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Recent advances in use of growth regulators on cotton – A review

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ABSTRACT : Cotton hybrids generally have robust architecture, greater horizontal (particularly 1st internode of sympodia) and vigorous growth with more plant height which leads to more vegetative growth and mutual shading resulting in shedding of reproductive parts. Excessive vegetative growth also reduces yield and encourages attack of insect pests. Various growth retardants like MH (Maleic hydrazide), ethylene (Ethephon), Cycocel (Chlorocholine chloride), Alar (Daminozide), Pix (Mepiquat chloride) have been found to reduce vegetative growth such as plant height, leaf area, internodal distance and enhanced sympodia and bolls/ plant, boll opening percentage, ginning percentage, seed oil, lint index, seed index, boll weight and seed cotton yield etc. but response varies with the location, climatic conditions, doses and time of application of various growth modifier (growth retardants). The present review deals with the influence of modification of morphoframe through growth modifier on growth, yield and quality of cotton.

Key words: Fibre quality, growth retardants, yield

Cotton (*Gossypium* spp L.) is one of the predominant fibre crops and plays a pivotal role in agriculture, industrial development, employment generation and economic development of India. It is also called as "King of Fibres" and "White Gold" due to higher economical value among all cash crops in India. Cotton is gradually assuming the status of a preferred fibre even for fashion fabrics. Cotton cultivation needs to be sustainable, offering livelihood security to millions of people in the country. In India an estimated 4 million farmers and about 60 million people depend on cotton production and textile industry to make their livelihood. Cotton is the most important cash and commercial crop contributing nearly 75 per cent of total raw material needs of textile industry in India. Textile industry is the number one export enterprise in the country earning revenue of over $ 8.5 billion. Hence, it is also called as 'White Gold', and plays a vital role in the economic development of the country. The species of *Gossypium* have seeds which are densely covered with long usually white hairs, forming the material known as cotton. Plant growth regulators are known to modify the source to sink relationship and increase the translocation and photosynthetic efficiency resulting in increased square and boll retention and boll setting per cent.

About 65 per cent cotton cultivation in India is under rainfed conditions. Cotton suffers from various biotic and abiotic stresses right from the germination to maturity. The growth during the seedling establishment phase plays an important role in yield realization. A good plant frame provides sufficient space for holding and catering the needs of the reproductive parts during the later part of growth. Under Indian conditions, the crop experiences initial water logging followed by sucking pests. Both these stresses cause considerable damage to the plant leading to stunted growth. As the present day cotton genotypes are photo insensitive, they start producing reproductive parts irrespective of the environmental and physical conditions by 40-

45 days after sowing. Hence, sufficient morphoframe does not develop on the plant to hold the reproductive parts. This is most so in *Bt* cotton where then is early shift to reproductive phase due to inbuilt protection from insect damage. This may lead the plants forced maturity or to reduction in boll setting. Whereas, in irrigated and higher rainfall receiving areas, development of excessive vegetative growth leads to low reproductive load and fruit set thus by which the yield is reduced. Similarly physiological disorders like natural shedding of fruiting bodies, leaf reddening, bad opening of bolls contributes to low yield. The cotton plant has perhaps the most complex structure of any major field crops. Its indeterminate growth and sympodial branch often defies analysis. Physiological efficiency of the plant holds the key for ideal performance of the crop in terms of growth, development and yield. However, efficiency is governed by many biotic and abiotic influences. Once an ideal genotype for a particular region is identified in terms of duration, productivity, growth habit and compatibility in the overall cropping system, the endeavour should optimize the yield realization through appropriate management methodologies including nutrient, moisture, insect pests, diseases and physiological maladies affecting the crop. Plant growth regulators have the potential to promote crop earliness, square and boll retention, higher nutrient uptake and keeping vegetative and reproductive growth in harmony to improve lint yield and quality (Kerby *et al.*, 1993). Several naturally occurring hormones work in the cotton plant to adjust plant growth. When plant growth regulators are applied to the cotton plant, they work in much the same way as the natural regulators already present. In many ways, they supplement or destroy the natural hormone. They often work together in ratios and concentrations to regulate growth. Relatively little is known about hormonal control of cut out but based on established effects of the hormones, it is thought that auxin, cytokinins and gibberellins promote growth and delay cut out. Abscisic acid, on the other hand, promotes cut-out as it inhibits growth and prolongs bud dormancy. Various growth regulators have been applied in cotton in attempts to set more bolls, limit vegetative growth or terminate fruiting. However, the performance of plants following the application of growth modifiers (growth retardants) is not always predictable (Kerby, 1985).

Cotton plays a dominant role in the industrial and agricultural economy of the country. The productivity of cotton in India is low as compared to world average. Introduction of *Bt* cotton in India after 2002 proved to be a turning point for cotton production and productivity in country. More and more farmers are resorting to *Bt* cotton leaving behind traditional hybrids. *Bt* hybrids are expected to retain more bolls at early growth stage because of better insect control over their non *Bt* counterparts. Developing bolls have a greater demand for photosynthetic and thus plants with higher boll load have greater inter organ competition for photo-assimilates (Guinn, 1985). This higher fruit load appears to be a major factor which causes slow growth of flowering and decreased boll retention further (Peterson *et al.*, 1978). It is important in view of fact that in cotton hybrids, the plant frame doesn’t develop fully due to early switch over to reproductive phase. An attempt has been made to present a brief review of research work done in India and abroad on these aspects here under.

RESEARCH REVIEW

Effect of PGR on physiological characters : Pettigrew *et al.,* (1993) observed that spraying of ethephon 0.28 kg/ha resulted in significantly lower Crop Growth Rate (CGR), Relative Growth Rate (RGR) and Net Assimilation Rate (NAR) as compared to check plots in cotton genotypes. Prakash and Prasad (2000) showed that the growth retardant chloromequat chloride at 50 and 100 ppm reduced the LAI over control in cotton. Prasad and Prasad (1994) found that the leaf area was lowest when applied with Cycocel at 50 ppm on cotton *cv.* Pusa 31. In contrast, Koler *et al.*, (2010) showed application of naphthalene acetic acid treatments (10, 20, 30 ppm) and observed that higher absolute growth rate (AGR) and crop growth rate (CGR). At initial stage (60-90 DAS), higher relative growth rate (RGR) was recorded with naphthalene acetic acid (NAA) over other growth retardant treatments in interspecific hybrid cotton. Similarly Hunnnur *et al.,* (2011) reported increased in growth parameters like LAI, CGR and LAD with the application of growth retardant *i.e.* mepiquat pentaborate at 1000 ppm in cotton *cv.* JK 99. Thakare *et al.*, (2011) highlighted from experiment that increased leaf area index (LAI) due to application of ethylene 45 ppm at square initiation stage in *Bt* cotton. Koler *et al.,* (2011) stated that the foliar spraying of mepiquat chloride 50 ppm at 90 DAS increased leaf area compared with cycocel and control in cotton. However, Zhao and Oosterhuis (2000) indicated that the physiological process like photosynthetic rate, stomatal conductance, transpiration rate and specific leaf weight increase with sprayed growth retardant Pix plus at 293 ml/ha in cotton. Quite the opposite application of mepiquat chloride 50 ppm at 90 DAS improved photosynthesis, transpiration, stomatal conductance and net assimilation rate (NAR) compared with chlormequat chloride in hybrid cotton *cv.* DHH 11 (Kumar *et al.,* 2005) and Kumar *et al.,* (2001) found that photosynthesis rate, transpiration rate and stomatal conductance decreased when the applied with ethrel 50 mM at 60 days after sowing in cotton *cv.* H 777.

Effects on growth characters : Rowland *et al.*, (1974) studied the effect of foliar application of growth retardants *viz.,* MH, CCC, TIBA, NAA and ethylene in cotton. In the investigation, MH and CCC were found more effective in decreasing plant height. In contrast De Silva (1971) noticed that decreased monopodial branches in cotton *cv.* Stato 65 when plants were treated with growth retardant CCC (125 or 250 ppm) at 38, 59 and 85 days after emergence.

Foliar application of ethephon 200, 400, 1000, or 2000 ppm caused shedding of young leaves, bolls and flower bud. However, bolls on treated plants increased to grow and matured rapidly compared to untreated control in cotton Anonymous (1977). Abdallah and Mohmoud (1978) reported that application of growth retardant CCC (50, 100 and 200 ppm) in cotton *cv.* Giza 75 decreased the internodal length and sympodial branches in cotton.Reddy *et al.*,(1990) reported that application of mepiquat chloride at 49 g/ha reduced plant height, main stems, vegetative branches, fruiting branches and node formation in cotton. Pettigrew *et al.*, (1992) studied the effect of ethephon on 2 genotypes (DLP 50 and MD 65-11) of cotton. The results indicated that ethephon (2.8 kg/ha) application increase main stem nodes and decreased plant height over the control treatment. Mahmaud *et al.,* (1994) in a pot experiment on cotton sprayed with 100, 300, 500 ppm ethrel and 1000, 3000, 5000 ppm. Alar found decreased plant height at

80 or 94 days after sowing.Another experiment conducted by Ahmed (1994) observed that there was increased in sympodia and flowers/plant when plants were sprayed with CCC 100 ppm in cotton.

Prasad and Prasad (1994) indicated that plant height was lower with CCC at 50 ppm spray which differed significantly from other plant growth regulators and water spray on cotton *cv.* Pusa 31. Singh and Brar (1999) observed higher leaf defoliation when applied with ethrel and Thidiazuron 75 g/ha as compared to untreated control in cotton. Zhao and Oosterhuis (2000) studied the effect of 2 growth retardants on physiological traits in cotton and found that the foliar spray of Pix plus and mepiquat chloride at 293 ml/ha decrease plant height than untreated control in cotton *cv.*Suregrow 125. Zulfiqar *et al.*, (2003) found that plant height increased with ethylene application (60 kg/ha) in cotton *cv.* BH 36. Kumar *et al.,* (2005) recorded increased in plant height and leaf area when applied with mepiquat chloride 50 ppm at 90 DAS in cotton.

Buttar and Agarwal (2004) reported the reduction in vegetative growth such as plant height, leaf area, internodal distance due to application of growth retardants like ethrel (ethephon), Pix (mepiquat chloride), cycocel (chlormequat chloride) and Alar (daminozide) in cotton. Prakash and Prasad (2000) noticed that the foliar spray of chloromequat chloride at 50 and 100 ppm reduced the plant height significantly over the control in cotton. Norton *et al.,* (2005) reported that application of 20 gallons/ac Pix to cotton plants provided balance between reproductive components (Squares, flowers, bolls) and vegetative components (leaves, stem, roots). A supportive finding with Niakan and Habibi (2013) observed that the Pix effect as plant growth regulators on *Gossypium hirsutum* L. cv Ci Ocra and showed that in pot condition in photoperiods 20±2°C and 14h light/10h dark. After 80 days, Pix was sprayed in different concentrations include 0 (control), 0.5,1, 1.5, 2 L/ha twice within 10 days on shoot of cotton plants and reported that Pix different treatments decreased stem length, leaf number and leaf area in comparison with control. Also Pix in higher concentration reduced shoot to root rate and nodes number in cotton. Also recorded reduce plant height due to pix plus Gonias *et al.*, (2012). An experiment conducted by Gupta and Chauhan (2005) tested that foliar sprays with different concentrations of ethrel delayed flowering when the application of 0.3 per cent ethrel as chemical hybridizing agent for foliar spray on *Gossypium hirsutum* L. var. Pusa 846. However, all the treatments of 0.2 and 0.3 per cent ethrel exhibited significant increase in the flowers/plant in *G. hirsutum*. Similarly, Gupta and Chauhan (2006) observed that foliar application of 0.2 and 0.3 per cent ethrel significantly increased the flowers/plant in *G. hirsutum* var. Pusa 846 when 2 varieties (*G. hirsutum* var. Pusa 846 and *G. arboreum* L. var RG 8) were tested. Pandey *et al.,* (2003) recorded that maximum flowers when the foliar application of ethrel 5 ìM at reproductive stage (55-60 days after sowing) in cotton *cv.* H 777. Bardhan and Kumar (2010) studied the foliar application of ethylene (30 and 45 ppm) at square initiation stage. The results indicated that application of 45 ppm ethylene significantly increase plant height as compared to control in cotton hybrids. Similarly, Thakare *et al.*, (2011) observed that foliar application of ethylene at 45 ppm at square initiation stage resulted in increase in plant height as compared to control in *Bt* cotton hybrids. Kumari and George (2013) reported that increased plant height and sympodia/plant when sprayed with ethrel 45 ppm at 35-45 DAS as compared to control in *Bt* hybrids.

A study was conducted on the effect of different plant growth regulator *viz.,* mepiquat pentaborate, chloromequat chloride, mepiquat chloride in *Bt* cotton *cv.* JK 99 by Hunnnur *et al.*, (2011) which revealed that application of mepiquat pentaborate at 1000 ppm significantly increased plant height compared with all other treatment in cotton. In contrast Wang *et al.,* (2014) at China Agricultural University, Beijing, China observed that there was shortening the internodes and reducing plant height/plant in cotton when plants were treated with mepiquat chloride.

Effect on fruiting forms : Pettigrew *et al.*, (1992) in a study an effect of ethephon on 2 cotton genotypes indicated that ethephon (2.8 kg/ha) application increased main stem nodes as compared to control treatment in cotton. El Antably and El Atta (1992) mentioned that the application of MH 100 ppm in 1990 and 50 ppm of the same substance in 1991 showed significantly increase in fruiting branches/plant and increase the vegetative branches/plant than other treatment and the control in Giza 75 cotton when application with 100 ppm MH in cotton. Henneberry *et al.*, (1992) reported that the nodes of first fruiting branches with an open or green boll were higher in 1.12 kg/ha ethephon treated plots as compared to control in cotton *cv.* Deltapine 61. Zhao and Oosterhuis (2000) reported that foliar spray of Pix plus and mepiquat chloride at 293 ml/ha decreased main stem node than untreated control plant. Buttar and Agarwal (2004) found increased sympodia/plant in cotton with the application of ethrel, Pix, cycocel and Alar. Bardhan and Kumar (2010) observed the effect of foliar application of ethylene (30 and 45 ppm) at square initiation stage and reported significantly increased main stem nodes, sympodia and fruiting forms with the application of ethylene at 45 ppm as compared to control and ethylene 30 ppm irrespective of cotton hybrids. Similarly, Thakare *et al.*, (2011) found that the foliar spraying of ethylene at 45 ppm at square initiation stage increased the fruiting forms and sympodia compared to control in *Bt* cotton *cv.* JKCH 99. Kumari and George (2010) noted that significantly higher sympodia/plant when foliar sprayed with 30 ppm ethrel at square initiation stage, but it was at par with application of 45 ppm ethrel in *Bt* cotton. The foliar spraying of 500 ppm Maleic hydrazide at 85 DAS recorded significantly reduced plant height and increased sympodia as compared to control in cotton *cv.* Bunny *Bt* (Anonymous 2011[h]). Hunnnur *et al.,* (2011) found that the sympodial branches, nodes and stem girth increase with mepiquat pentaborate application (1000 ppm) in cotton. Thakare and Kumar (2012) studied the effect of foliar application of ethylene at 45 ppm and found higher bolls in the first and second position of the fruiting branch in *Bt* hybrids as compared to non *Bt* hybrid. Similarly, Kumari *et al.,* (2012) observed increased sympodial branches when applied with ethrel 30 ppm at 35-45 days after sowing in cotton hybrids. Kumari and George (2013) showed that application of ethrel 45 ppm at 35-45 DAS resulted in increased bolls/plant, seed cotton yield and dry matter production (kg/ha) as compared to control in *Bt* hybrids.

Buttar and Singh (2013) also reported increase in sympodia with application of ethrel 2500 ppm at 145 DAS in *Bt* cotton hybrid *cv.* RCH 134. Chaudhari *et al.,* (2013) noted similar effect with 500 ppm Maleic hydrazide at 85 DAS in Bunny *Bt*.

Effects of PGR on crop phenological characters : According to Lipe and Morgan (1973), ethylene a gaseous hormone is the main cause of premature flower and fruit shedding in cotton. Agakishiev and Pal'vanova (1976) reported that spraying of ethrel 0.05 per cent on cotton plant during flowering stage accelerated crop maturity in cotton. Kandasamy (1980) indicated that spraying of Gramoxone 1.5 to 3.5 l/ha as defoliant on cotton *cv.* MCU 9 had significantly advanced the harvesting and increased earliness index of cotton than control. King *et al.,* (1990) reported that ethephon applied to prebloom cotton at the rates of 0.34 and 0.68 kg/ha delayed flowering for approximately 3 week, after which rates of flowering were higher in ethephon treated as compared to untreated plots in cotton. Similarly, Henneberry *et al.*, (1992) recorded delayed flowering due to application of ethephon 1.12 kg/ha in cotton.

Kennedy *et al.*, (1991) observed that foliar spray of ethephon (0.28 kg/ha) on super okra cotton removing early squares and resulted delayed the initiation of fruiting, which continued into a delayed crop maturity. Fruiting occurred more rapidly in square removal treatments than control. Leonard and Pinkas (1972) reported that applied the C_2H_2 producing chemical ethephon either directly to square or over entire plant to abscise squares on lower fruiting branches and found that application of ethephon promoted squares shedding and delayed floral initiation by approximately 4 main stem nodes in the most effective in cotton. A study on the effect of different growth regulator and defoliant *viz.,* Cycocel, NAA, GA_3, ethrel and Thidiazuron (0, 75, 150 and 225 g/ha) in cotton carried out by Singh and Brar (1999) at Ludhiana reported that application of ethrel and Thidiazuron 75 g/ha significantly increase earliness index and crop maturity in cotton. Brown *et al.,* (1999) evaluated the effect of foliar application of Maleic hydrazide, ethephon, chlormequat (CCC) and Cyclanilide and observed that ethephon at 0.2 lb/ac and Cyclanilide at 0.1 lb/ac was given significantly higher upper canopy fruit shedding percentage and boll weight than the control in cotton *cv.* NuCotn33B. Mohamed (2009) revealed that application of ethrel 5, 10 and 20 ppm increased flowers in 2 seasons in cotton *cv.* Brakat 90.

Effect of PGR on yield contributing characters : Singh (1971) found that only H 14, out of 3 cottons H 14, F 320 and J 34 (G. *hirsutum* L.) was given significantly increase yield of *kapas* when treated with CCC after 80 days of sowing. However, Singh and Singh (1977) found that the foliar application of ethrel at 500 ppm gave significantly increased bolls, boll weight and seed cotton yield compared to untreated control in cotton *cv.* H-14. Kittock *et al.,* (1973) observed that spraying on cotton plants with ethephon at 1.12 kg/ha reduced the green immature bolls remaining after harvest by 98 per cent in cotton. Agakishiev and Pal' Vanova (1976) found that the foliar application of ethrel 0.05 per cent showed increase yield in 1st picking of cotton. However, seed cotton yield was not affected. Similarly, Scott (1990) noted that the foliar application of ethephon increased seed cotton yield in the first harvest of cotton *cv.* DES 119 and DPL 20 and foliar application of ethrel 3000 ppm at 145 days after sowing increased seed cotton yield in first picking and recorded highest earliness index as compared to control in cotton *cv.* Bunny *Bt* (Anonymous 2010[a]). Singh and Tripathi (1977) noted increased bolls opening percentage, bolls and seed cotton yield with defoliants ethrel 7.5 l/ha at 40 and 60 per cent boll opening in cotton *cv.* J 205. Singh and Tripathi (1976) studied the effect of spraying of chemical defoliants like paraquat at 1 to 2 l/ha, ammonium thiocyanate at 8 to 10 kg/ha and boll eye at 1.5 to 3 l/ha in cotton (var. J 205) and showed that spraying of paraquat at 2.0 l/ha significantly increased seed cotton yield, bolland opened bolls at 40 days after spray as well as enhanced the maturity as compared to control in cotton. Oosterhuis (1977) found that cotton yield was slightly increased with ethrel application (10 or 100 g/ha) as compared to control. In another experiment conducted by Anonymous (1977) noted that foliar application of ethephon 200, 400, 1000, or 2000 ppm slightly improved matured bolls, bolls weight and fiber quality but bolls weight was decreased in immature bolls in cotton. Singh and Kumar (1978) observed that application of defoliants (ethrel, paraquat and sodium cacodylate) increased the yield in cotton *cv.* LSS, J 205, BN and Hybrid 4 compared to their respective control. Weir and Gaggero (1982) reported increase in yield of cotton *cv.*Acala SJ 2 when the crop was treated with 200 ppm ethephon compared to control. Similarly, Prokofex and Rasulov (1979) mentioned that spraying of cotton plants with ethephon 0.04, 0.2 and 0.4 per cent after 19 to 21 bolls/plant were formed, enhanced boll ripening and increased seed cotton yield specially with low rate of ethephon.

Thakral *et al.*, (1991) noted increased seed cotton yield with defoliant treatments *i.e.* ethrel and drop compared to control at 40 and 60 per cent of boll opening in cotton. Similarly, Sawan *et al.,* (1984) noted that spraying of ethrel (at 5 and 10 ppm) after 90 days from planting led to increased the open bolls, lint percentage, boll weight and seed cotton yield/plant in Giza 66 and Giza 70 cotton varieties. Phillip *et al.,* (2000) reported increase seed cotton yield due to mepiquat products in cotton. Similarly, Sawan *et al.,* (2001) also found that foliar application of growth retardants (Pix, cycocel and Alar at 300 ppm) resulted in increased cotton seed yield, seed index and seed oil. Similar to Ali *et al.,* (2012) studied that mepiquate chloride, Acetyl salicylic acid and naphthalene acetic acid (plant growth regulators) were applied on 10th, 25th August and 9th September 2004 and reported that there was no significant effect of plant growth regulators application on plant height but significantly effect on volume of bolls and yield in comparison to control. Moreover, application of hormones significantly delayed the maturity of cotton cv. CRIS 134.Smith *et al.,* (1986) recorded reduced seed cotton yield when treated cotton with ethephon 1.12 kg/ha at 48 to 62 per cent opened bolls in first year. However, in next year when ethephon applied to cotton at 12 to 25 per cent opened bolls it did not reduce seed cotton yields relative to application with 48 to 72 per cent opened bolls in cotton *cv.* Stoneville. Donald *et al.,* (2001) reported that the application of plant growth regulators in cotton caused significant increased in lint yield and fibre yield in cotton. Similarly, Yang *et al.,* (2014) observed that the foliar application of the PGRs, mepiquat chloride (MC) and Miantaijin [MTJ, a combination of MC with diethyl aminoethyl hexanoate (DA 6)] during squaring and flowering periods significantly increased lint yield in cotton *cvs.* Guoxinmian3 (GX3) and SCRC28 as test materials. Owen and Craig (2003) observed that mepiquat chloride significantly hastened the progress of flowering, increased fruit harvest percentage relative to untreated cotton. Abdel *et al.*, (1987) observed that when cotton plants *cv.* Giza 81 were treated with ethrel (40 ppm) at the beginning of flowering it showed increased seed cotton yield from 25.01 g to 37.6 to 42.0 g/plant. Kennedy *et al.*, (1991) determined efficiency of ethephon (0.28 kg/ha) on removing early squares and found lower average yield due to square removal as compared to control in super okra leaf cotton. According to Pettigrew *et al.*, (1992) foliar application of ethephon (2.8 kg/ha) decrease seed cotton yield and boll weight as compared to control in 2 cotton genotypes (DLP 50 and MD 65-11). However, leaf area index and vegetative dry weight was not affected by the spray. El Antably and El Atta (1992) revealed that applied with 50 ppm MH (maleic hydrazide) on cotton showed increased bolls/ plant in both 1990 and 1991 season. However, changeable results were obtained for the final yield of seed cotton in Giza 75 cotton. Mehetre *et al.*, (1993) reported that application of 5000 ppm ethephon at 40 per cent boll bursting stage gave highest mean seed cotton yield of 1.27 t/ha in cotton *cv.* Kop 498. Similarly, Wankhade *et al.*, (1994) observed that ethephon application significantly increased seed cotton yield compared with control in cotton *cv.* AHH 468.

Prasad and Prasad (1994) reported that the bolls/plant were lowest with 50 ppm CCC which differed significantly from other PGR's treatment and water spray in cotton *cv.*Pusa 31. While, Pawar and Giri (1976) reported that the application of CCC at 40 and 80 ppm increased the bolls/plant significantly over control in cotton *cv.* CJ 73. Snipes and Baskin (1994) tested the different defoliators *viz.,*Tribufos 1.26, Thidiazuron 0.2 and ethephon 2.24 kg/ha and reported that the foliar application of ethephon increased seed cotton yield and lint yield as compared to tribufos, thidiazuron and untreated control in cotton *cv.* DES 119. Ahmed (1994) observed increased bolls/plant by using growth retardants like CCC, Pix and Alar at different concentrations in cotton. Babu *et al.*, (1995) reported that the application of defoliants (ethephon 4000 ppm and 200 g thidiazuron/ha) significantly increase seed cotton yield in cotton *cv.* AH 107. Tan Qiling *et al.*, (1995) reported that boll weight was slightly improved due to ethephon application (200-2000 ppm) compared to control in cotton. Singh and Brar (1999) stated that application of ethrel and thidiazuron 75 g/ha increases bolls opening percentage, bolls and seed cotton yield in cotton *cv.* F 846. Similarly, Prasad *et al.,* (1997) found that ethrel 2.0 kg/ha when sprayed at 60 per cent boll bursting recorded significantly higher boll opening percentage, boll weight, seed cotton yield and highest earliness index obtained in *G. hirsutum* variety RST 9. Brown *et al.,* (1999) tested maleic hydrazide at 2 lb/ac and ethephon 0.2 lb/ac and found increase seed cotton yield and average boll weight as compared to chlormequat in cotton *cv.* Deltapine 20B. Zhao and Oosterhuis (2000) noted that foliar spray of Pix plus at 293 ml/ha increased total dry matter, boll weight and lint yield compared to control. An effect of mepiquat chloride (Pix), benzyl adenine (BA), ethephon (Prep) and their combinations on the growth and yield of cotton *cv.* Giza 83 was determined in a field experiment by Abed (2001). All the treatments increased the bolls, average boll weight, yield of seed cotton, lint yield/plant and 100 seed weight while reducing the bad bolls in cotton. Zulfiqar *et al.*, (2003) noted that bolls/ plant increased with ethylene application (60 kg/ ha) in cotton *cv.* BH 36. Buttar and Agarwal (2004) found that ethrel, Pix, cycocel, and Alar increased bolls/plant, boll weight, boll opening percentage and seed cotton yield. Gupta and Chauhan (2006) observed that one spraying 0.1 per cent ethephon or ethrel before floral bud initiation significantly increased boll weight, seed/boll, 100 seed weight and lint weight in *G. hirsutum* var. Pusa 846 and *G. arboreum* var. RG 8. At the same time, Gupta and Chauhan (2005) tested that efficacy of ethrel (2-Chloroethyl phosphonic acid) and Benzotriazole (1, 2, 3-benzotriazole) as chemical hybridizing agents on *G. hirsutum* var. Pusa 846. The result indicated that the boll weight and 100 seed weight was slightly enhanced by single spray of 0.1 per cent ethrel in cotton. Thus, ethrel could be used as a potential hybridizing agent for *G. hirsutum.* Mohamed (2009) showed that application of ethrel 10 ppm increased bolls/ plant, seed cotton yield and earliness in 2 seasons in cotton *cv.* Brakat 90. Bardhan and Kumar (2010) evaluated the foliar application of ethylene at square initiation stage and observed that application of ethylene at 45 ppm significantly increased bolls/plant and seed cotton yield upto 25 per cent as compared to control and ethylene at 30 ppm in irrespective of hybrid type. However, Kumari and George (2010) reported that 30 ppm ethrel significantly gave higher bolls/plant and seed cotton yield, but it was *at par* with 45 ppm ethrel at square initiation stage in *Bt* cotton hybrids. Sarlach *et al.,* (2010) studied the effect of ethrel (defoliant) on a late maturing *Bt* cotton hybrid var. RCH 134 *Bt* and reported that application of 800 ppm ethrel at 145 days after sowing increased picked bolls, seed cotton yield, lint yield with maximum boll opening percentage as compared with control. An experiment conducted at RARS, Guntur showed that 5.7 or 8.56 mM ethrel application significantly improved yield attributing characters like sympodia, fruiting parts, seed cotton yield and leaf areacompared to control in *Bt* cotton hybrids (Anonymous, 2010[d]). The application of 5.7 mM ethrel at square initiation recorded significantly increased yield attributing characters like fruiting parts and seed cotton yield as compared to control in Bunny *Bt* and Bunny non *Bt* genotypes in cotton (Anonymous, 2010[b]). Sarlach *et al.,* (2010) studied that application of single and double spray of NAA (20 µg/ml and 40 µg/ml) and single spray of cycocel (100 µg/ml and 250 µg/ml) was observed that 2 sprays of NAA at 20 µg/ml *i.e.* one spray at flower initiation and second spray after 15 days of flower initiation has significant effect in improving the source sink ratio, sympodia and bolls/plant, boll setting percentage, seed cotton yield and lint yield over cycocel and control in LH 2076 cotton variety. The application of maleic hydrazide 500 ppm at 85 DAS recorded significantly lower plant height and significantly higher seed cotton yield over control in *Bt* cotton hybrids when tested at ARS, Guntur. Similarly, significant variation was noticed among the treatments for plant height, monopodia/plant, sympodia, nodes, squares and flowers/plant and boll weight (Anonymous, 2010[e]). The application of MH 500 ppm at 85 DAS maximum bolls/plant, boll weight and more seed cotton yield than control treatment in cotton hybrids tested at Dharwad (Anonymous, 2010[f]). maleic hydrazide 500 ppm at 85 DAS recorded significantly increased bolls/plant, boll weight, biomass, harvest index and seed cotton yield as compared to untreated control in cotton *cv.* Bunny *Bt* at MCRS, Surat (Anonymous 2011[h]). And the another results showed by foliar spraying of maleic hydrazide at 500 ppm changed the plant morphology with reduced internodal elongation and improve Leaf area index (LAI) with Leaf area duration (LAD) and seed cotton yield as compared to control in cotton genotypes (Anonymous, 2010[g]). Koler *et al.,* (2011) studied the effect of plant growth regulators *viz.,* cycocel and mepiquat chloride in cotton *cv.* DHB 290 and reported that the spraying of mepiquat chloride 50 ppm at 90 DAS increased bolls/plant, boll weight, seed cotton yield, harvest index and total dry weight compared with Cycocel and control in cotton. Similarly, Kumar *et al.,* (2005) reported that application of mepiquat chloride 50 ppm at 90 DAS improved boll weight, seed cotton yield and total dry matter in cotton *cv.* DHH 11. Kerby *et al.,* (1986) observed that the application of mepiquat chloride at 49 g/ha significantly increased the bolls and nodes/plant. Thakare *et al.*, (2011) reported that foliar application of ethylene at 45 ppm at square initiation stage increased boll weight, seed cotton yield and biomass as compared to control and 30 ppm ethylene in *Bt* cotton *cv.* JKCH 99. Similar concentration recorded highest bolls/plant, boll weight and seed cotton yield irrespective of the *Bt* cotton hybrids (Anonymous 2011[j]). Rajni *et al.*, (2011) reported that defoliation with ethrel 1.5 l/ha at 60 boll opening percentage (BOP) gave higher picked bolls/plant and boll opening percentage as compared to control in *Bt* cotton hybrid *cv.*RCH 134. However, maximum boll weight and seed cotton yield was obtained in treatment ethrel at 1.0 l/ha, followed by Thidiazuron 100 g l/ha applied at 60 BOP. Hunnnur *et al.,* (2011) revealed that application of mepiquat pentaborate at 1000 ppm increased total dry matter content and seed cotton yield as compared to all other treatment in cotton. Nawalagatti *et al.,* (2011) also observed that mepiquat pentaborate at 1000 ppm gave significantly higher dry matter, bolls/plant, boll weight, seed cotton yield and harvest index over control in cotton var. JK 99. In constrast, Sarlach and Sharma (2012) recorded that the application of 2 sprays of NAA @ 20 ìg/ml with 15 days interval starting from flower initiation gave highest bolls/plant (39.44), boll setting percentage (53.86) and boll opening percentage (82.18). The second highest boll/plant (37.97) was recorded by 2 sprays of 10 ìg/ml cobalt chloride with 15 days interval starting from flower initiation. Both these treatments also recorded an increased seed cotton yield of 23.03 q/ha and 22.71 q/ha as compared to control (17.40q/ha) in cotton. Pagar *et al.,* (2011) showed that the foliar sprays of Atonik @ 0.1, 0.25 and 0.5 per cent and NAA @ 20 ppm and 40 ppm significantly increased seed cotton yield over control. Whereas, yield increase due to foliar spray of NAA was (20 ppm) was 21.55 per cent higher over control of irrigated cotton cv.NHH 44. Kumari and George (2012) showed that foliar application of maleic hydrazide at 500 ppm at 85 days after sowing recorded increased bolls/plant, seed cotton yield, boll weight and dry matter production as compared to control in cotton hybrids *cv.* Kashinath *Bt* and Bunny non *Bt* Thakare and Kumar (2012) found that increased bolls/plant and seed cotton yield in *Bt* cotton hybrids when the foliage sprayed with ethylene 45 ppm at square initiation stage in cotton hybrids. Kumari *et al.,* (2012) recorded significantly higher bolls/plant, seed cotton yield and dry matter production with 30 ppm ethrel in cotton hybrids. Buttar and Singh (2013) stated that the foliar application of ethrel 2500 ppm at 145 DAS in *Bt* cotton hybrid *cv.* RCH 134 increased bolls/plant and seed cotton yield as compared to control. The higher seed cotton yields at all the levels of ethrel were obtained when defoliant was applied at 145 as compared to 130 days after sowing in cotton. Kumari *et al.,* (2013) got similar result with ethrel 3000 ppm at 145 DAS in Bunny BG I cotton. However, foliar sprayed of ethrel 1500 and 2000 ppm at 130 DAS increased boll weight in cotton. Chaudhari *et al.,* (2013) reported that foliar application of MH 500 ppm at 85 DAS significantly increased bolls/plant, boll weight and seed cotton yield as compared to control in cotton *cv.* Bunny *Bt* Similar results were obtained CICR Nagpur (Anonymous, 2010[i]). Elayan *et al.,* (2013) reported that superior in bolls opening, seed index, earliness percentage and seed cotton yield when use of 50 ppm pix, while 30 ppm NAA was superior in plant height. Fiber properties were not significantly affected by growth regulators in all characters under study in both seasons in Egyptian cotton.

Effect of PGR on economical characters : Bangarwa *et al.,* (1981) evaluated the application of various growth retardants *viz.,* ethephon, paraquat and bolls eye and reported that ethephon at 2 to 3 l/ha + paraquat 2.5 to 3.5 l/ha increased oil content and seed index in first picking and ginning per cent in second picking in cotton *cv.* H.14. Mavarkar *et al.,* (1992) noted lower seed index and oil percentage when sprayed with defoliant treatments *i.e.* ethrel and Drop at 30 and 60 per cent of boll opening in cotton. However, Sawan *et al.,* (1993) reported that application of cycocel or Alar with different concentration increased oil content, seed index and seed cotton yield compared to control in Egyptian cotton *cv.* Giza 75. Prasad and Prasad (1994) showed that spraying of 50 ppm Cycocel increased lint index significantly over water spray in cotton *cv.* Pusa 31. Buttar and Agarwal (2004) exhibited that foliage sprayed with ethrel, Pix, cycocel and Alar increased ginning percentage, seed oil, lint index and 100 seed weight in cotton. Mohamed (2009) concluded that lint percentage was highest in plants treated with ethrel 10 and 20 ppm at start of flowering and also showed that weight of 100 seeds at the stage of maximum flowering in cotton *cv.* Brakat 90. Sarlach *et al.,* (2010) reported that yield component traits like boll weight, seed index, lint index and ginning outturn did not exhibit any impact with the application of ethrel in cotton *cv.* RCH 134 *Bt.* Similarly Sarlach and Sharma (2012) reported that did not have any significant effect on quality parameters such as lint percentage, lint index and seed index when application of NAA and cobalt chloride on *Bt* cotton (RCH 134) and non *Bt* (RCH 314).

Kumari and George (2012) found increased ginning percentage, lint index and seed index in cotton hybrids *cv.* Kashinath Bunny *Bt* and non *Bt* when applied with maleic hydrazide 500 ppm at 85 days after sowing in cotton. Singh and Singh (1977) observed increase in ginning outturn and fibre strength when cotton plant sprayed with ethrel at 500 ppm. Kumari and George (2013) showed that increased harvest index, seed index (g), lint index (g) and ginning outturn when application of ethrel 45 ppm was given at 35 to 45 DAS which was comparable with control in *Bt* hybrids.

Effect of PGR on fibre quality parameters : Smith *et al.,* (1986) reported that application ethephon at 1.12 kg/ha did not have any adverse effect on fibre properties in cotton *cv.* Stoneville. Thakral *et al.*, (1991) stated that there were no significant differences in fibre quality parameters due to defoliant treatment (ethrel and drop treatment) at 40 and 60 percentage of boll openings in cotton while Snipes and Baskin (1994) noted that foliar application of ethephon 2.24 kg/ha increased strength (g/tex) compared to tribufos, thidiazuron and untreated control in cotton *cv.* DES 119. Pettigrew *et al.*, (1992) found that the foliar spraying of ethephon 2.8 kg/ha decreased fibre quality parameters as compared to control in 2 cotton genotypes (DLP 50 and MD 65 11). Prasad *et al.,* (1997) revealed that none of the fibre properties were significantly affected when cotton variety RST 9 was treated with 2.0 kg/ha ethrel (ethephon 39). Also similar results obtained by Prasad and Prasad (1994) also indicated that none of the plant growth regulators showed any significant change in fibre quality parameters in cotton *cv.* Pusa 31. Tan-Qiling *et al.*, (1995) found increase and slightly improved fibre quality compared to control in cotton with the foliar application of ethephon (200-2000 ppm). Singh and Brar (1999) observed that the foliar spraying of ethrel and thidiazuron 75 g/ha as a defoliant had non significant effect on fibre properties (span length, bundle strength and maturity coefficient) in cotton *cv.* F 846. Mohamed (2009) showed that lower concentration of ethrel (5, 10 ppm) increased micronaire value when applied at start and maximum flowering. While higher concentration (20 ppm) decreased micronaire value at both stages in cotton *cv.* Brakat 90. Bardhan and Kumar (2010) found that no adverse effect on fiber quality parameters of hybrid cotton when application of 30 and 45 ppm ethylene at square initiation stage. Sarlach *et al.,* (2010) reported that higher concentration of ethrel (800 ppm) application did not show any adverse effect on fiber quality in cotton hybrids. Highest seed cotton yield, seed index, lint index and ginning percentage was obtained in 8.56 mM ethylene at square initiation compared to control in cotton *cv.*, RCH 2 *Bt* at RARS, Guntur (Anonymous, 2010[c]). Pagar *et al.,* (2011) reported that foliar sprays of Atonik (0.25%) and NAA (20 ppm) significantly increased the staple length 0.82 per cent and fineness 4.57 per cent comparison with control in irrigated cotton cv.NHH 44. Atonik and NAA treatments also significantly increased the lint index, bundle strength and ginning (%) as compared to control, while seed index was highest with control (6.88 g.). Kumari *et al.,* (2013) found no adverse effect on fiber quality parameters when cotton was treated with ethrel 3000 ppm at 145 DAS and ethrel 30 ppm at square initiation stage, similar results observed by Kumari *et al.,* (2012).

Effect of PGR on economics : Singh and Singh (1977) reported that application of 500 ppm ethrel was found to be highly profitable (net profit) compared to untreated control in cotton. Prasad *et al.,* (1997) observed higher net return and benefit cost ratio when the application of ethrel at 2.0 kg/ha as compared to water spray in cotton *cv.* RST 9. Anonymous (2011[j]) showed that application of 45 ppm ethylene at square initiation indicated that enhanced net return, benefit cost ratio and gross returns compared to untreated control in *Bt* hybrids. Rajni *et al.*, (2011) reported that highest net return and benefit cost ration was obtained when *Bt* cotton hybrid *cv.*RCH 134 treated with ethrel 1.5 l/ha as compared to untreated control. Chaudhari *et al.,* (2013) found that benefit cost ratio was superior with the application of maleic hydrazide 500 ppm at 85 DAS compared to untreated control in cotton. Similar observations were made at Surat. Gobi and Vaiyapuri (2013) studied that effect of plant growth regulator (40 ppm NAA at 45 and 60 DAS) on economics of cotton *cv.*, LRA 5166 recorded highest net return and return rupee compared to untreated control.

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