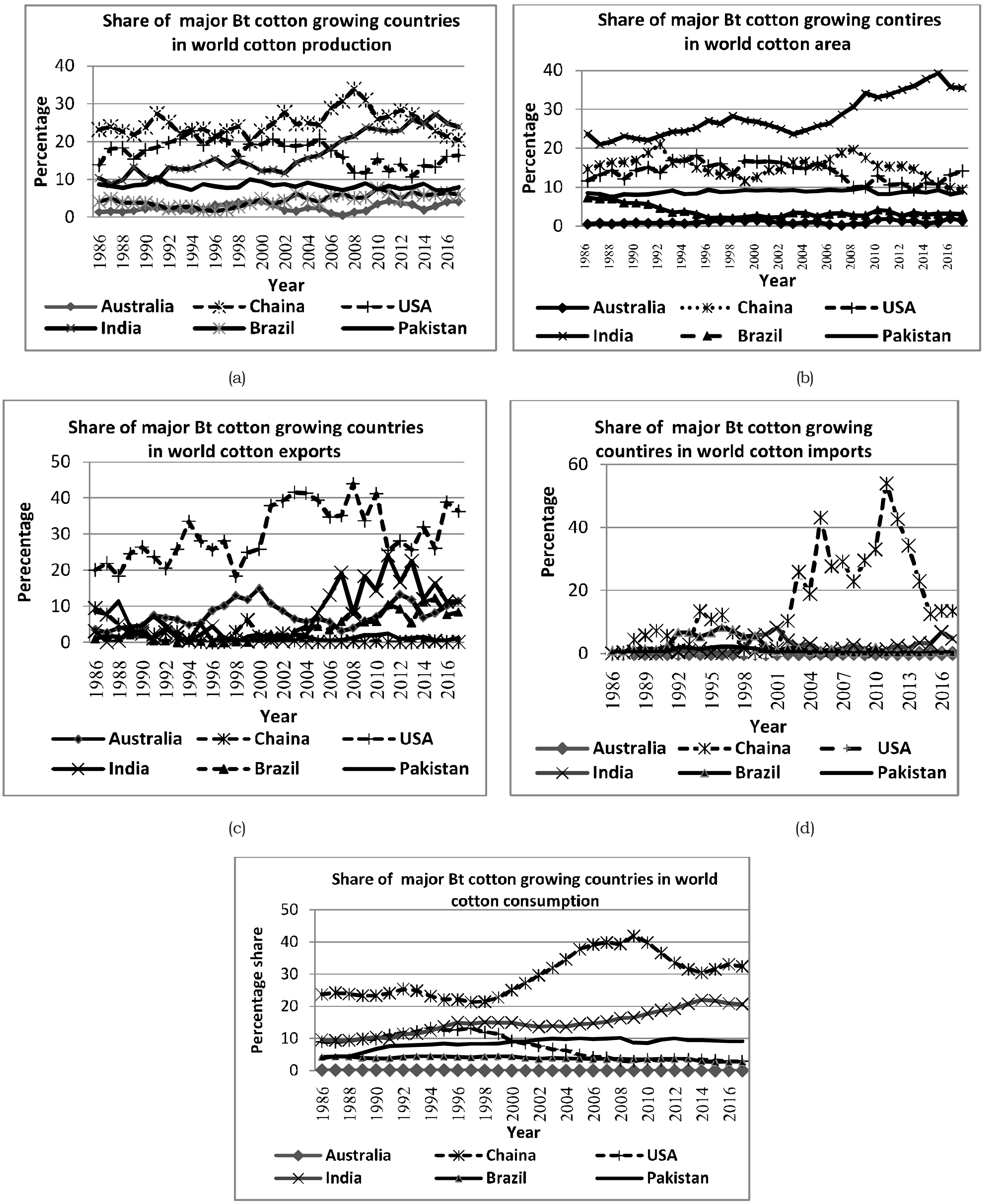

Fig. 8. Share of major *Bt* cotton growing countries in World cotton area, production, import, export and consumption

Table 4. Summary of trends in area, production, productivity, import, export and domestic consumption of cotton in major cotton growing countries before and after the introduction of *Bt* cotton

Country	Before introduction of *Bt* cotton	After introduction of *Bt* cotton	Significant Changes after introduction of *Bt* cotton
Australia	Area, production, productivity and exports increased with positive growth rate	Wide fluctuations in area and production with positive growth rate. Productivity increased with high growth rate. Exports fluctuated with negative growth rate.	Productivity export
USA	Area and production increased with positive growth rate. Lower and fluctuating yield and export with positive growth. Imports remained constant with positive growth. Domestic consumption increased with positive growth	Area decreased with negative growth rate. Wide fluctuations in Production with negative growth. Increasing trend of yield with high positive growth. Exports increased with positive growth. Negative imports. Decreasing trend and negative growth in domestic consumption	Export productivity
China	Declining trend in area with negative growth. Decreasing trend with positive growth in production. Increased yield with positive growth. Decreased exports with negative growth. Reduced imports with positive growth. Domestic consumption remained constant with negative growth.	Declining trend in area with negative growth. Production Increased in the beginning and decreased recently with negative growth. Increased yield with positive growth. Decreased exports with negative growth. Wide fluctuations in imports domestic consumption with positive growth.	Productivity
India	Area, production and yield decreased with positive growth rate. Reduced exports with negative growth. Increased imports and domestic consumption with positive growth.	Increased area, production, yield, imports and domestic consumption with positive growth rates. Fluctuating and Increased trend of exports with positive growth.	Area expansion Production Export productivity
Brazil	Area remained constant with negative growth . rate. Increased production with positive growth rate. High level of yields with positive growth. Decreased imports with negative growth rate. Increased domestic consumption with positive growth rate	Area remained constant with negative growth. Wide fluctuations in production with positive growth. Increased yield with positive growth. Wide fluctuations in export with positive growth. Decreased imports and domestic consumption.	Export productivity
Pakistan	Area remained constant with negative growth. Decreased production and yields with negative growth. Export, import and domestic consumption fluctuated with positive growth.	Area remained constant with negative growth. Decreased production with negative growth. Yield fluctuated with negative growth. Exports with negative growth. Import and domestic consumption increased with positive growth	No change net importer

Table 5 (a). Share (in percentage) of major *Bt* cotton growing countries in world cotton area, production, import, export and domestic consumption

Year	Area						Production						Export					
	Australia	USA	China	India	Pakistan	Brazil	Australia	USA	China	India	Brazil	Pakistan	Australia	USA	China	India	Brazil	Pakistan
1986	0.50	11.68	14.67	23.68	7.26	8.54	1.40	13.83	23.17	10.31	4.13	8.62	3.54	20.04	9.50	3.05	0.91	8.61
1987	0.80	13.15	15.69	20.96	6.98	8.32	1.57	18.12	23.94	8.77	4.87	8.28	2.72	21.86	7.71	0.06	1.98	7.83
1988	0.57	14.29	16.36	21.70	7.00	7.41	1.46	18.30	22.68	9.75	3.87	7.78	3.94	18.36	4.89	0.45	1.39	11.29
1989	0.76	12.18	16.42	23.13	5.99	8.20	1.76	15.30	21.83	13.22	3.84	8.39	4.21	24.54	2.76	3.43	2.11	4.37
1990	0.84	14.32	16.86	22.44	5.96	8.03	2.28	17.79	23.75	10.48	3.78	8.63	4.64	26.36	3.14	2.40	2.42	4.59
1991	0.81	15.09	18.81	22.04	5.66	8.16	2.42	18.50	27.41	9.76	3.22	10.50	7.48	23.56	2.13	1.07	0.47	7.30
1992	0.80	13.79	20.94	23.11	4.55	8.69	2.08	19.70	25.15	13.09	2.34	8.59	6.80	20.45	2.69	3.89	0.43	4.62
1993	0.86	16.84	16.28	24.22	3.53	9.13	1.95	20.77	22.14	12.62	2.86	8.09	6.34	25.78	2.81	1.39	0.02	1.19
1994	0.69	16.72	17.15	24.38	3.78	8.22	1.78	22.78	23.06	12.92	2.86	7.24	4.83	33.44	0.65	0.37	0.54	0.53
1995	0.84	18.03	15.09	25.23	3.15	8.35	2.10	19.06	23.32	14.11	2.01	8.81	5.34	28.02	0.07	2.07	0.37	5.23
1996	1.17	15.46	14.00	27.04	2.06	9.33	3.10	21.03	21.43	15.46	1.56	8.13	8.90	25.64	0.04	4.43	0.00	0.44
1997	1.33	16.05	13.29	26.35	2.26	8.76	3.43	20.35	22.84	13.36	2.05	7.77	10.13	28.01	0.09	1.17	0.00	1.42
1998	1.62	13.15	13.56	28.24	2.08	8.89	3.87	16.17	24.05	14.97	2.78	7.97	12.93	18.28	2.87	0.83	0.10	0.04
1999	1.43	16.79	11.52	27.17	2.32	9.22	3.93	19.30	20.02	13.85	3.66	9.98	11.84	24.88	6.24	0.26	0.04	1.53
2000	1.59	16.50	12.68	26.79	2.66	9.15	4.15	19.29	22.78	12.27	4.84	9.40	14.92	25.77	1.69	0.36	1.20	2.23
2001	1.20	16.60	14.29	25.89	2.22	9.24	3.25	20.61	24.77	12.49	3.57	8.41	10.76	37.83	1.18	0.21	2.32	0.62
2002	0.71	16.33	14.62	24.91	2.39	9.08	1.87	18.91	27.68	11.65	4.27	8.76	8.73	39.14	2.47	0.18	1.61	0.76
2003	0.62	15.06	16.43	23.65	3.41	9.26	1.65	18.88	24.61	14.48	6.22	8.11	6.51	41.50	0.52	2.11	2.91	0.51
2004	0.89	14.78	16.50	24.57	3.28	8.93	2.47	19.13	24.93	15.64	4.86	9.17	5.72	41.31	0.09	1.89	4.46	1.60
2005	0.97	16.19	15.51	25.72	2.46	8.99	2.36	20.54	24.41	16.38	4.04	8.47	6.42	39.34	0.08	8.18	4.39	0.64
2006	0.43	14.84	17.14	26.41	3.15	9.36	1.10	17.55	28.86	18.29	5.69	7.79	5.69	34.63	0.24	13.03	3.47	0.58
2007	0.20	12.91	18.85	28.70	3.27	9.12	0.52	15.93	30.69	20.48	6.10	7.09	3.13	35.03	0.16	19.27	5.73	0.69
2008	0.54	10.00	19.75	30.71	2.75	9.47	1.41	11.84	33.89	21.51	5.06	7.89	3.98	43.90	0.28	7.81	9.07	1.18
2009	0.66	10.10	17.55	34.14	2.77	9.93	1.72	11.78	30.95	23.70	5.27	8.94	5.90	33.64	0.06	18.31	5.56	2.03
2010	1.72	12.84	15.56	33.03	4.15	8.30	3.57	15.39	25.93	23.12	7.65	7.34	7.16	41.18	0.35	14.32	5.73	1.95
2011	1.82	10.61	15.25	33.82	3.88	8.32	4.31	12.20	26.63	22.72	6.81	8.30	10.08	25.46	0.12	24.08	10.41	2.52
2012	1.30	10.99	15.44	34.95	2.62	8.74	3.71	13.97	28.25	23.00	4.84	7.51	13.28	28.04	0.10	16.70	9.27	0.97
2013	1.34	9.38	14.74	35.93	3.44	8.91	3.41	10.72	27.21	25.75	6.65	7.89	11.80	25.61	0.06	22.53	5.42	1.24
2014	0.60	11.11	12.92	37.73	3.00	8.66	1.93	13.69	25.17	24.75	5.87	8.89	6.81	31.88	0.20	11.90	11.08	1.45
2015	1.03	10.79	10.07	39.28	3.15	9.24	2.95	13.32	22.74	27.28	6.10	7.23	8.08	25.94	0.36	16.34	12.23	0.71
2016	1.98	13.11	9.88	35.78	3.17	8.18	4.13	16.12	21.36	24.89	6.39	7.23	10.16	38.78	0.13	11.23	7.62	0.53
2017	1.39	14.19	9.40	35.44	3.08	8.78	4.09	16.37	20.46	23.87	5.97	7.93	11.43	36.32	0.13	11.30	8.34	1.21

Table 5 (a). Share (in percentage) of major *Bt* cotton growing countries in world cotton area, production, import, export and domestic consumption

Year	Import						Domestic Consumption						All six major Bt cotton growing countries				
	Australia	USA	China	India	Pakistan	Brazil	Australia	USA	China	India	Brazil	Pakistan	Area	Production	Export	Import	Consumption
1986	0.003	0.01	0.05	-	0.73	0.17	0.13	8.96	23.70	9.59	4.24	3.86	66.32	61.45	45.65	0.97	50.46
1987	0.013	0.01	0.28	0.35	0.65	0.16	0.13	8.78	24.21	9.38	4.40	4.50	65.90	65.55	42.18	1.46	51.40
1988	0.003	0.01	4.31	0.51	1.41	0.33	0.13	9.25	23.87	9.45	4.39	4.34	67.34	63.83	40.31	6.57	51.44
1989	0.003	0.01	5.73	0.05	1.59	0.38	0.13	9.86	23.30	9.92	4.02	5.60	66.67	64.33	41.42	7.75	52.83
1990	0.003	0.01	7.21	0.00	1.34	0.34	0.15	9.77	23.34	10.46	3.88	6.71	68.45	66.71	43.55	8.91	54.30
1991	0.007	0.04	5.62	0.74	2.26	0.61	0.15	11.12	24.09	9.99	3.88	7.60	70.58	71.80	42.03	9.28	56.83
1992	0.000	0.00	0.89	0.38	6.74	1.94	0.15	11.64	25.35	11.35	4.22	7.79	71.87	70.96	38.88	9.95	60.50
1993	0.000	0.02	2.89	0.79	6.68	1.86	0.11	12.15	24.85	11.48	4.47	7.92	70.86	68.42	37.54	12.25	60.97
1994	0.000	0.07	13.40	1.46	5.32	1.37	0.16	13.24	23.19	12.51	4.45	8.07	70.93	70.65	40.36	21.61	61.62
1995	0.011	1.51	10.77	0.31	6.55	1.89	0.14	12.50	22.04	13.76	4.40	8.46	70.69	69.41	41.10	21.04	61.30
1996	0.003	1.41	12.22	0.05	8.35	2.28	0.07	12.73	22.12	15.02	4.21	8.04	69.06	70.71	39.45	24.31	62.19
1997	0.004	0.05	6.65	0.56	7.27	2.19	0.11	13.14	21.28	14.62	4.10	8.32	68.03	69.79	40.81	16.72	61.57
1998	0.000	1.79	1.36	2.08	5.45	1.74	0.01	11.96	21.49	15.09	4.39	8.40	67.54	69.80	35.05	12.41	61.34
1999	0.000	0.35	0.42	5.72	5.57	1.55	0.03	11.43	22.74	14.97	4.54	8.48	68.47	70.74	44.79	13.61	62.19
2000	0.000	0.06	0.88	5.97	2.30	0.68	0.00	9.23	25.04	14.92	4.44	8.95	69.37	72.73	46.17	9.89	62.58
2001	0.007	0.07	1.53	8.14	0.86	0.23	0.00	8.41	27.13	14.18	3.94	9.10	69.44	73.10	52.91	10.85	62.76
2002	0.000	0.22	10.34	4.02	1.86	0.48	0.00	7.62	29.66	13.62	3.67	9.65	68.04	73.13	52.90	16.93	64.23
2003	0.000	0.13	25.84	2.34	1.59	0.36	0.00	6.67	31.86	13.90	3.98	9.91	68.43	73.96	54.06	30.27	66.32
2004	0.003	0.09	18.79	3.05	0.62	0.14	0.00	6.30	34.51	13.71	3.85	9.75	68.94	76.19	55.05	22.70	68.12
2005	0.000	0.06	43.15	0.89	0.69	0.12	0.00	4.92	37.77	14.50	3.74	10.01	69.83	76.20	59.05	44.91	70.94
2006	0.000	0.05	27.64	1.21	1.34	0.27	0.00	4.27	39.17	14.77	3.61	9.81	71.33	79.27	57.64	30.52	71.65
2007	0.000	0.03	29.22	1.52	0.42	0.08	0.00	4.12	39.86	15.29	3.66	9.88	73.05	80.81	64.02	31.27	72.81
2008	0.000	0.00	22.85	2.61	0.16	0.04	0.00	3.01	39.29	16.31	3.72	10.22	73.22	81.60	66.22	25.66	72.55
2009	0.000	0.00	29.53	1.30	0.41	0.09	0.00	2.96	41.85	16.53	3.56	8.73	75.15	82.36	65.50	31.33	73.63
2010	0.000	0.02	33.00	0.55	1.94	0.42	0.00	3.54	39.84	17.80	3.59	8.60	75.60	83.00	70.70	35.93	73.37
2011	0.000	0.04	53.97	1.32	0.06	0.01	0.00	3.01	36.59	18.73	3.71	9.65	73.69	80.97	72.68	55.40	71.68
2012	0.000	0.02	42.65	2.49	0.14	0.02	0.00	3.58	33.45	19.28	3.67	10.01	74.03	81.28	68.36	45.32	69.99
2013	0.000	0.03	34.25	1.64	0.36	0.07	0.00	3.51	31.54	20.80	3.70	9.53	73.74	81.63	66.67	36.34	69.08
2014	0.000	0.03	22.94	3.40	0.07	0.01	0.00	3.39	30.49	21.97	2.91	9.53	74.02	80.30	63.32	26.45	68.30
2015	0.000	0.09	12.51	3.04	0.26	0.06	0.00	3.25	31.47	21.80	2.65	9.28	73.56	79.62	63.66	15.96	68.45
2016	0.000	0.03	13.47	6.73	0.54	0.11	0.00	2.89	33.05	20.93	2.69	9.10	72.09	80.12	68.47	20.88	68.66
2017	0.000	0.03	13.45	4.71	0.27	0.06	0.00	2.91	32.42	20.65	2.69	9.06	72.27	78.68	68.73	18.50	67.73

textile products has undergone a structural changes. One of the notable changes is the emergence of China as a dominant consumer and importer of raw cotton in the world (Yoo-Kyoung Seock, 2013)

The share of different *Bt* cotton growing countries in global cotton consumption (Fig. 8e) from 1986 to 2017 has increased only in China, India and Pakistan and decreased in other three countries (Australia, USA and Brazil). During 2017 China has the maximum share to the tune of 32.42 per cent fallowed by India (20.65%), Pakistan (9.06%), USA (2.91%) and Brazil (2.69%). The USA raw cotton consumption share was decreased to 2.9 per cent during 2017, which was above 10 per cent during 1990's because of the shift in textile industry from USA and EU to Asian countries in last three decades in terms of its production basis. As the production of textile commodities was unprofitable for the manufacturers in USA and Europe they sought for alternative destinations in Asian countries where abundant and cheap manpower, vast natural resources and favourable economic policies made attractive destinations for manufacturing of textile products (FICCI, 2016). China, India and Pakistan has taken the maximum gain of this shift and emerged as the major textile manufacturing base in the world. Now USA is the largest consumption base in the world while manufacturing is concentrated in Asian countries such as China, India and Pakistan which are also the large consumption bases of textile production.

CONCLUSION

Cotton production in the world has been a major success story in recent years and has witnessed a major change in global cotton sector. In major *Bt* cotton growing countries cotton has emerged as a successful commercial crop in terms of increased exports, raw material supply to textile industry, employment opportunities and increased income to the farming community. After the introduction of biotech verities of cotton in many countries of the world there was a significant change in area, production and productivity of raw cotton. However this change is not uniform among all the *Bt* cotton adapted countries. It is evident that India is the major beneficiary of *Bt* technology among all the major *Bt* cotton growing countries. In India there was a phenomenal increase in cotton area, production, productivity and export after the adaption of *Bt* cotton on a large scale. Introduction of *Bt* cotton helped in expansion of cotton area both in irrigated and rainfed condition this triggered the growth in Indian cotton yield, production and exports. At the same time USA, Australia, Brazil, China and Pakistan experienced the decreased area under cotton cultivation after the adaption of *Bt* cotton. There was a significant change in productivity and export in Brazil, Australia, USA and India. Except Pakistan in all the five countries the cotton yields were increased in absolute terms after the introduction of *Bt* cotton. In case of Pakistan there were no significant changes in cotton sector after the adaption of *Bt* technology. Based on this, the following implications have been drawn to develop the cotton sector in the world on a sustainable basis.

1. In China and Pakistan efforts are needed to bring more area under cotton cultivation with larger adaption of *Bt*

varieties by supplying quality cotton seeds which will ensure better returns to the farmers.

2. The position achieved by major *Bt* cotton growing countries such as USA, China and Brazil in rising yield is quite higher compared to India. Hence there is a need to improve the cotton yield in India by adapting high density plantation which is successfully adapted in Brazil where cotton is grown under rainfed condition.

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Rainfall variability in Vidarbha and its impact on yield of major crop in Vidarbha

SANJAY. S.WANJARI, MADHURI LAUTE G.P.SAKARKAR, V.M.BHALE, D B. V SAOJI. A. R. TUPE AND KIRAN GONDSE

Agromet Section Department of Agronomy, Dr.Punjabrao Deshmukh Krishi Vidyapeeth, Akola - 444 104

**E-mail : wanjari.sanjay@rediffmail.com*

ABSTRACT : Drought characteristics for 11 district of Vidarbha was also analyzed and it was observed that Buldhana district was experienced highest mild drought years (10 years) where as washim has recorded one severe drought during the experimental period followed by Gondia. Out of 19 years study buldhana district has noticed near 10 mild drought years followed by bhandara with 9 mild drought years followed by Nagpur with 8 mild drought years followed by Akola, wardha and Amravati with 7 mild drought years on overall basis of Vidarbha of 19 years study it was observed that there were 7 mild drought years and 3 moderate drought years and 9 year were no drought was observed it shows positive correlation with yield.

Onset of monsoon was analyzed for last five decade (Table 1.) in decade one *i.e.* 1971 to 1980 did not found variation in starting of monsoon, whereas during second decade (1981 to 1999) consecutive three years *i.e.*1982, 1983 and 1984 shows the delay in onset of monsoon. This decade coup of (1991 to 2000).Three years (*i.e.* 1995, 1996 and 1999) registered with late monsoon and yield levels were affected during delayed monsoon. Conditions fourth decade comprises of 2001 to 2010 where four years *i.e.* 2001, 2002 2003 and 2010 should delayed. Onset of monsoon in such years it was observed that pulses sowing was delayed reflected in lower productivity also similarly at fifth decade (2011 to 2017) it was observed that two years (2014 to 2015) characterized by delay in monsoon *i.e.* in July which also reflected in delayed pulses sowing (Greengram and blackgram) which resulted in drastic reduction productivity also.

Rainfall pattern and yield : Correlation of yield and rainfall was carried out for major crops *i.e.* sorghum cotton and soybean for entire period (1998 to 2002, 2003 to 2007, 2008 to 2012 and 2013 to 2014) it is observed from the data presented in (Table 2.) During the period of 1998 to 2002 it is observed that yield of sorghum, soybean and cotton found to be non significant indicating that there is no significant relationship whereas, during 2003-2007 period sorghum yield was found significant correlation with rainfall at 5 per cent level and similarly cotton was also found significant at 5 per cent and 1per cent during 2003 to 2007 similarly 2008 to 2012 period indicated significant correlation with rainfall and yield of sorghum soybean and cotton at 5 per cent significant level overall period of 2013 to 2016 indicated that there is positive and significant association with rainfall and yield of sorghum soybean and cotton at 5 per cent and 1 per cent level in Vidarbha region.

The primary source of water for agricultural production for most of the world is rainfall. Three main characteristics of rainfall are its amount, frequency and intensity, the values of which vary from place to place, day to day, month to month and also year to year. Precise knowledge of these three main characteristics is essential for planning its full utilization

Rainfall pattern : Data of vidarbha was analysed for different trait indicated that

An analysis of three districts of western vidharbha zone *i.e.* Akola, Buldhana and washim indicated that maximum annual rainfall was noticed in washim district *i.e.* 800.2mm with minimum rainfall intensity was 395.5 mm were as it was noted that maximum rainfall 1134.4mm from the study period of 1998 to 2016

Table 1. Annual rainfall variation at different districts in Vidarbha (1998-2016)

Name of taluka	**Average**	Rainfall (mm)			CV (%)
		Minimum	Maximum	SD (mm)	
Western Vidarbha zone					
Akola	**755.84**	492.5	990.2	159.78	21.14
Buldhana	**763.03**	551.1	1039.8	170.03	22.28
Washim	**800.02**	395.5	1134.4	212.55	26.56
Central Vidarbha zone					
Nagpur	**1089.48**	699.2	1455.8	234.66	21.53
Yavatmal	**846.76**	474.9	1209.5	227.62	26.88
Amravati	**859.55**	636.8	1201.4	167.46	19.48
Wardha	**965.64**	245.5	1384.4	262.48	27.20
Eastern Vidarbha zone					
Gadchiroli	**1402.09**	862.2	2030.7	334.50	23.85
Gondia	**1336.09**	949.9	1920.8	258.84	19.37
Chandrapur	**1162.29**	666.9	1703.3	298.50	25.68
Bhandara	**1192.82**	765.3	1691.2	262.13	21.97
Vidarbha	**1025.42**	718.32	1413.68	185.88	18.12

with a standard deviation of 312.55 and coefficient of variance was 26.56 in Washim district and lowest coefficient of variance was observed for Akola district with average rainfall of 755.84mm . As regards to central vidarbha zone Nagpur district was recorded highest annual rainfall *i.e.* 1089.48mm and standard deviation was higher *i.e.*234.66 and coefficient of variation was 215.3 but among three district *i.e.* Nagpur, Yavatmal and Amravati Maximum coefficient of variation (cv) was observed in Yavatmal district .As regards to eastern Vidarbha zone Chandrapur district was recorded highest cv but Standerd Deviation(SD) was higher in case of Gadchiroli district.

Drought analysis : As Per the criteria of Indian Meteorological Department, IMD for analysis of rainfall, no drought years, moderate drought years, severe drought years were found out.

a) Rainfall more than normal as No drought:

b) Rainfall is 0-25 per cent deficit than normal then it is called as Mild drought

c) Rainfall is 26-50 per cent deficit than normal then it is called as Moderate drought :

d) Rainfall is more than 50 per cent deficit than normal it is called as severe drought:

Table2. Categorization of drought years of Vidarbha region according to criteria of Indian Meteorological Department (out of 19 year study)

Sr. No.	Taluka name	Types of drought				**Total drought years**
		No drought	Mild	Moderate	Severe	
1	Akola	9	7	3	-	**10**
2	Buldhana	7	10	2	-	**12**
3	Washim	9	5	4	1	**10**
4	Nagpur	9	8	2	-	**10**
5	Yavatmal	11	5	3	-	**8**
6	Amravati	9	7	3	-	**10**
7	Wardha	10	7	2	-	**9**
8	Gadchiroli	11	5	3	-	**8**
9	Gondia	9	9	1	-	**10**
10	Chandrapur	11	5	3	-	**8**
11	Bhandara	8	9	2	-	**11**
12	Vidarbha	9	7	3	-	**10**

Correlation studies : Correlation study was also undertaken to know the association with rainfall and yield during various growth periods and study indicated that there is a positive and significant correlation of yield and rainfall was observed for major crops *i.e.* sorghum cotton and soybean for entire period (1998 to 2002, 2003 to 2007, 2008 to 2012 and 2013 to 2014) it is observed from the data presented in (Table 2.) During the period of 1998 to 2002 it is observed that yield of Sorghum, Soybean and cotton found to be non-significant indicating that there is no significant relationship whereas, during 2003-2007 period sorghum yield was found significant correlation with rainfall at 5 per cent level and similarly

CORRELATION STUDIES in VIDARBHA Region							
	period	SORGHUM		SOYBEAN		COTTON	
		5%	1%	5%	1%	5%	1%
1	1998-2002	NS	NS	NS	NS	NS	NS
2	2003-2007	SIG	NS	NS	NS	SIG	SIG
3	2008-2012	SIG	NS	SIG	NS	SIG	NS
4	2013-2016 (overall Period)	SIG	SIG	SIG	SIG	SIG	SIG

cotton was also found significant at 5 per cent and 1per cent during 2003 to 2007 similarly 2008 to 2012 period indicated significant correlation with rainfall and yield of sorghum soybean and cotton at 5 per cent significant level overall period of 2013 to 2016 indicated that there is positive and significant association with rainfall and yield of sorghum soybean and cotton at 5 per cent and 1 per cent level in vidarbha region.

CONCLUSIONS

1. The number of drought years are more than the number of No drought years. Hence, it is concluded that there may be 50 per cent chances of occurrence of drought in the next subsequent year
2. In most of the years of Vidarbha and Akola district one to two dry spell were observed which needs proper agronomic consideration/management
3. The correlation of rainfall and productivity of soybean, cotton and sorghum, it is observed that rainfall and productivity of soybean and cotton are significantly correlated.
4. Proper agronomic considerations to mitigate the mid season drought. (*i.e.* planting on BBF.OR opening of ridges and furrow
5. Use of organic amendments need to be promoted on large scale so as to improve water holding capacity

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Mobile based extension for cotton growers in north west Rajasthan

BHAGWAN SINGH MEENA AND SURENDER KUMAR
Agricultural Research Station (SKRAU), Sriganganagar
**E-mail: bsmeena1969@rediffmail.com*

ABSTRACT *:* India is largest cultivator of cotton, stand second in the world. It has been facing challenges with regard to sustaining and increasing its productivity level. In recent years productivity has showed increasing trend by inclusion of improved production technologies of cotton from research system. Among the various reasons cited for low productivity, wide gap in technology dissemination found to be significant. Hence, transfer of cotton technologies among cotton growers is the way to enhance yield of cotton crop. Many cotton growers in the country did not know about improved cotton production technologies as they did not have reach of extension workers. The extension needs of the cotton growers in the country are diversified and extension functionaries required to be updated about new development in cotton technologies. The Information and Communication support for cotton technology transfer to cotton growers in recent time has been beneficial. Seeing the utility of Information Communication Technologies in the Agriculture Sector, the Central Institute for Cotton Research, Nagpur under TMC has executed a extension mechanism "e-kapas network" for effective knowledge transfer of cotton crop from 2013-14 to 2016-17. The project activities were undertaken as per objectives. The database of **35700** cotton farmers of zone 1b of Rajasthan was developed. The voice SMS on cotton POP was started from September, 2013which were delivered on registered mobile nos. of cotton growers. The Voice SMS module was recorded in the computer and sent to registered cotton farmers weekly were sent to the farmers. During the year 2013-14 to 2016-17, 221 SMS were sent. The farmers were found the service very useful. Some of the problems faced in the service were no response from farmers as their mobile no. was on either switch off or not reachable. There is a gap between the farmers mobile numbers uploaded and accepted by the website. Establishment of representative network of registered cotton farmers through e-Kapas network project have helped in intensive pest monitoring, overcoming pest epidemic situation through awareness and quick advisory provided directly to farmers. Wider application of mobile in farm information dissemination should be promoted for timely and precise information to farmers.

Keyword : *ICT, mobile, cotton, Voice message,*

Information Communication Technologies (ICT) has provided new ideas, methods and technology disseminating and improving the knowledge and information among people of different societies. Furthermore, ICTs have helped the people in different sectors of society and given new opportunities for development in all sectors. The term ICTs used to include electronic and print media such as mobile phones, internet, telephone, computer, radio, and television. ICTs have reduced the gap among different communities and together them. ICT diffused information and knowledge among societies especially in rural areas of the developing countries.

Cotton is one the most important and commercial fiber crop in India. It occupies first place in the world by occupying 13 million ha area. India is the third largest producer of cotton in the world with a productivity of only 300 kg / ha, although within the limits of our agro-climatic situations, as against the world average of 558 kg/ha . Cotton is the major and important commercial crop of the zone. Farmers are cultivating this crop from long time and consider it as a backbone of the economy. This crop requires updated technological Knowhow and quality inputs. This type mechanism to disseminate improved technologies of this crop will be of immense utility to farmers. Technology dissemination enhances knowledge and adoption of cotton package of practical by the farmers.

The agriculture based developing nations like India are inventing and releasing new farm technologies from the crop research system, but these technologies have not been successful in bringing breakthrough increase in productivity. There is a criticism about the practicing of Agricultural Extension in the current context of globalization and changing paradigm. The analysis on those TOT efforts revealed that they .were effective in some aspects but handicapped due to inadequate interaction with the research efforts and non-availability of latest technological dissemination tools for ready transfer. Many of them excluded the novel extension methods viz, cyber extension, market led extension, Farmer-led extension and environmental extension for a wider reach. There is an urgent need for developing a TOT model using modern ICTs that can establish a strong linkage between the research and end users to swiftly disseminate the technologies, advisories and thereby create and sustain significant change in the productivity and profitability. The increasing penetration of mobile network and handsets in India, therefore, presents an opportunity to overcome information asymmetry and to make useful information more widely and swiftly available to all cotton growers. Establishment of representative network of registered cotton farmers through e-kapas network project would help in intensive pest monitoring, overcoming pest epidemic situation through awareness and quick advisory provided directly to farmers. Further, training and accessing of web base data in vernacular language (weather, production technology, market, new introduction and price) of entire country to the registered farmers helped then to be better aware of the technology.

These ICT base interventions are farmers' friendly and cost effective solutions tailored to the needs of the farmers have created new channels to communicate through mobile technology in a well connected way in space and time. With the rapid technology development the mobile phones become from a mere communication device to smart phone with an ability to tap a variety of information and services. In this way the ICT tools have permitted quick dissemination of agro-technologies from research /lab to farmers. Lab to field concept has got a boost with the introduction of ICT based tools in agriculture. The study Mobile based extension for cotton growers in North- West Rajasthan has been made to on the utility of the voice SMS under e-kapas with the following specific objectives:

1. To study the profile of cotton growers.
2. To study mobile use pattern of cotton growers.
3. To study the utility& feedback of voice-SMS of cotton.

MATERIALS AND METHODS

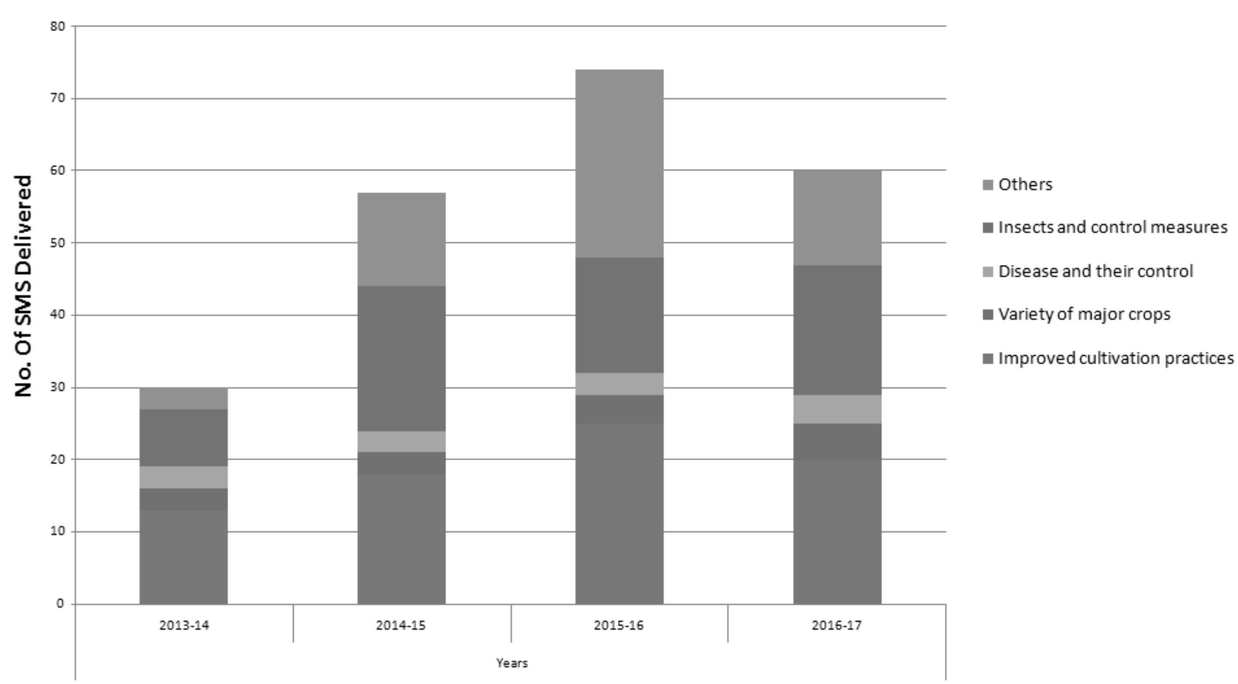
The study was conducted at Agriculture Research Station, Sriganganagar after completion of three year of launching of voice SMS through mobiles to cotton farmers under ekapas network project. A detail analysis was carried out by taking all 35700 farmers beneficiaries of voice SMS. A database of farmers who has been consulted voice calls have been developed & utilized for study purpose. A sample of 100 farmers was taken to collect information on profile; mobile use pattern & feedback of voice SMS. Primary data have been collected by using pre-tested structured interview schedule.

RESULTS AND DISCUSSION

The results of the study have been presented along with tables and discussion on profile of respondents, mobile use of pattern, year wise, Area wise voice SMS sent.

Profile of respondents : The results indicated (table 1) that 91% male farmers and 9% female farmers surveyed under study. More than half 57% of the respondent's age was between 31-50 years old while 22 % respondent's age was below 30 years. The study indicated that

Fig. -1 Area wise details of voice SMS on cotton



the 40 % of the respondents were having metric level of education followed by 26 % having bachelor degree. 22 % of them were having education up to primary level. The respondents were also asked about their marital status the results showed that 88 % of them were married and 12 % were single. Furthermore, the land holding possession of the respondents' reveals that 48 % were falls into medium category (2-4 ha.) and 31 % were falls into large category (>4ha.). Rest 17 % of the respondents were small farmers (< 2ha.). It can be interpreted from the study that better education level and large land holding size indicated good socio-economic status of the farmers. This bears significance influence on their mobile use pattern and awareness of high level adoption of modern recommended package of practices for higher production.

Table 1. Profile of respondents (N=100)

Particulars	Frequency	Percentage
Age		
Young (bellow 30 years)	22	22
Middle (31-50 years)	57	57
Old (More than 50 years)	21	21
Gender		
Male	91	91
Female	09	09
Educational Level		
Illiterate	12	12
Primary	22	22
Metric	40	40
Bachelor	26	26
Marital		
Single	12	12
Married	88	88
Land Holding		
Small (Less than 2 hac.)	17	17
Medium (2-4 hac.)	48	48
Large (More than 4 hac.)	31	31

Mobile use pattern among farmers : The study found (table 2) that almost (100%) cotton farmers consider mobile phone as necessary instrument in today's life. Among the responds 28 % used smart phones. Rest of the farmers were having others type of handset without android application. The investigation found that respondents (98%) use mobile phone for receiving massages include text (54%) and voice massage (46%). Among the respondents under the study (28%) use mobile for getting agricultural information through personal call, SMS calls. The study further analyzed the available network for mobile service by mobile companies and found that Airtel and Idea have wider coverage more than 80%. BSNL and Reliance also have small number of service.

Information need in agriculture reveals that most of respondents require information on crop varieties, irrigation, disease, insect control, seed treatment and weather information. The study found that majority of the farmer preferred twice a week calls (74%) for agriculture information. For getting agriculture information (82%).56% preferred text SMS as compared to voice SMS (44%). Regarding off season SMS massages on mobile phones, majority (71%) preferred dairy enterprises followed by agriculture technology (30%).

Year-wise registered database of cotton farmers : Year-wise registered cotton farmers under the project for cotton voice SMS have been presented in table 3. The database of cotton farmers has developed from September 2013 to 2016 (four year). Year wise registration of cotton growers were 7000 farmers in 2013, 6227 farmers in 2014, 8247 farmers in 2015 and

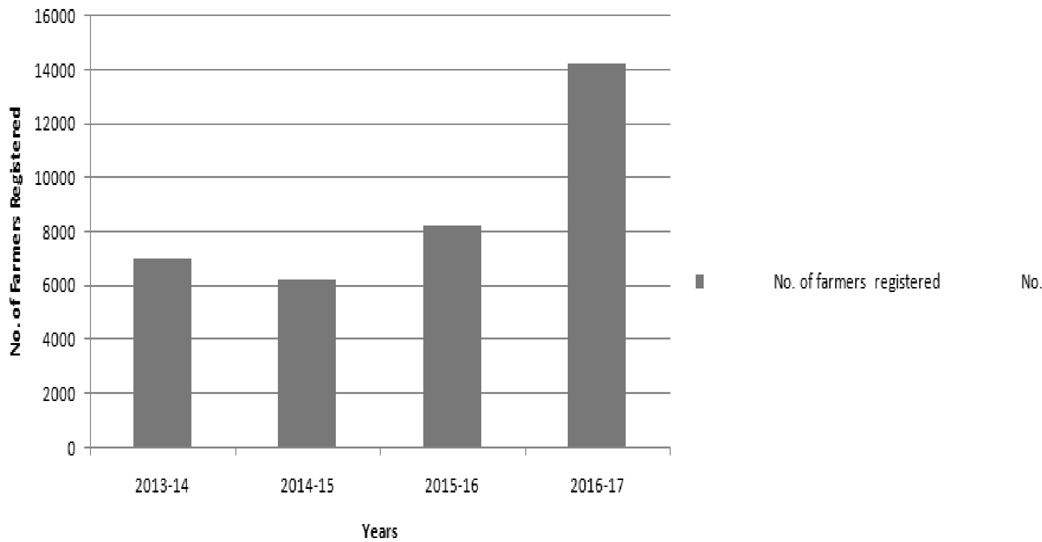


Fig. 2. Year wise detail of farmers registered for Voice SMS

14226 farmers in 2016 under e-kapas network project. The SMS module was recorded in the computer and sent to registered cotton farmers through web based platform.

Cotton Technologies- area wise detail of voice SMS : The voice SMS sent to farmers have been presented in Table 4. The maximum voice SMS sent were on improved cultivation practices (35.64%). This showed that voice SMS on crop cultivation practices so that they can harvest a good yield from their limited resources. Information on seed rate, seed treatment, sowing time, soil treatment, methods of sowing and irrigation practices were provided to farmers through voice SMS. Information on cotton insect management was sent through voice SMS was 28.22 % and on disease was 05.45% of the farmers. Most of the voice SMS were related to major diseases and insects of cotton and their recommended control measures. The major diseases were cotton leaf curl virus (CLCuV), root rot, while the major insects whose control measures were sent to the farmers were sucking pest whitefly, jassid of cotton and bollworms in cotton. Recommended control measures were advised by the expert scientists through voice SMS received by registered cotton farmers.

Year-wise detail of voice SMS : Year-wise detail of voice SMS on cotton have been presented in table 5. The voice SMS on cotton were sent in four year under e-kapas from September, 2013 to March, 2017. An analysis of voice SMS of cotton sent on year-wise showed specific pattern base on start of season of *Kharif* in the area. The maximum voice SMS on cotton

Table 3. Year wise detail of farmers registered for Voice SMS

S. No.	Year	No. of farmers registered	
		No.	Percentage
1.	2013-14	7000	19.60
2.	2014-15	6227	17.44
3.	2015-16	8247	23.11
4.	2016-17	14226	39.85
	Total	**35700**	**100**

Table 2 Mobile/Internet use pattern among cotton farmers (N=100)

S. No.	Variable	Frequency (F)	Percentage (%)
1	Mobile phone is necessary in today's life	Yes = 100	100
		No = 0	
2	Mobile is good Instrument	Yes = 100	100
		No = 0	
3	Smart phone users	Yes = 28	28
		No = 72	72
4	Mobile phone is used for receiving message	Yes = 98	98
		No = 2	2
5	Which type of message use	Text = 54	54
		Voice = 46	46
		Both(Text & Voice)=11	11
6	Mobile is used for agriculture information	Yes – 28	28
		No = 72	72
7	Received message from any department / Agency / Institute	Yes = 8	8
		No = 92	92
8	Information received though SMS/Calls is useful	Yes = 98	98
		No = 2	2
9	Network Availability	BSNL-4	4
		VODAFONE- 36	36
		AIRTEL- 38	38
		IDEA- 20	20
		RELIANCE- 2	2
10	Toll Free Message facility is required	Yes = 100	100
		No – 0	
11	Information needs in Agriculture 1.Crop Varieties – 582.Irrigation – 553.Disease and Insect Control – 704.Horticulture – 205.Weather – 676. Soil-477.Seed Treatment-498.Mushroom-69.Drip-4710.ALL - 8		
12	Preference of sound for receiving message	Male – 7	14
		Female – 4	4
		Both – 89	89
13	Convenient Time for Calls / SMS	Morning – 22	22
		Evening- 74	74
		Noon – 4	4
14	Frequency of Calls / SMS	Daily – 6	6
		Twice a week – 82	82
		Weekly – 12	12
15	Which type of SMS service better	Voice – 44	44
		Text -56	56

were sent in *kharif* season. This is evident from the pattern of package of practice that farmers are more aware to take technical information at the start of season's *kharif* as there is sowing time of cotton crops and knowledge of critical inputs and scientific management practices of crops.

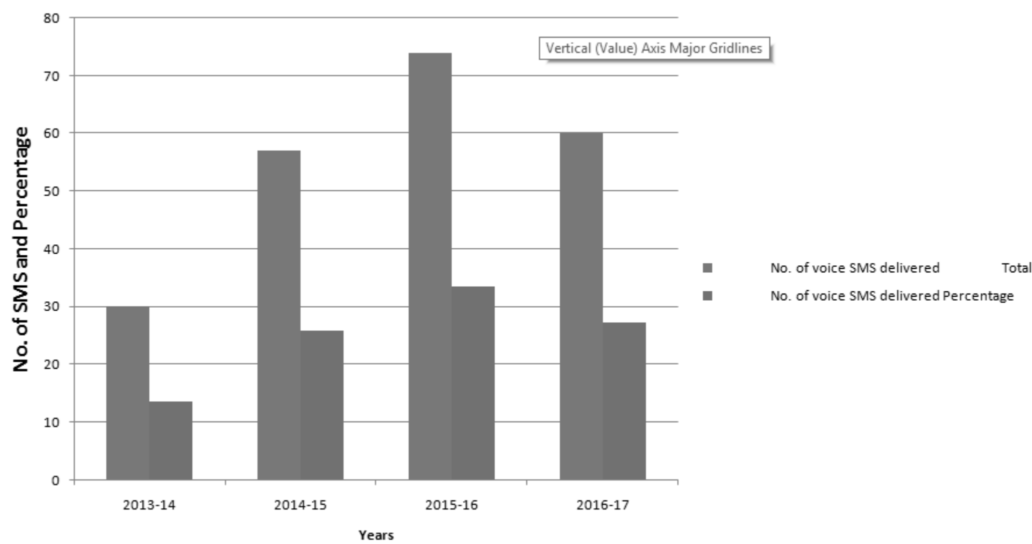


Fig. 3. Year wise voice SMS delivered

Table 4. Area wise voice SMS on cotton

S. No.	Particulars of Query	Total no. of voice SMS delivered					
		2013-2014	2014-2015	2015-2016	2016-2017	Total	Percentage
1.	Improved cultivation practices	13	18	25	20	76	34.49
2.	Variety of major crops	3	03	04	5	15	6.44
3.	Disease and their control	3	03	03	4	13	5.98
4.	Insects and control measures	8	20	16	18	62	28.16
5.	Others	3	13	26	13	55	24.93
	Total	**30**	**57**	**74**	**60**	**221**	**100**

Table 5. Year-wise voice SMS on cotton

S. No.	Year	No. of voice SMS delivered	
		Total	Percentage
1.	2013-14	30	13.58
2.	2014-15	57	25.79
3.	2015-16	74	33.48
4.	2016-17	60	27.15
	Total	**221**	**100**

The feedback from the registered revealed that this extension technique was highly acceptable and helped the farmers to take crucial decisions for crop management in the season. Except few minor limitations, the technology holds high potential to cover each and every farmer and disseminate not only latest technologies related to cotton but in other crops and allied agriculture sectors.

CONCLUSION

Most of the cotton growers found the voice SMS delivered on time, relevant, has good audio quality and good technology content on cotton production technology. Regarding impact of voice SMS of ekapas mobile advisory on adoption of cotton technology, majority of the cotton farmers told that they adopted cotton management practices delivered through voice service. The responses of the cotton growers towards voice call service were very satisfactory and positive. They received voice call SMS weekly without paying any fee. The audio quality of voice SMS was clear and audible. The technical contents on cotton were adopted by them. Some farmers felt the need for information on other important crops of the area under the project. Few farmers preferred text message to voice message as it can the retrieved as and when required. Information on weather, horticulture and market price should be provided along with cotton crop. Some of the problems faced in the service were - No response from farmers as their mobile were either switch off or not reachable or on DND mode.

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Prospects, aspects and scope of organic farming in cotton cultivation in India

RUCHI SONI* AND AJAY SINGH RAJPUT

Regional Centre of Organic Farming, Department of Agriculture and Cooperation, Ministry of Agriculture and Famers Welfare, Government of India, Nagpur - 440 023

**E-mail*: ruchihpau1987@gmail.com*

ABSTRACT : No doubt chemical inputs including fertilizers and pesticides have played a significant role in the green revolution by providing the major plant nutrients, but their harmful impacts on soil health and environment can't be ignored. Harmful impacts of synthetic and conventional cotton farming on the environment and human health are also well known. Around 60 per cent of the harvested cotton weight belong to seed that is further processed to edible oil and rest used as animal fodder that ultimately enters the food chain. Reduced cotton production and increased input costs by using conventional farming, have left several farmers in a debt trap. Moreover, the pesticides sprayed on it not only kill the target pests but also affect beneficial insects pests required for better yield and growth of cotton, which have become a major problem and a serious matter of concern. As a result, these conventional techniques imparting negative effects on human health and affecting ecological balance. In this case, organic farming has emerged like a remedy to bring a long lasting sustainability to the cotton production. It emphasizes to sustain crop production in an eco friendly manner which provides good quality product without any harmful chemical constituents in it. This article represents the aspects and prospects of organic farming in cotton cultivation.

Cotton (*Gossypium* spp.), known as "King of Fibre" or "White Gold", is among the most important commercial crops grown all over the world. In Asia, India contributes major production and cultivation of cotton and accounting for two-third of the global organic cotton production. Two indigenous varieties of cotton *Gossypium herbaceum* and *G. arboreum* are widely grown in India. These varieties are known for their characteristics including resistance to drought, diseases, viral attacks lead to leaf curl disease and a variety of insects-pests with a drawback of low yielding. In 1980s, a high yielding nutrient responsive teraploid cotton variety *G. hirsutum* was introduced which relied on the use of chemical fertilizers and pesticides and hence, led to a modern and effective way of cotton cultivation (Blaise *et al.,* 2004). All the above factors resulted into harmful effects on environment including poor soil health and fertility in modern agricultural systems along with increase in cost production (Greer *et al.,* 2008). It has been reported that World-wide cotton production uses more than 20 per cent of all insecticides used in modern agriculture systems (https://www.fibl.org/fileadmin/documents/en/developmentcooperation/productionsystems/cottonguide-large.pdf). In many areas of the World, irrigated cotton cultivation has resulted into depletion of ground and surface water sources. Many conventional cotton farmers in developing countries including India face financial crisis due to poor soil health, high production costs, and resistant insect-pests affecting the crop with low market value.

Organic farming technologies emphasize the maximum use of natural organic resources like agricultural wastes, crop residues, composts, organic manure, green manure, bio-fertilizers and livestock feed additives and simultaneously minimum use of chemical inputs and growth regulators in the crop production to improve soil health and fertility (Soni *et al.,* 2017). In has been reported that organic systems facilitate greater organic matter content and nutrients status in the soil than the high input agricultural systems (Clark *et al.,* 1998). In organic systems, recycling of green manure and farmyard manure result in the addition of N in soil and reduce the risk of leaching (Halberg *et al.,* 1995). In this scenario, organic farming has become a better alternative to motivate farmers to turn to organic cultivation in order to restore soil health and fertility, reduce production costs, and to get a better amount for their certified organic harvest. Organic cotton occupies only around less than 1 per cent of global cotton production (FiBL organic crop guide) and this eco-friendly farming may help in increasing the cotton productivity and contributes in sustainable agriculture too. Keeping in view the above factors, this article focuses on aspects and prospects of organic farming on cotton cultivation.

Advantages of adopting organic farming for cotton cultivation : Cotton cultivation plays a major role in sustaining the livelihood of around 5.8 million cotton farmers and employment of about 40-50 million people in its processing and trade (Ministry of Textiles report on Cotton fibre). India occupies the largest cotton cultivated area which constitutes about 30% of the global cotton area (Fig 1). Cotton is cultivated over diverse agro climatic conditions and agricultural production systems. Many improvements have been done in cotton production over the lasts 5 decades but the use of chemical inputs leads to prohibitive costs along with negative social and environmental impacts. All the conditions collectively made a need to adopt organic farming for cotton cultivation and these following factors favor its promotion (Kogan, 1998):

Pesticide application : One of the major factors is application of high level of pesticide in cotton cultivation. In present scenario, about 46% of the total pesticide produced in India is used in cotton production, which occupies only 5% of the cultivated area. Irrespective of using such heavy pesticides on the crop, unsatisfactory and deprived pest control is generally found as the main reason for low productivity. It has been documented that around 150000–250000 tones of technical grade pesticides are applied into the cotton ecosystem worldwide every year and for a sustainable environment it is high time to revert this trend.

Broad genetic variability : Cotton offers a wide range of genetic variability with four cultivated species in numerous cultivated races, and considered as a host of varieties and intra-inter specific hybrids. Several cultivars with recompense facilities, low fertilizer requirement and resistance to various insect-pests are available to fit into the organic production system.

Long term crop with abundant scope for compensation : Cotton is semi-xerophyte crop and a forced annual with undefined growth habit. Its ability to tolerate pest-insect attacks and withstand with moisture and nutrient supply is advantageous to minimize yield losses under organic conditions. Its efficiency to absorb nutrient formulations through foliar application is higher in comparison to many other crops. These natural physiological conditions make cotton an ideal crop for organic farming.

Pest management as a major risk in cotton cultivation : The modern agriculture production technology is based on excess use of fertilizers and on chemicals pesticides to control insect-pests, phytopathogens along with weeds and growth regulators. Use of chemicals has resulted into hazards to mankind by affecting environmental conditions, soil health, and agro-ecology and resulting into low profitability in cotton farming.

Consumer interest : Negative impacts created by chemical inputs in environment have also made consumers to be conscious about their lifestyles, food habits and eco friendly garments too. The whole situation prompted the attention of farmers to cultivate cotton organically and demand of consumers for eco friendly and green cotton. There are several advantages of growing cotton organically by using organic inputs than conventional farming and few are discussed in the Table 1 (FiBL organic cotton guide).

Organic cotton and major elements for its cultivation : During the cultivation of organic cotton, the use of chemical fertilsers and pesticides prohibited along with the use of genetically modified seeds. Organic cotton seeds

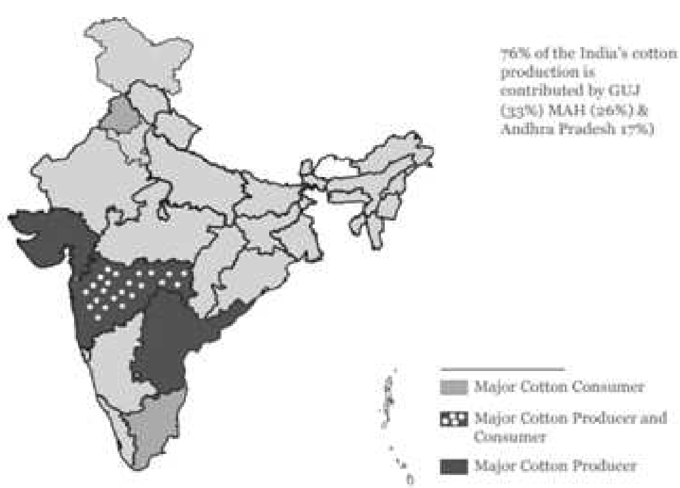

Fig. 1. India's major cotton producing and consuming states (source Yes Bank Research)

Table 1. Advantages of growing cotton through organic farming system than conventional

Factor affecting	Organic farming system	Conventional framing system
Environment	Increased biodiversity	Pesticides kill beneficial insect-pests
	Eco-balance between beneficial pests-insects	Pollution of soil and water
	No pollution	Resistance of pests
Health	No health risks	Accident with pesticides
	Healthy organic food	Chronic diseases (cancer, infertility, weakness etc.)
Soil	Improved soil health and fertility and crop rotation regularly	Risk of declining soil fertility and poor crop rotation
	Positive relation between buyer and farmer	Lack of buyer's honesty to the farmers
Market	High market value for organic produce	Dependency of farmers of general market rates
	Framers recognized as groups	Individual farmer
Economy	Low cost for input hence low financial risks	High production cost
	Satisfying yield once soil health is improved	High Financial risk

are recommended. Organic cotton is unintentionally grown in many areas of countries (Table 2). Use of animal or food waste manures and crop rotation are also implemented in organic cotton production. It also emphasizes the use of bio-pesticides and pheromone traps to control insects, pests and weeds in order to conserve beneficial bio-diversity. Some key elements of the technology developed for organic farming are mentioned below (Kairon *et al.,*1998)

Table 2. Different varieties of cotton grown organically in India

S. No.	Location	Variety
1	Andhra Pradesh	Nandicum
2	Gujarat	Wagad/V-797
3	Karnataka	Jayadhar/Suyodhar
4	Khandesh	Y-1
5	Madhya Pradesh	Maljari

Varietals selection : Some hybrids that grow well in chemical fertilizers are not always suitable to this type of cultivation. Straight varieties such as ANJALI (LRK.516), PKV.08, LRA 5166, DHY.286, RAJAT amongst hirsutum cottons and AKA 8401 in arboreum (*Desi*) cotton are more suitable for organic cultivation.

Seed rate and sowing : 25 kg/ha of seeds with 75x15 cm spacing ensures the population of 85000-90000 plant is recommended. Fuzzy seeds that are mixed with wet clay containing some amount of FYM or vermicompost are ideally chosen.

Intercropping : Intercropping with one row of cowpea (*Vigna inguiculata*) should be planted between two cotton rows for being incorporated at tendril stage to improve the soil fertility.

Crop rotation : Crop rotation with legumes, cover cropping, green manuring, compost (vermicompost, trichocompost, FYM), bio-mulches, biofertilizers are generally employed to improve soil fertility status.

Weed management and pest management : Weed management is mainly achieved through preventive techniques including selection of perennial weed free field, clean seeds, completely decomposed compost/ FYM, crop rotation, cover cropping, mulching, smother crop etc. and soil solarizataion. Pest management is achieved through the selection of pest resistant varieties, conservation of natural enemies and in adequate inhibition of predators, parasites and phyto pathogens by using exclusively organic supplements.

Organic agriculture in India and its regulatory mechanism : National Programme on Organic Production (NPOP) governs the regulatory mechanism based on two acts; one for export and another for domestic markets (http://ncof.dacnet.nic.in/objectiveandimplementation/ObjectivesandImplementationcomponents.pdf). NPOP notified under Foreign Trade Development and Regulation Act (FTDR) takes care of the export necessities and also has gain equivalence by European Union and Sweden along with USDA acceptance for its conformity appraisal system. As per the results, the organic merchandise certified by any Indian accredited certification agency under NPOP can be exported to the countries including Europe, Sweden and USA without the prerequisite of re certification. The NPOP has also been notified under Agriculture Produce Grading, Marking and Certification Act (APGMC) to regulate the organic produce requirements of import and domestic market. Regulatory body of NPOP under FTDR act is Agricultural and Processed Foods Export Development Authority (APEDA) under Ministry of Commerce and NPOP under APGMC act is Agricultural Marketing Advisor (AMA) under Ministry of Agriculture (Ramesh and Dhananjaya, 2016). APEDA have formulated standards similar to International Federation of Organic Agriculture Movement (IFOAM) and Codex Elementaris of European Union manual which provided the important principles for conversion of conventional into organic cultivation. At present, there are 23 accredited certification agencies working for the process of certification and granted by National Accreditation Body (NAB).

Traditional liquid organic manures for organic cotton cultivation : Besides that, they have been proven to improve the physical-chemical and biological properties of the soil which further increases its fertility and productivity. They play a key role in improving both the structure and texture of the soils, conserve moisture and also increase its water holding capacity and also helps in maintaining C:N ratio in the soil. The traditional cow product-based organic inputs/organic manures are prepared in a less expensive manner and are very effective in maintaining the soil health by augmenting population of microflora so that to make fix nutrients available to the plants (Bhat *et al.,* 2017). Some of the liquid organic manures helpful in cotton cultivation are mentioned below:

Panchagavya : The formulation increases resistance against pests and diseases and nematodes, microbial population of soil will be increased and reduces evaporation loss and enhances water use efficiency. Panchagavya contains many useful microorganisms such as fungi, bacteria, actinomycetes and various micronutrients (Somasundaram and Amanullah, 2007). The ingredients used are cow urine, cow dung, cow ghee, cow milk, cow curd, prepared over a period of 34 days (Source National Center of Organic Farming, Ghaziabad). The formulation act as tonic to enrich the soil, induce plant vigour with quality production. Diverse microbes detected in panchagavya are fungi, bacteria, Lactobacillus, total anaerobes, acid formers and methanogens. Jayanth Kumar *et al.,* (2017) reported that organic priming methods especially panchagavya showed significance difference in germination, length, fresh weight, dry weight and vigour index of cotton seedlings in comparison to control. The treatment also helped to improve the quality of cotton seeds which are cost effective and economic, nontoxic, eco-friendly sources.

Enriched panchgavya (Dashagavya) : Enriched panchgavya (Dashagavya) are used to promote plant growth and act as soil enricher and contains same ingredients as that of panchagavya (Gopakkali and Sharanappa, 2014). Cow dung 5 kg., cow urine 3 lit. (liters), cow milk 2 lit., curd 2 lit., cow deshi ghee 1 kg., sugarcane juice 3 lit., tender coconut water 3 lit., banana paste of 12 fruits and toddy or grape juice 2 lits are used. Mix cow dung and ghee in a container and ferment for 3 days with intermittent stirring. Sugarcane juice can be replaced with 500 g jaggery in 3 liter of water. In case of non-availability of toddy or grape juice 100g yeast powder mixed with 100 g jaggery and 2 liter of warm water can also be used. After 18 days of incubation at room temperature, dashgavya is diluted with 100 liter water and used as soil treatment and foliar spray (Source National Center of Organic Farming, Ghaziabad).

Sanjeevak : Sanjeevak act as an effective soil conditioner and helps in improving soil fertility and health along with maintaining beneficial microbial population in the soil (Bhat *et al.,* 2017). 100 kg cow dung, 100 lit cow urine and 500 g jaggary are mixed in 300 lit of water in a 500 lit closed drum. Ferment for 10 days. Dilute with 20 times water and sprinkle in one acre either as soil spray or along with irrigation water (Source National Center of Organic Farming, Ghaziabad). Sanjeevak was reported to have very pronounced effect on root growth in case of crops like cotton as observed by Phate *et al.,* 2014).

Jivamrat : Jivamrat also act as a soil enricher and helps in the improvement of soil fertility and health (Bhat *et al.,* 2017). For its preparation, mix cow dung 10 kg, cow urine 10 lit, jaggary 2 kg., any pulse grain flour 2 kg and live forest soil 1 kg in 200 lit of water. Ferment for 5 to 7 days. Stir the solution regularly three times a day. Use in one acre with irrigation water (Source National Center of Organic Farming, Ghaziabad).

Amrutpani : Amrutpani is applied to crop in order to enhance the biological efficiency of crop plants and food production for eco-friendly nutrient and disease management and improve soil health in organic farming (Naresh *et al.,* 2018). It is prepared by mixing 10 kg cow dung with 500 g honey to form a creamy paste. 250 g of cow desi ghee is added and mix at high speed. After dilution with 200 lit of water, sprinkle this suspension in one acre over soil or with irrigation water. After 30 days apply second dose in between the row of plants or through irrigation water Source (National Center of Organic Farming, Ghaziabad).

Vermiwash : The application of the vermiwash into the soil significantly influences the biogeochemical cycles of nitrogen and phosphorus with the help of beneficial microbes (Chattopadhyay, 2014). For its preparation, a pitcher was filled with a layer of sand along with a layer of dry biomass and a thick covering of cow dung. As the material was filled up to 2/3 of pitcher, 200-300 adult earthworms (*Eisenia foetida*) were added. Another pitcher filled with water was placed over it so that water got trickled drop wise in the pitcher having earthworms. Another empty pitcher was placed below it to collect the brown colored leachate, vermiwash (Source National Center of Organic Farming, Ghaziabad).

Beejmirit : Beejmirit is generally used in seed treatment or priming and contributes in improving plant growth. Ingredients used are cow dung (50 gm), cow urine (50 ml), cow milk (fresh) (50 ml), lime stone (2-3 gm) and water (1L). They are mixed thoroughly preferably in plastic/glass jar and keep overnight and used (Source National Center of Organic Farming, Ghaziabad).

Non traditional organic manures for organic cotton cultivation : A large number of products generally referred as soil and plant organic additives are of non traditional characteristics and available to be used as eco-friendly alternative in the organic farming system. These are the formulations of beneficial microbes like bacteria or fungi or contain busters for enhancing the population and activity of microorganisms that balance favorable soil conditions to improve soil’s physical and chemical conditions that further result in improved cotton growth and crop productivity.

Biofertilizer : These preparations contain living or latent cells of microbes capable of transforming the unavailable form of naturally occurring nutrients in to a form which can be easily assimilated by the plants. It can replace 20–50 per cent of chemical fertilizer N and 15–25 per cent of phosphatic fertilizers, they are cheap and highly cost effective, activates soil biologically and increasing natural fertility of soil and do not cause any harmful effect on soil and environment. Yupeng *et al.,* (2017) reported high nitrogen fixing, phosphate solubilizing, Phytohormones, producing isolates of *Azotobacter*, *Azospirillum*, *Acetobacter* and *Pseudomonas* showed significant higher root/ shoot length and ultimately increase in yield of cotton crop.

Mycorrhizae : Mycorrhizae are referred to as the symbiotic association of fungus with roots of vascular plants. Mycorrhizae possess the main advantage of stimulating extension of root system to the host plant, penetration of fungus in host plant and expanding the network of root system in the soil and facilitating an enhanced phosphorus uptake, trace metals, influence water uptake and nutrients uptake. Arbuscular Mycorrhiza fungi form a symbiotic relationship with cotton roots in even the salinated soil and enhance nutrient and water uptake of plant and growth of the plant as well as cotton yield (Khaitov and Teshaev, 2015).

Role of green manure intercropping in organic cotton cultivation : Incorporation of leguminous crops *viz., dhaincha*, sunnhemp, *mung* etc., are used as green manure and impart the beneficial effect on soil fertility. Intercropping and incorporation of green manure supply nitrogen and increase the nutrient efficiency and cotton productivity (Dubey *et al.,* 2015). Cotton is a wide spaced and initial slow growing crop and therefore, offers scope for intercropping green manure. As cotton and plant protection are indivisible, green manure intercrop serves as plant protectant. The intercropping green manures and unconventional green manures significant enhance the growth, nutrient contribution, pest control and productivity of cotton (Vaiyapuri *et al.,* 2008)

Organic cotton superiority over *Bt* cotton in India : Organic cotton is incomparably superior to genetically modified Bt cotton. It is more environmentally friendly, better for the health of the community and for the local economy than GM cotton (www.grain.org/research_files/bt_vs_npm.pdf). These *Bt* varieties all carried Monsanto's *cry1Ac* gene and display low genetic diversity; providing early pest resistance (Jayaraman *et al.,* 2005). It was reported that organic cotton farmers grew many varieties including Brahma, Maruthi, Dasera, Gemini, Sumo, Tulasi, Bhagya, Durga, Kranthi in comparison to Bt- cotton users. Moreover, *Bt* cotton was reported more prone to pests and diseases (Gala *et al.,* 2005). Organic cotton growers observed a lower incidence of insect-pests attack than Bt-cotton grower (Kranthi, 2012). A majority of organic cotton farmers reported low incidence of spotted bollworm, American bollworm, and tobacco Caterpillar. Beneficial insects prevail on organic cotton rather Bt-cotton. Xue *et al.,* (2002) reported that the Bt cotton endotoxin destroys many beneficial insects, and that has a knock on effect on the birds and small mammals that are the natural predators of these insects. Organic cotton has been gained farmers attention because of the factors discussed above proved as an appropriate option to maintain the sustainability.

Future Scope : A major obstruction in the promotion of organic cotton farming is observed in the lack of a local accredited certifying agency and the appointment of overseas companies at high cost. Now many certifying agencies are available in India to certify the organic product. The growth of organic cotton cultivation in this country depends on the following conditions include evaluation of market demand for organic cotton worldwide, research for identifying cotton varieties suitable for organic cultivation and for preparing location-specific organic protocols for commercial cultivation keeping in view the need for conservation and optimal utilization of natural resources while maximizing productivity. Future research will bring further insights on agronomic and economic performance of the organic farming systems on cotton productivity. Development of "Brand India" specifically for textile products from organic cotton is also a matter of concern.

CONCLUSION

Organic farming relies on holistic

approaches for the cultivation of organic cotton that integrates various elements together, including social, environmental, economic, and technological aspects. However, cotton productivity is reported as significantly improved through organic farming systems at lower input levels, which can make it more profitable. Evaluation of specific organic manures and their proper and accurate validation for organic cotton production can be sustainable and productive and deliver real benefits to the farmers.

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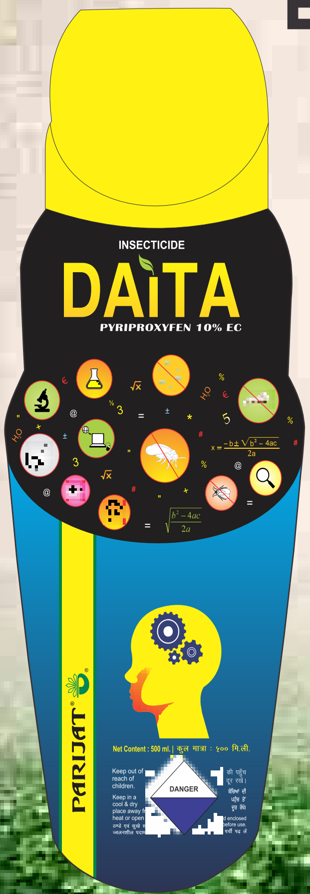

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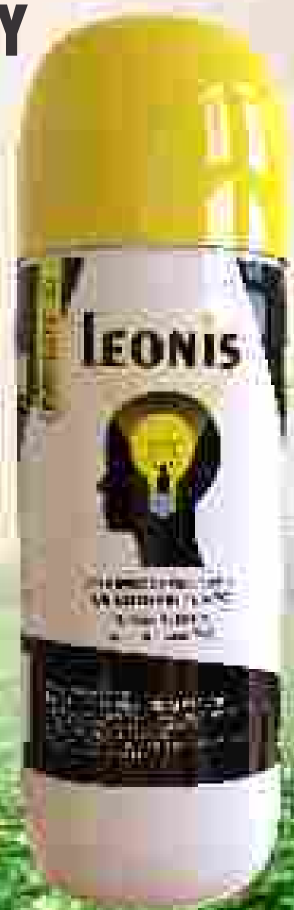

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