J. Cotton Res. Dev. **33** (2) 224-241 (July, 2019) **ISSN No. 0972-8619**

Use of microbial inoculants in cotton: A review

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ABSTRACT : Cotton is an important cash crop and plays a vital role in the economic and social affairs of the world. In Punjab during the year 2016-2017, *desi* cotton was grown on 7 thousand ha where as american cotton was grown on 2.78 lakh ha. Nevertheless, organic cotton production holds a minor percentage of the cotton growing area and is slowly gaining momentum in the global cotton market. Organic farming devoids the use of noxious and persistent fertilizers and pesticides. Furthermore, *Gossypium arboreum* has been documented to have medicinal properties and for medicinal use, organic cotton ought to be preferred as it is devoid of chemical fertilizers and pesticides as huge amount of synthetic fertilizers are used for conventional production of cotton, especially hybrid cotton which occupies 95 per cent of the total cotton area in India. Thus, sustainable agricultural production requires new approaches to reduce the application of polluting agrochemicals. Minerals, organic components and microorganisms are three major solid components of the soil. They profoundly affect the physical, chemical, and biological properties and processes of terrestrial systems. The microbial inoculants could play a pertinent role in integrated nutrient management as well as organic farming. The present review will feature various aspects of microbial inoculants like mechanism of action; need to apply microbial inoculants, advantages and disadvantages, application of various microbial inoculants in cotton crop, disease control by use of microbial inoculants and commercially available microbial inoculants for cotton. The realization attained from literature assessed herein will help to understand the role of microbial inoculants in cultivation of cotton.

Key words : Cotton, integrated nutrient management, microbial inoculants, organic farming

Cotton is a crucial profit crop (cash crop).It contributes a vital portion of underdone (raw) material for the textile (Fabric) industry and playing a vital role in the social affairs and economic affairs of the world (Hosamani *et al*., 2013). It is cultivated predominantly for its fibre (used in the manufacture of cloths), manufacturing of threads and for extraction cotton seed oil (Deshmukh *et al*., 2013). In Punjab during 2017-2018, *desi* cotton was grown on 5 thousand ha where as American cotton was grown on 2.86 lakh ha with an average yield of 750kg lint / ha (Anonymous, 2017).On the flipside, area under organic cotton production is in minor percentage in India (Charyulu and Biswas, 2010). Nevertheless, in the global cotton market production of organic cotton is steadily gaining momentum (Bachmann, 2012). In India, more than 70 per cent of the world's organic cotton is grown. India has been the global leader in organic cotton production over the past 6 years. India grew organic cotton in 3.37 lakh ha and produced 5.9 lakh bales at 72 per cent of the global organic cotton in the year. Organic system of farming that sustains and recharges soil productiveness without the use of noxious and persistent fertilizers and pesticides (Kranthi, 2013).

Furthermore, *G. arboreum* has been documented as medicinal plant (antidiabetic) in different geo political zones of Nigeria (Etuk and Mohammed, 2009). The leaves have been found to possess some antifungal and antibacterial properties (Saidu and Abdullahi, 2011). An infusion of the leaf is taken as an antedote for bronchitis and colds (Essien *et al.*, 2011). It has also been used as contraceptive (oral) in humans due to the presence of gossypol in the leaf extract (Coutinho, 2002). In India used cotton seeds are used for the treatment of coughs, constipation and gonorrhea. Infusions of the seeds and leaves of cotton can be used to treat scorpion stings and Snake bites. Unani, Siddha and Ayurvedic physicians use cotton to treat colds, diarrhaea, blood circulation, ear problems and gout (Chaturvedi and Nag, 2015). Moreover, oil obtained from cotton seed is used industrially in array of products, including margarine, cooking oils, salad, salad dressing and mayonnaise etcetera. It is also made into soap, cosmetics, lubricants, sulphonated oils and protective coatings (Todou and Konsala, 2011).

For medicinal use, organic cotton ought to be preferred as it is devoid of chemical fertilizers and pesticides as huge amount of synthetic fertilizers are used for conventional production of cotton, especially hybrid cotton which occupies 95 per cent of the total cotton area in India (Kranthi, 2013). The projection made in India for 2020 AD is around 47.5 million bales of lint to meet the anticipated domestic and export requirement. To fulfil this projected requirement, the cotton production has to be enhanced by 15 per cent and it has to come mainly from increased productivity (Jana *et al.,*2018). Traditional use of synthetic fertilizers to revamp the cotton production cannot be eliminated, but as the costs of fertilizers are escalating at quite a high rate therefore, these have to be fully or partially replaced with some worthwhile approach (Adesemoye *et al.*, 2009).

Synthetic fertilizers are industrially engineered (manipulated) substances that are formulated of exact quantities of nitrogen, phosphorus and potassium, and their excessive use results in air and ground water pollution by eutrophication of water bodies (Youssef and Eissa, 2014) .In general, of the total applied fertilizer 60 to 90 per cent is lost and the remaining (10 to 40%) is used by plants. This further highlights that the usage of chemical nitrogen fertilizers represents a crucial atmospheric (environmental) hazard due to its usage and production as it involves pollution (Zhang *et al.,* 2015) .Within 40-50 per cent of total fertilizer involved in nitrogen uptake are not absorbed instantly by plants and are lost due to volatilization leaching and denitrification. Poor assimilation of nutrients eventually leads to increasing utilization of synthetic nitrogen fertilizers. This dwindle biodiversity, fertility of soil, further it contaminates water (ground) and therefore influences human health (Kraiser and Das, 2011).

Three major solid components of the soil which affect the biological, physical and chemical properties and processes of terrestrial systems are organic components, minerals and microorganisms (Mohammadi *et al.,* 2011). New outlooks to ebb the usage of polluting agrochemicals are requires to sustainable agricultural production. So, there is urgent need to encourage possible methods of soil fertilization that depends on organic inputs to revamp supply of nutrients and conserve field management (Araujo *et al.,* 2008). The microbial inoculants could play a pertinent role in organic farming as being the important component of organic farming. Likewise, for sustainable crop production (Babar *et al.,* 2011), Microbial inoculant via nitrogen fixation, phosphate and potassium solubilisation or mineralization, production of antibiotics, biodegradation of organic matter in the soil and keep the soil environment rich in all kinds of micro- and macro-nutrients (Sinha *et al.,* 2014).

Microbial inoculants: A group of rhizospheric bacteria (rhizobacteria) that exercise a beneficial influence on plant growth is referred to as plant growth promoting rhizobacteria, belongs to several genera: *e.g., Alcaligenes*, *Actinoplanes*, *Arthrobacter*, *Azotobacter*, *Bacillus*, *Agrobacterium*, *Pseudomonas* sp., *Rhizobium*. Multiple species of *Paenibacillus* and *Bacillus* are also known to promote plant growth (Pindi *et al.,* 2014).Worldwide plant growth promoting rhizobacteria (PGPR) have been used worldwide as microbial inoculants for escalating crop yields and fertility of soil (Khalid *et al.,* 2009). Hallmark of the most beneficial plant growth promoting (PGP) microbes is multifunctionality (Avis *et al.,*2008).

Historically, the microbial inoculants were originally recognized in 1888 by a Dutch scientist. Further, with the launch of Nitragin with a laboratory culture of Rhizobia in 1895 by Nobe and Hiltner started the use of microbial inoculants (Ghosh, 2004).Then subsequently cyanobacteria (Blue green algae) and *Azotabactor* were discovered.

In the year 1956, the first commercial production of microbial inoculant in India started under the guidance of N.V Joshi. India Government for the production, promotion and distribution of microbial inoculant implemented a National Project on Development and Use of Bio-fertlizer. At Ghaziabad, National Bio-fertilizer Development Centre was established for the training program related to the promotion of bio-fertilizer in India (Majumdar, 2015)

Mechanism of action: Satyaprakash *et al.* (2017) reported that the beneficial effects of plant growth promoting rhizobacteria are due to the interaction between PGPR and their host plant and also due to their antagonistic activity against plant pathogens

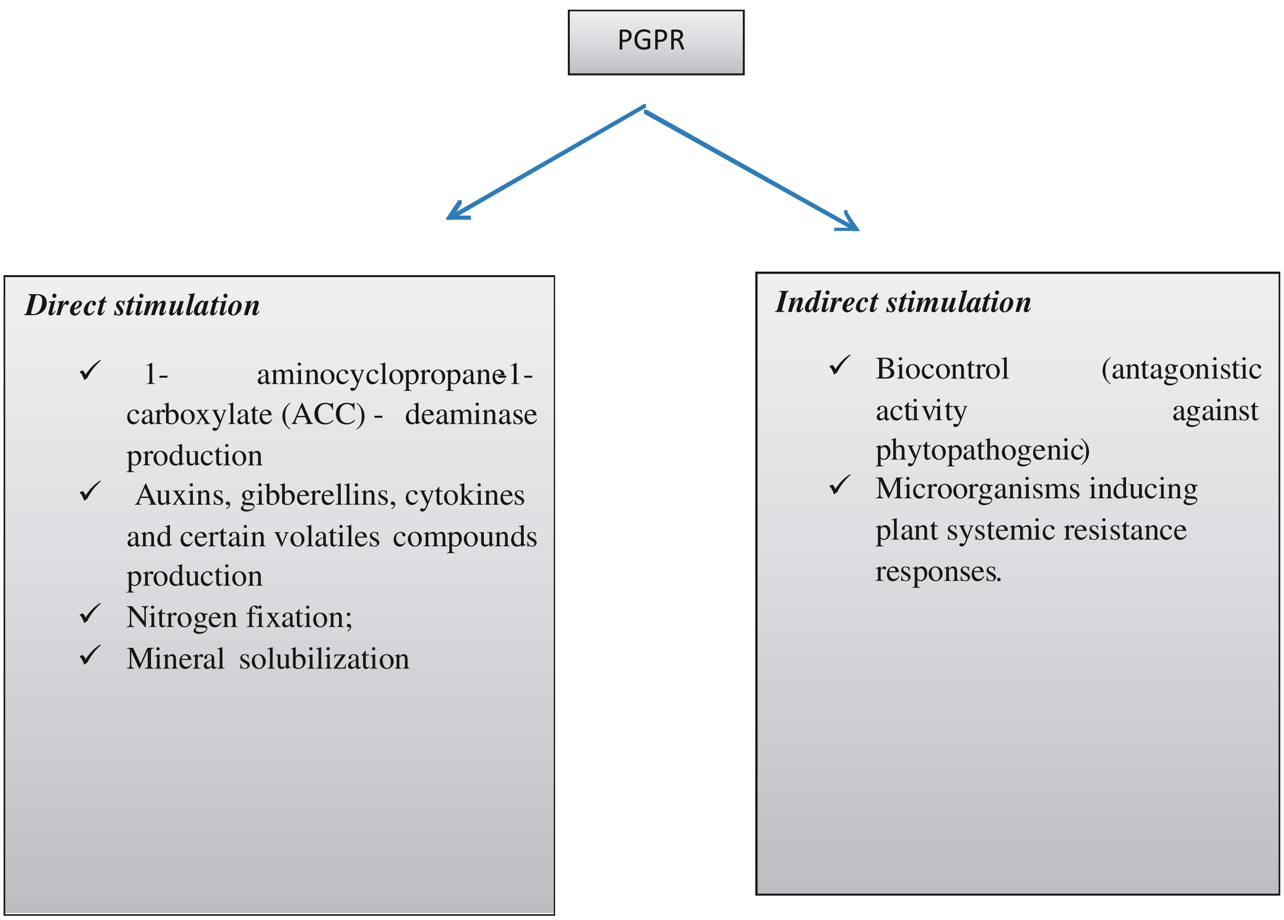
Need to apply microbial inoculants: Nitrogen imparts a predominant role in crop yield. It is a crucial determinant of the growth and yield of irrigated cotton (Ahmad, 2000).

In industry Haber-Bosch process is used to produce nitrogenous fertilizers which are high energy consumption process (about 13,500 K Cal/Kg N fixed). In most of such factories fossil fuels are the main source of energy. However, the cost of crude oil has enhanced due to Gulf Crisis. Nevertheless, fossil fuel based method of farming more expensive accordingly. To root out this tribulation, it is important to look for a substitute approach for nutrients supply to crops (Sivakumar, 2014)

Advantages of microbial inoculants : Microbial inoculants have innumerable edges in comparison with chemical fertilizers, fungicides and pesticides:

- Minimize risk of environmental damage and potentially human health;
- Application is safe
- More targeted activity
- Small quantities is effective
- Under appropriate conditions able to multiply(where their population size is controlled by the plant and indigenous microbes) and may able survive to the next season;
- Faster and more effective decomposition
- Can be used in amalgamation with conventional pest management or on their own (Berg, 2009).
- 20-30 per cent increase in yield.
- Replacement of chemical fertilizer (nitrogen and phosphorus) by 25 per cent.
- Stimulate the growth of plant.
- Biologically activate the soil
- Help to restore natural fertility of soil
- In the long term build fertility of soil
- Cost effective
- They pose no harm to the environment and are eco-friendly (Ghumare *et al.,* 2014).

When used together with chemical fertilisers, it is pertinent to describe the relevant ratio between fertilisers and inoculum size.



Management strategies combining pesticides or herbicides application along with microbial inoculants ought to be test for stand of the microbial inoculants to the chemical fertilizers and for optimum technique of coapplication (Pereg and McMillan, 2015).

Disadvantages of microbial inoculants: The acceptability of microbial inoculants has been rather low chiefly might be due to the following reasons

- ü Do not show fast and amazing responses
- ü Production and application requires skill
- ü Storage is difficult
- ü Lack of awareness about the application and advantages of microbial inoculants. Inadequacy of suitable strains and carrier (Bhattacharjee and Dey, 2014)
- ü Shelf life is short
- ü High temperature susceptibility
- ü Transportationand storage tribulation ofmicrobial inoculants (Chen, 2006)
- ü Handling difficulties during storage and transportation.
- ü The main confront of the microbial inoculants production units is organism viability up to field application. Sort of the useful organisms are very successful in vitro, but may not successful at certain stage of farming (cropping) or at harvesting (Pindi and Satyanarayana, 2012)

Application of various microbial inoculants in cotton crop : The number of field and laboratory studies on plant growth promoting microbial inoculants for cotton has enhanced (Table 1).Many experimental studies focusing on co-inoculation with multiple organisms. Under irrigation plethora of nitrogen fixing, phosphate solubilising and indole-3- acetic (IAA) acid producing bacteria from *Azotobacter*, *Acetobacter*, *Azospirillum*, and *Pseudomonas* genera have been used as inoculants (Pereg and McMilllan, 2015)

Co inoculation of microbial inoculants in cotton: Soil application of consortia of microbial inoculants at sowing helps the plants for uptake of nutrient during early stage by ameliorating soil fertility by atmospheric nitrogen and phosphate solubilization.

Bishnoi (2005) reported maximal advantage in terms of cotton yield by the application of Pink Pigmented Facultative Methylotrophic, *Bacillus* and *Azospirillum* Surat. Egamberdiyeva (2005) (2005) demonstrated the stimulatory effect of bacterial species of *Arthrobacter, Bacillus*, *Pseudomonas* and *Rhizobium* on growth and yield along with nitrogen and phosphorus uptake of cotton. The results further showed the improvement in length of root and shoot and phosphorous content of soil.

Narula *et al.* (2005) used phytohormones producing, phosphate solubilizing and high nitrogen fixing isolates of *Acetobacter, Pseudomonas*, *Azospirillum* and *Azotobacter* as microbial inoculants for cotton. These nominated microbial inoculants were tested for their advantageous properties i.e. IAA production, ammonia excretion and nitrogen fixation and phosphate solubilisation. Further, diverse chosen strains were tested with American (H 1098) and Desi (HD 123) cotton (under field conditions). During the year 2000-2001, on the basis of boll number and boll weight / plant AVK 51 (C36; 76.2 g/plant), HT 57 (27; 56.9 g/plant), AC 18 (33; 61.5 g/plant), Ala 27 (36; 61.5 g/plant), Ala 27 (36; 61.4 g/plant) and Pseudomonas (34; 71.3 g/plant) were recognized as noteworthy for both Desi and American varieties of cotton. Similar results were observed in 2001-2002. Moreover, 25 Kg/ha nitrogen saving was noted with *Azotobacter chroococcum* (AVK 51) for cotton crop.

Dhale *et al.* (2010) also announced notable increase in seed cotton yield (irrigated cotton) with the usage of synthetic fertilizers and inoculation of pink pigmented facultative methylotrophic (PPFM), phosphate solubilizing bacteria (PSB) and *Azospirillum*. The excellence of Surat strain of pink pigmented facultative methylotrophic (PPFM), phosphate solubilizing bacteria (PSB) and *Azospirillum* was noticeable at all the levels of fertilizer followed by MAU strain of pink pigmented facultative methylotrophic (PPFM), phosphate solubilizing bacteria (PSB) and *Azospirillum*. Microbial inoculants also lead to improvement in the quality of fibre. In addition EIG per cent, length of span, Tenacity and uniformity ratio also reported to increase with the application of chemical fertilizers and microbial inoculants.

Ramalakshmi and Raj (2008) investigated the impact of inoculation of Azophos, phosphobacteria and *Azospirillum*on rainfed cotton in a premonsoon sowing (in a typical black soil) at Agricultural Research Station, Kovilpatti, Tamil Nadu, India in the year 2001 and found that microbial inoculants inoculation results in significant increase in the length of shoot and root of cotton. The longest root length was noted with phosphobacteria whereas maximum length of shoot, biomass of plant and dry weight were observed with mycorrhiza and Azophos. The count of bolls/plant with microbial inoculants fluctuated between 9.8-11.5 contrast to 6.1 in control (uninoculated). The boll count was comparatively more with 11.50/plant with mycorrhiza and Azophos. The results further manifested anaugmentation of weight of boll due to microbial inoculants application with 2.88 to 2.98 g / boll compared to 2.65 g / boll in control(uninoculated).Similarly, mycorrhiza and Azophos gave a more yield of kapas (1079 kg / ha) followed by mycorrhiza (1015 kg / ha) and Azophos (982 kg / ha), respectively.

Yasmin *et al.* (2013) reported ameliorated cotton yield by the treatment of cottonseeds with amalgam of *Bacillus fusiformis* SIO and *Pseudomonas aeruginosa* (isolated from cotton in Pakistan) under reduced fertilizer conditions.

Vora *et al.* (2015) studied the impact of ten different combinations encompassing of inorganic fertilizers (NPK), organic, vermin-compost, compost, gypsum and castor cake. Remarkably best net returns and yield of cotton were documented under treatment with nitrogen@ 80 Kg/ha, compost @ 10 t compost/ha, castor cake @500kg/ha and microbial inoculants (*Azotobacter* and PSM).

Laxman *et al.,* (2017) documented outstandingly higher yield of seed cotton with the utilization of microbial inoculants consortia (*Azotobactor* + PSB + KSB + VAM @ l/ha) to soil along with foliar nutrition of 18:18:18 @ 1.5 / cent (1670 kg/ha) over other treatments. Qureshi *et al.,* (2017) tested the consortium of *Azospirillum* sp. and *Azotobacter* (PGPR) with three levels of nitrogen (60, 90, 120 kg/ha) while phosphorus was applied @ 60 kg/ha to all the treatments. The highest yield of seed cotton was recorded at 120 kg/ha as compared to its respective control (2238 kg 120 kg/ha). The highest bolls number / plant, weight of boll and height of plant were also recorded at the same treatment. The present study reported the assenting effect of plant growth promoting rhizobacteria on the yield components of cotton.

***Bacillus* sp :** *Bacillus* sp holds remarkable abilities for synthesizing a broad array of beneficial substances and is considered to be the safe micro organism (Stein, 2005). *Bacillus* species are general dweller among the resident microflora of tissues (inner) of array of plants such as sweet corn, cotton, spruce, grapes and peas where it plays a crucial role in plant growth promotion and plant protection (Berg *et al.,* 2005).

Gutierrez – Manero *et al.,* (2001) reported the production of gibberellins (GA) from *Bacillus licheniformis* and *Bacillus pumilus* .Further the production of indole-3- acetic acid (IAA) bacterium *Bacillus amyloliquefaciens* FZB42 first demonstrated by Idris *et al.,* (2007). Indole-3-acetic acid plays a vital role in differentiation of root vascular tissue, initation of lateral root (regulation), polar root hair positioning and gravitropismof root (Aloni *et al.* 2006).

Senthil Kumar *et al.,* (2009) isolated *Bacillus* spp. having vigorous plant growth promoting traits like antibiotics, siderophore, HCN, phosphate solubilization, IAA production nitrogen fixation, and hydrolytic enzymes from soybean.

Pindi *et al.,* (2014) reported enhanced cotton plant growth in terms of physical parameters, biochemic and phytohormonal properties and reinforce growth of plant in deep black soils followed by shallow black soils by application of *Bacillus* sp PU 7.

***Azotobacter* sp. :** It belongs to the family Azotobacteriaceae and it is one of the vital non symbiotic (free living nitrogen fixing bacterium). It is used as microbial inoculants for all non leguminous plants such as rice, wheat, sugarcane, cotton, mustard linseed (Vyas and Meena, 2018) coconuts, sugar beets, coffee, sorghum, maize, tobacco, tea, jute, sunflower, castor, seasum, barley and rubber (Wani *et al.,* 2013). *Azotobacter* is known to upgrade growth of plant through biological nitrogen fixation and IAA production (Hafeez *et al.,* 2004).

Likewise, the amalgamated use of nitrogen @ 30kg, farmyard manure (FYM) @ 12 Mg./ha and *Azotobacter* (M4) resulted in substantial escalation in attributes of yield and cotton seed yield (Das *et al.,* 2004).

Kumar *et al.,* (2006) documented increase in the count of *Azotobacter* sp. over time in the rhizosphere at cotton. Survival, establishment and proliferation in rhizosphere are vital for a microbial inoculant to facilitate plant growth.

Paul *et al.,* (2011) reported significant enhancement in number of flowers / plant due to seed bacterization with all *A. chroococcum* strains. Bonilla *et al.,* (2013) reported boost in biomass by the use of *Azotobacter chroococcum* (AC1 and ACIO). In addition, notable difference in all growth attributes of plant was recorded between the positive control (full fertilizer rate) and the inoculated treatment.

Phosphate solubilizing bacteria : Since 1903, phosphate solubilising bacteria (PSB) have been used for the production of crop. These bacteria play provital role in providing phosphate to plants in a sustainable and environment congenial demeanour (Khan *et al.,* 2007). Phosphate solubilising bacteria are competent of solubilising stockpiled phosphatic compound in soil by secretion of organic acids, siderophores, protons and phenolic compounds (Landeweert *et al.,* 2001).

Akhtar *et al.,* (2010) conducted a field study on cotton crop by use of *Bacillus* sp and results revealed that *Bacillus* sp remarkably revamped the yield of seed cotton, bolls number / plant, weight of boll, height of plant, length of staple, phosphorous of plant and available phosphorous content in the soil. Likewise, Zaidi and Khan (2005) reported that utilization of solubilizers of phosphate exclusively or along with fixers of nitrogen found to advantageous for wheat and cotton fields.

Pink pigmented facultative methylotrophic : The genus methylobacterium commonly known as PPFM bacteria are of omnipresent in environment. Influence growth of plant by synthesis of IAA (indole-3-acetic acid), vitamins (Basile *et al.,* 1985) and cytokinins (Koenig *et al.,* 2002). These bacteria are widely found in plant rhizosphere, on seeds and plant phyllosphere (Ivanova *et al.,* 2000). Foliar spray of PPFMs outstandingly improved height of plant, dry weight of plant, number of bolls, weight of bolls and cotton kapas yield (Madhaiyan *et al.,* 2005). In addition, through induced systemic resistance, methylotrophs indirectly dwindle or quell the harmful impact of disease causing microorganisms (Madhaiyan, 2003) and its application escalate the photosynthetic activity by revamping the number of stomata, malic acid content and chlorophyll of crops (Cervantes-martinez *et al.,* 2004) .

Table 1. PGP microbial inoculants beneficial to cotton in field and laboratory trials over the last decade (Pereg and McMillan, 2015)

Microbial inoculants	Experimental system	Effects	Reference
Coinoculation of *Azospirillum*, *Methylobacterium*, P-solubilising	Field inoculation under drip irrigation *Bacillus* spp.	Increased growth and yield when combined with chemical fertilizer	Gomathy *et al.,* (2008)
Coinoculation of *Azospirillum,* methylotrops, P-solublising bacteria	Field trials in winter irrigated cotton	Increased cotton yield with reduced application of chemical fertilizer	Nalayini *et al.,* (2010)
Pseudomonasfluorescens	Greenhouse trials using different formulations for application	Promoted plant growth, type of formulation important	Ardakani *et al.,* (2010)
Bacillus edaphicus	Greenhouse pot trials	Increased root and shoot growth	Sheng(2005)
Rooultellaplanticola	Pot trials, Saline soils	Enhanced seed germination, increased plant height and weight	Wu *et al.,* (2012)

Thangamani and Sundaram (2005) reported that production of indole-3-acetic acid (IAA) by pink pigmented facultative methylotrophic vary from 3.44 to 25.51 μg/ml. Anurajan (2003) also described that production of GA (gebberellic acid) by *Methylobacterium* sp. and the amount of gebberellic acid production was found to vary with fluctuating ranging from 10.9 to 106.97 μg/ml of the culture broth.

Mycorrhizal inoculation : One of the most familiar beneficial interactions prevailing in soil is symbiosis between plant roots and arbuscular mycorrhizal fungi (Smith and Smith, 2011). Vesicular arbuscular mycorrhiza fungi are found integrated with bulk of farming crops which enhanced accumulation of plant nutrients. It plays a crucial role in crop farming and turnover of nutrient (Andrade, 2004). Arbuscular mycorrhizal fungi escalate the uptake of soil inorganic nutrients, predominantly phosphorus (Neumann and George, 2010). Vesicular-arbuscular mycorrhiza fungi reported to invigorating plant growth by physiological influences or by diminishing the gravity of diseases results from the soil pathogens (Gupta, 2004).

Sridevi and Ramakrishnan (2010) reported promoted growth of cotton seedlings, escalated number of flowers and bolls due to mycorrhizal inoculation and this further result in the enhancement in yield of seedcotton.

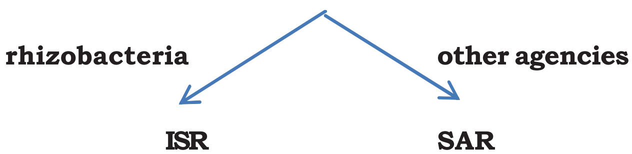
***Azospirillum*:** Among the PGPR (plant growth promoting rhizobacteria), most frequently studied organisms is *Azospirillum*. It is a fine root colonizer, prospective growth hormone producer and associative in nature. It enhances crops yield by improving architecture of roots and eventually improve the uptake of nutrients (Steenhoudt and Vanderleyden, 2000). *Azospirillum* also produce growth promoters like gibberellins, ethylene, cytokinins and auxins (Hungria *et al.,* 2015) besides increasing leaf chlorophyll content (Inagaki *et al.*, 2015). Reis *et al.* (2015) showed the advantages of *Azospirillum* spp. revamping the yield of gamut of crops.

It has been reported that combined application of *Azospirillum* sp and *Azotobacter* affects the yield components like cotton plant height, bolls/plant, weight of boll at each level of nitrogen might be due to colonization of rhizosphere, availability of nutrients and phytohormones biosynthesis (Egamberdiyeva, 2007)

Roesch *et al.,* (2007) also revealed that *Azospirillum* spp improved the nitrogen fixation range from 15.43 to 95.21 ig of N mg / protein / day indicating high potential to increase crop yield. Patil *et al.,* (2011) studied the influence of *Azospirillum* on the quality of fibre and irrigated cotton yield. Surat strain of *Azospirillum* brought about maximal increment in bolls number, maximum weight of boll, branches numberand maximum yield of cotton seed. The uniformity ratio, length of span, elongation and tenacity percentage was enhanced while the value of micronaire and shoot fibre index was least with the use of *Azospirillum* (Surat strain).

Disease control by use of PGPR *viz.* microbial inoculants: Improvement in the defensive capacity of plant against spectrum of pathogens and pests through attained stimulation is known as 'Induced Resistance'. Systemic acquired resistance (SAR) or induced systemic resistance resulted from enhanced resistance because of agent of induction upon infection by a pathogen (Hammerschmidt and Kuc, 1995).

Induction of systemic resistance (Van Loon *et al.*, 1998)



When the inducing organism causes necrosis, SAR is expressed to a maximum level (Cameron *et al.,* 1994) on the flipside ISR by plant growth promoting rhizobacteria do not cause any necrotic manifestation to the host plants (Van Loon *et al.,* 1998).

There are array of determinants of bacteria concerned with the induction of systemic resistance by plant growth promoting rhizobacteria such as siderophore, lipopolysaccharides which occur in the outer membrane of bacterial cells and salicylic acid production (Van Loon *et al.,* 1998). Mechanisms associated with the suppression of pathogen by plant growth promoting rhizobacteria (PGPR)also includes antibiotic production, substrate competition and induced systemic resistance in the host (Van Loon *et al.,* 1998).

Khan *et al.,* (2010) and Farooq *et al.,* (2011) reported that cotton leaf curl virus affects the yield as well as it worsens the quality of fibre. However, by plant growth promoting rhizobacteria inoculation its attack may be diluted.

Saharan and Nehra (2011) demonstrated that inoculation with plant growth promoting rhizobacteria improves yield attributes of cotton and reduces the effect of pathogen. Further, revealed stimulation in growth of plant by improvement in height of plant, bolls number and weight of boll, yield and quality of fibre.

In general, under organic cotton production the square, open boll, locule damages and sucking pests population were remarkably less in the seed treatment and soil application of recommended microbial inoculant (bio-fertilizer) and foliar application of pink pigmented facultative methylotropic, *neem* cake 250 kg/ha and raising of sun hemp between rows incorporated before flowering sowing and Intercropping with green gram (Anonymous, 2018).

***Trichoderma* :** Trichoderma naturally present in most soils and excessively studied for their capacity for improvement in growth of plant, antibiotics production, parasitize other fungi and competition with deleterious plant microorganisms. It has been used as microbial inoculants and bio agent (biological agent) (Adams *et al.,* 2007) .The advantages of *Trichoderma* species in revamping growth of plant can be realized via galores of mechanisms such as inorganic nutrients sequestration, improved development of root hair, mycoparasitism, toxins degradation, antibiosis, pathogenic enzymes pathways inactivation, resistance to pathogens, improved uptake of nutrient and solubilisation (Lorito *et al.,* 2010). Hexon *et al.,* (2009) demonstrated that *Trichoderma* spp promotes formation of lateral roots through the production of indole-3-acetic acid. Various endeavours have been approached to use *Trichoderma* spp (as bio stimulants) for establishment seedling, plant growth enhancement and to activate plant growth (Shanmugaiah *et al.,* 2009).

Ranveer *et al.,* (2018) reported

Trichoderma microbial inoculants can be used in cotton. Commercialization of *Trichoderma* microbial inoculants raises hope in farmers. *Trichoderma* escalates overall plant health, by creating a positive environment with symbiotic relationship with plants and releases array of secondary metabolites including, growth hormones, endochitinase, proteolytic enzymes (Benitez *et al.,* 2004).

Commercially available microbial inoculants for cotton : Biomax, is based in India, is a key supplier of microbial inoculants worldwide. Commercial products of Biomax for plethora of crops are (Garcia-Fraile *et al.,* 2015):

- Life®,
- Biomix®,
- Biozink®,
- Biodine®

Other giant microbial inoculants manufacturing companies in India are:

- Ajay Biotech Ltd.,
- Madras Fertilizers Ltd.,
- Gujarat State Fertilizers and Chemicals Ltd.,
- T. Stanesand Company Ltd.,
- Camson Bio Technologies Ltd.,
- National Fertilizers Ltd.,
- Rashtriya Chemicals and Fertilizers Ltd

In addition, PIX PLUS® amalgamates *Bacillus cereus* with mepiquat chloride. It is merchandised to enhance number and size of bolls, escalating yield by up to 82lb/acre on average (ArystaLifeScience, USA, www.arysta-na.com).

Current products in the USA include Ascend™ PA, a microbial inoculants containing the *Glomusintraradicies* (mycorrhizal fungi), and it enhances growth of cotton by 300% (BioScientific, Inc., Arizona, USA, www.BioSci.com).

REFERENCES

Hosamani, V., Halepyati, A.S., Shashikumar, M., Santhosh, U.N., Nataraja, M. and Manu, T.G. 2013. Quality uptake of nutrients and economics of irrigated *Bt* cotton (*Gossypium hirsutum* L.) as influenced by macro nutrients and liquid fertilizers. *Global J. Biol. Agric .Health Sci.* **2**: 29.

Deshmukh, M.S., Patil, V.D., Jadhav, A.S., Gadade G.D. and Dhamak, A.L. 2013. Assessment of soil quality parameters and yield of rainfed Bt. Cotton as influenced by application of herbicides in Vertisols. *Int. J. Agric. Sci .* **3**: 553-57.

Anonymous, 2017. *Statistics of Punjab Agriculture.* Punjab Agricultural University, Ludhiana.

Charyulu, D.K. and Biswas, S. 2010. *Economics and efficiency of organic farming vis-à-vis conventional farming in India*, Indian Institute of Management, Ahmedabad, India, April.

Bachmann, F. 2012. Potential and limitations of organic and fair trade cotton for improving livelihoods of smallholders: evidence from Central Asia. *Renew.Agr.FoodSyst.***27**:138-47.

Kranthi, RK. 2013. The 'Organic Cotton' Argument. *Cotton Statistics and news*. 2013 No. 32 5th November, Published every Tuesday.

Etuk, E.U. and Mohammed B. J. 2009. Informant consensus selection method: A reliability assessment on medicinal plants used in north western Nigeria for treatment of diabetes mellitus. *Afri. J. Pharmacol.* **3**:496-500.

Saidu, T.B. and Abdullahi, M. 2011. Phytochemical determinations and antibacterial activities of the leaf extracts of *Combretummolle* and *Gossypium arboretum*. Bayero. *J. Pure Appl. Sci.* **4** : 132-36.

Essien, E.E., Aboaba, S.O. and Ogunwande, I.A. 2011. Constituents and antimicrobial properties of the leaf essential oil of *Gossypium barbadense* (Linn.). *J. Med. Plants Res.* **5** : 702-05.

Coutinho, E. M. 2002. Gossypol: A contraceptive for men. Contraception.**65** : 259-63.

Chaturvedi, A. and Nag, T. N. 2015. Medicinal Value of Cotton. *Int. J. Med. Pharm Res.*, **1**: 147-49.

Todou, G. and Konsala, S. 2011. *Gossypium barbadense* L. [Internet] Record from PROTA4U. Brink, M. and Achigan-Dako, E.G. (Editors). PROTA (Plant Resources of Tropical Africa/ Ressourcesvégétales de l'Afriquetropicale), Wageningen, Netherlands. <http://www.prota4u.org/search.asp>.

Jana Harish, J., Pawar, D.D., Kale, K.D., Hasure, R.R. and Dingre, S.K. 2018. Nutrient availability in *Bt* cotton under drip fertigation. *Int. J. Curr. Microbiol. App. Sci.* **7** : 3373-79.

Adesemoye, A.O., Torbert, H.A. and Kloepper, J.W. 2009. Plant growth promoting rhizobacteria allow reduced application rates of chemical fertilizers. *Microb. Ecol.* **58** : 921-29.

Youssef, M.M.A. and Eissa, M. F. M. 2014. Microbial inoculantss and their role in management of plant parasitic nematodes. *A review. E3 J. Biotechnol. Pharm Res.* **5:**1-6.

Zhang, X., Davidson, E.A., Mauzerall, D.L., Searchinger, T.D., Dumas, P. and Shen, Y. 2015. Managing nitrogen for sustainable development. *Nature,* **528**:51-59.

Kraiser, T., Gras, D.E., Gutierrez, A.G., González, B. and Gutiérrez, R.A. 2011. A holistic view of nitrogen acquisition in plants. *J. Exp. Bot.* **62** : 1455-66.

Mohammadi, K., Heidari, G., Khalesro, S. and Sohrabi, Y. 2011. Soil management, microorganisms and organic matter interactions : A review. *African J. Biotechnol.* **10** : 19840- 49.

Araujo, A.S.F., Santos, V.B. and Monteiro, R.T.R. 2008. Responses of soil microbial biomass and activity for practices of organic and conventional farming systems in Piauistate, Brazil. *Eur. J. Soil Biol.* **44** : 225-30.

Babar, L.K., Iftikhar, T., Khan, H.N., and Hameed, M.N. 2011. Agronomic trials on sugarcane crop under Faisalabad conditions, Pakistan. *Pak. J. Bot.* **43** : 929-35.

Sinha, R.K., Valani, D., Chauhan, K. and Agarwal. 2014. Embarking on a second green revolution for sustainable agriculture by vermiculture biotechnology using earthworms: reviving the dreams of Sir Charles Darwin. *Int. J. Agric. Health Saf.* **1** : 50-64.

Pindi, P.K., Sultana, T. and Vootla, P.K. 2014. Plant growth regulation of *Bt* cotton through Bacillus species. *Biotech.* **4** : 305-15.

Khalid, A., Arshad, M., Shaharoona, B., and Mahmood. T., 2009. Plant growth promoting rhizobacteria and sustainable agriculture in

Microbial Strategies for Crop Improvement (Springer, Berlin/Heidelberg, Germany) 2009, 133-60.

Avis, T.J., Gravel, V., Antoun, H. and Tweddell, R.J. 2008. Multifaceted beneficial effects of rhizosphere microorganisms on plant health and productivity. *Soil Biol. Biochem*. **40** : 1733-40.

Ghosh, N. 2004. *Promoting Bio-Fertilizers in Indian.* Agriculture, Research Project conducted at the Institute of Economic Growth for Ministry of Agriculture.

Majumdar, K. 2015. Bio fertilizer use in Indian agriculture. *Paripex – Ind. J. Res*. **4** : 377-81.

Satyaprakash, M., Nikitha, T., Reddi, E.U.B., Sadhana, B. and SatyaVani, S. 2017. A Review on phosphorous and phosphate solubilising bacteria and their role in plant nutrition. *Int. J. Curr. Microbiol. App. Sci.* **6** : 2133-44.

Ahmad, N. 2010. Fertilizer scenario in Pakistan : Policies and development. *Proceedings of Conference on Agricultural and Fertilizer Use. 2010 NFDC, Pand D Div. Govt. of Pakistan, February 15-16, 1999 (2000)*

Sivakumar, T. 2014. Review on Microbial Inoculants. *Int. J. curr. Res. Chem. Pharm. Sci.* **1**:17-23.

Berg, G. 2009. Plant-microbe interactions promoting plant growth and health: perspectives for controlled use of microorganisms in agriculture. *Appl. Microbiol. Biotechnol.* **84**:11-8.

Ghumare, V., Rana, M., Gavkare, O. and B. Khachi 2014. Bio fertilizers increasing soil fertility and Crop Productivity. *J. Industrial Pollution Control,* **30**:196-201.

Pereg L. and McMillan, M. 2015. Scoping the potential uses of beneficial microorganisms for increasing productivity in cotton cropping systems. *Soil Biol. Biochem.* **80** : 349-58

Bhattacharjee, R. and Dey, U. 2014. Biofertilizer, a way towards organic agriculture: *A review. African J. Microbiol. Res*. **8** : 2332-42

Chen, J. 2006. The combined use of chemical and organic fertilizer and or microbial inoculants for crop growth and soil fertility. *International Workshop on sustained management of the Soil-rhizosphere system for efficient crop production and fertilizer use*. Land Development Department, Bangkok 10900 Thailand, 16 – 20 October (2006) 37.

Pindi, P.K. and Satyanarayana, S.D.V. 2012. Liquid Microbial Consortium- A Potential Tool for Sustainable Soil Health. *J. Biofertil. Biopestici.* **3**:124.

Bishnoi, L.K., Rajender, S. and Narula, N. 2005. *Bioinoculants for sustainable production in cotton in south- west region of Haryana*, National Symposium on Microbial technology for productive agriculture. Tamil Nadu Agricultural University, Coimbatore, India, 7-8 September 2005.

Egamberdiyeva, D. 2005. Plant growth promoting rhizobacteria isolated from a calsisol in semi arid region of Uzbekistan: biochemical characterization and effectiveness. *J. Plant Nutr. Soil Sci.* **168**:94-99.

Narula, N., Saharan, B., Kumar, V., Bhatia, R., Bishnoi, L.K., Lather, B. and K. Lakshminarayana 2005. Impact of the use of biofertilizers on cotton (*Gossypium hirsutum*) crop under irrigated agro-ecosystem. *Arch. Agron. Soil Sci.* **51**:69-77.

Dhale, D., Chatte, S. and Jadhav, V.T. 2010. Effect of bio-inoculants on growth, yield and fibre quality of cotton under irrigation. *Res. J. Agric. Biol. Sci.* **6**:542-47.

Ramalaxmi, A. and Anthoni Raj, S. 2008. Effect of inoculation of microbial inoculants on cotton growth and yield. *J. Soils Crops.* **18**:273-78.

Yasmin, S., Hafeez, F., Schmid, M., and Hartmann, A. 2013. Plant beneficial rhizobacteria for sustainable increased yield of cotton with reduced level of chemical fertilizer. *Pak. J. Bot.* **45** : 655-62.

Vora, V.D., Rakholiya, K.D., Rupapara, K.V., Sutaria G.S. and Akbari, K.N. 2015. Effect of integrated nutrient management on *Bt* cotton and post harvest soil fertility under dry farming agriculture. *Asian J. Agric. Res.* **9** : 350-65.

Laxman, T., Srinivas, A., Avil Kumar, K. and Ram Prakash, T. 2017. Yield and yield attributes of *Bt* cotton as influenced by the microbial inoculants consortia and foliar nutrition under rainfed. *Int. J. Curr. Microbiol. App. Sci.* **6** : 1-4.

Qureshi, M. A., Ali, M.A., Mujeeb, F., Ahmad, M.J., Rashid, S., Ullah, S. and Anjum, M.A. 2017. Yield and quality response of cotton to a consortium of PGPR at graded fertilizer levels. *Int. J. Biosci.***10**: 46.

Stein, T. 2005. *Bacillus subtilis* antibiotics: structures, synthesis and specific functions. *Mol. Microbiol.* **56**:845-57.

Berg, G., Zachow, C., Lottmann, J., Götz, M., Costa, R. and Smalla, K. 2005. Impact of plant species and site on rhizosphere associated fungi antagonistic to *Verticillium dahlia* Kleb. *Appl. Environ. Microbiol.***71** : 4203-13.

Gutierrez-Manero, F.J., Ramos, B., Probanza, A., Mehouachi, J. and Talon, M. 2001. The plant growth promoting rhizobacteria *Bacillus pumilus* and *Bacillus licheniformis* produce high amounts of physiologically active gibberellins. *Physiol. Plant.* **111 :** 206-11.

Idris, E.E.S., Iglesias, D.J., Talon, M. and Borriss, R. 2007. Tryptophan dependent production of indole-3-acetic acid (IAA) affects level of plant growth promotion by *Bacillus amyloliquefaciens* FZB42. *Mol. Plant Microbe Interact.* **20** : 597-19.

Aloni, R., Aloni, E., Langhans, M. and Ullrich, C.L. 2006. Role of cytokinin and auxin in shaping root architecture: regulating vascular differentiation, lateral root initiation, root apical dominance and root gravitropism. *Ann. Bot.* **97 :** 883-93.

Senthil kumar, M., Swarnlakshmi, K., Govindasamy, V., Lee, Y.K. and Annapurna, K. 2009. Biocontrol potential of soybean bacterial endophytes against charcoal rot fungus *Rhizoctonia bataticola. Curr. Microbiol.* **58** : 288-93.

Vyas, D. and Meena, R.H. 2018. Role of Microbial Inoculants in Integrated Plant Nutrient System (IPNS). *Int. Res. J. Nat. Appl. Sci.* **5**:77.

Wani, S. A., Chand, S. and Ali, T. 2013. Potential use of *Azotobacter chroococcum* in crop production: an overview. *Curr. Agric. Res. J.* **1:**35-38.

Hafeez, F.Y., Safda, A. U. Chaudhry and K. A. Malik. 2004. Rhizobial inoculation improves seedling emergence, nutrient uptake and growth of cotton. Aust. J. Exp. Ag.44: 617-22.

Das, A.M., Prasad, M.E., Shivay, Y.S. and Subha., K.M. 2004. Productivity and sustainability of cotton (*Gossypium hirsutum* L.) wheat (*Triticum aestivum* L.) cropping system as influenced by prilled urea, farmyard manure and *Azotobacter*. *J. Agron. Crop Sci.***190:**298-304

Kumar, R., Bhatia, R., Sikka, V., Suneja, S. and N. Narula. 2006. Genetic tagging of *Azotobacter chroococcum* for colonization on wheat (*Triticum aestivum*) and cotton (*Gossypium* sp.) roots. *Arch. Agron. Soil Sci.* **52:**359-64.

Paul, S., Rathi, M.S., Tyagi, S.P. 2011. Interactive effect with AM fungi and Azotobacter inoculated seed on germination, plant growth and yield in cotton (*Gossypium hirsutum*). *Indian J. Agric. Sci.* **81**:1041-45.

Bonilla, R., Novo, R.,Roncallo, B., Camelo, M., Criollo,P., Estrada,E.A., Garrido,M.F., López ,M., Moreno-Galván, A, Obando, M., Parra, L., Rivera, D., Rojas-Tapias, D., Van Strahlen, M. and Zambrano, C. 2013. *Azotobacter* sp. applied research aimed to growth promotion of crops with economics interest in Colombia. In: Rizósfera, BiodiversidadyAgricultura Sustentable. (Ed. García de Salomone IE, Vásquez S, Penna C, Cassán F; Argentina: Lit Verlag), pp.151-73.

Khan, M. S., Zaidi, A. and Wani, P.A. 2007. Role of phosphate-solubilizing microorganisms in sustainable agriculture - *a review. Agron. Sustain. Dev.* **27**:29-43.

Landeweert, R., Hoffland,E., Finlay, R.D., Kuyper, T.W. and Van Breemen, N. 2001. Linking plants to rocks, ectomycorrhizal fungi mobilize nutrients from minerals. *Trends Ecol. Evol.***16** : 248-54.

Akhtar, N., Iqbal, A., Qureshi M.A. and Khan, K.H.2010. Effect of phosphate solubilizing bacterias on the phosphorous availability and yield of cotton (*Gossypium hirsutum*). *J. Sci. Res.***1**:17-25

Zaidi, A. and Khan, S. 2005. Interactive effect of rhizospheric microorganisms on growth, yield and nutrient uptake of wheat. *J. Plant Nutr.* **28** : 2079-92.

Gomathy, M., Prakesh, D., Thangaraju, M., Sundaram, S.P. and Sundaram, P.M. 2008. Impact of biofertigation of Azophosmet on cotton yield under drip irrigation. *Res. J. Agric. Biol. Sci.* **4**: 695-99

Nalayini, P., Sankaranarayanan, K. and Anandham, R. 2010. Bio inoculants for enhancing the productivity and nutrient uptake of winter irrigated cotton (*Gossypium hirsutum*) under graded levels of nitrogen and phosphatic fertilizers. *Ind. J. Agronom.***55**:64-67.

Ardakani, S., Heydari, A., Tayebi, L. and Mohammadi, M. 2010. Promotion of cotton seedling growth characteristics by development and use of new bioformulations. *Int. J. Bot.***6**:95-100.

Sheng, X. 2005. Growth promotion and increased potassium uptake of cotton and rape by a potassium releasing strain of *Bacillus edaphicus*. *Soil Biol. Biochem.***37**:1918-22.

Wu, Z., Yue, H. and Lu, J. 2012. Characterization of rhizobacterial strain Rs-2 with ACC deaminase activity and its performance in promoting cotton growth under salinity stress. *World J Microbiol. Biotechnol.* **28**:2383-93.

Basile, D.V., Basile, M.,. L, Q.Y. and Corpe, W.A. 1985. Vitamin B12-stimulated growth and development of Jungermannia leiantha Grolle and Gymnocolea inflate Dum. (Hepaticae). *Bryologist*, **88**:77-81.

Koenig, R.L., Morris, R.O. and Polacco, J.C.2002. tRNA is the source of low level trans-zeatin production in *Methylobacterium* spp. *J. Bacteriol.* **184**:1832-1842.

Ivanova, E. G., Doronina, N. V., Shepelyakovskaya, A.O., Laman, A.G., Brovko, F.A. and Yu Trotsenko,A. 2000. Facultative and obligate aerobic methylobacteria synthesize cytokinins. *Mikrobiologiya*, **69** : 764-69.

Madhaiyan, M., Poonguzhali, S., Sundaram, S.P. and Tongmin, S.A. 2005. A new insight into foliar applied methanol influencing phylloplane methylotrophic dynamics and growth promotion of cotton (*Gossypium hirsutum* L.) and sugarcane (*Saccharum officinarum* L.). *Environ. Expt. Bot.* **57** : 168-76.

Madhaiyan, M. 2003. *Molecular aspects, diversity and plant interaction of facultative methylotrophs occurring in tropical plants*, *Ph.D. Thesis*, Tamil Nadu Agricultural University, Coimbatore.

Cervantes-martinez, J., Lopez-diaz, S. and Rodrigue z-garay, B. 2004. Detection of the effects of *Methylobacterium* in Agave tequilana Weber var. azulby laser induced fluorescence. *Plant Sci.* **166**: 889-92.

Thangamani, G and Sundaram, S.P. 2005. *Potential of facultative methylotrophs in increasing the yield of tomato crop*. Abstract of Poster Presented in 3 rd National Conference Association Appl. Microbiol. (IAAM), Centre for Plant Biotechnology and Molecular Biology, College of Horticulture, Kerala Agricultural University, Thrissur, Kerala. 10-12 January.

Anurajan, S. 2005. *Studies on the occurrence of pink pigmented facultative methylotrophs on vegetable crops*, *M. Sc. Thesis*, Tamil Nadu Agricultural University, Coimbatore, 2003.

Smith, S.E. and Smith, F.A. 2011. Roles of arbuscular mycorrhizas in plant nutrition and growth: new paradigms from cellular to ecosystem scales. *Annu. Rev. Plant Biol.* **62 :** 227–50

Andrade, G.2004. Role of functional groups of microorganisms on the rhizosphere microcosm dynamics, in Plant Surface Microbiology, eds A. Varma, L. Abbott, D. Werne, and R. Hampp (New York, NY: Springer), 51.

Neumann, E. and George, E. 2010. "Nutrient uptake: the arbuscular mycorrhiza fungal symbiosis as a plant nutrient acquisition strategy," in Arbuscular Mycorrhizas: Physiology and Function, eds H. Koltai and Y. Kapulnik (New York, NY: Springer), 137.

Gupta, A.K .2004. *The complete technology book on microbial inoculants and organic farming.* National Institute of Industrial Research, Press, India, 2004.

Sridevi, S. and Ramakrishnan, K. 2010. The effect of NPK fertilizer and AM fungi on the growth and yield of cotton (*Gossypium hirsutum* L.) var. LRA 5166. *Recent Res. Sci.Technol.* **2** : 39-41.

Steenhoudt, O. and Vanderleyden. J. 2000. *Azospirillum*, a free-living nitrogen-fixing bacterium closely associated with grasses: genetic, biochemical and ecological aspects. *FEMS Microbiol. Rev.* **24**:487–506

Hungria, M., Nogueira, M.A. and Araujo, R.S. 2015. Soybean seed co-inoculation with *Bradyrhizobium* spp. and *Azospirillum brasilense*: A new biotechnological tool to improve yield and sustainability. *Am. J. Plant Sci.* **6**: 811-17.

Inagaki, A. M. , Guimarães, V. F., Lana, M.C., Klein, J., Costa, A. C. R ., Rodrigues, L.F.O.S., and Rampim. L. 2015. Maize initial growth with the inoculation of plant growth-promoting bacteria (PGPB) under different soil acidity levels. *Aust. J. Crop Sci.* **9** : 271-80.

Reis, A. R., Favarin, J.L., Gratão, P.L., Capaldi, F.R. and Azvedo, R.A.. 2015. Antioxidant metabolism in coffee (Coffeaarábica L.) plants in response to nitrogen supply. *Theor. Exp. Plant Physiol,* **1**: 1-11.

Egamberdiyeva, D .2007. The effect of plant growth promoting bacteria on growth and nutrient uptake of maize in two different soils. *Appl. Soil Ecol.* **36**:184-89.

Roesch, L.F.W., Quadros, P.D., Camargo, F.A.O and Triplett, E.W. 2007. Screening of diazotrophic bacteria *Azospirillum* spp. for nitrogen fixation and auxin production in multipled field sites in Southern Brazil. *World J. Microbiol. Biotechnol.* **23**:1377-83.

Patil, M.B., Kadam, S.M. and Pillai, S.G. 2011. Effect of *Azospirillum* on fibre quality and yield of irrigated cotton. *Asian J. Bio. Sci.* **61**:88.

Hammerschmidt, R. and Kuc, J., 1995. Induced Resistance to Disease in Plants. Kluwer Academic Publishers, DordrechtL, The Netherlands, p. 182.

Van Loon, L. C., Bakker, P.A.H.M. and Pieterse, C. M. J.1998. Systemic resistance induced by rhizosphere bacteria. *Annu. Rev. Phytopathol.* **36** : 453-83.

Cameron, R.K., Dixon, R. and Lamb, C. 1994. Biologically induced systemic acquired resistance in *Arabidopsis thaliana. Plant J.* **5** : 715-25.

Khan. I., Masood, A. and Ahmad, A. 2010. Effect of nitrogen fixing bacteria on plant growth and yield of *Brassica juncea. J. phytol.* **2** : 25-27.

Farooq, A., Farooq, J., Mahmood, A., Shakeel, A., Rehman, A., Batool, A., Riaz, M., Shahid, M. T. H. and Mehboob S. 2011. An overview of cotton leaf curl virus disease (CLCuD) a serious threat to cotton productivity. *Aust. J. Crop Sci.* **5**:1823-31.

Saharan, B.S. and Nehra, V. 2011. Plant Growth Promoting Rhizobacteria: *A Critical Review. Life Sci. Med. Res.* **21**:1-30.

Anonymous 2017. *Annual Report* . ICAR - All India Coordinated Research Project on Cotton (2017- 2018).

Adams, P., De-Leij, F.A.A.M. and Lynch, J.M. 2007. *Trichoderma harzianum* Rifai 1295-22 mediates growth promotion of crack willow (Salix fragilis) saplings in both clean and metal-contaminated soil. *Microb. Ecol.* **54:**306-313.

Lorito, M., Woo, S.L., Harman G.E. and Monte, E. 2010. Translational research on *Trichoderma*: from 'omics to the field. *Annu. Rev. Phytopathol.***48**:395-417.

Hexon, A.C., Lourdes, M.R., Carlos C.P. and Jose, L.B. 2009. *Trichoderma virens*, a plant beneficial fungus, enhances biomass production and promotes lateral root growth through an auxin-dependent mechanism in Arabidopsis. *Plant Physiol.***149**: 1579-1592.

Shanmugaiah, V., Balasubramanian, N., Gomathinayagam, S., Monoharan P.T. and Rajendran, A. 2009. Effect of single application of *Trichoderma viride* and *Pseudomonas fluorences* on growth promotion in cotton plants. *Afr. J. Agric. Res.* **4 :** 1220-25.

Ranveer, K.K., Victor, A., Yogendra, S.G., and Vivek, K. 2018. Trichoderma: a Most Common Microbial inoculants with Multiple Roles in Agriculture. Biomed. *J. Sci. Tech. Res.* **4** : 1-3.

Benítez, T., Rincón, A., Carmen Limón, M. and Codón, A.C. 2004. Biocontrol mechanisms of *Trichoderma* strains. *Intl. Microbiol.* **7** : 249-60.

García-Fraile, P., Menéndez, E. and Rivas, R. 2015. Role of bacterial microbial inoculants in agriculture and forestry**.** *Bioengg.* **2**:183-205.

Received for publication : November 20, 2018
Accepted for publication : February 3, 2019