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Key Agronomic Issues for Higher Production and Sustainability in Bt Cotton: A Review

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ABSTRACT

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With the advent of *Bt* cultivars cotton production is reinvigorated in the country with China being on the verge of being knocked down on the production front. However, of late the stagnating or the decreasing productivity either due to degrading natural resources and faulty practices and/or susceptibility of transgenic cultivars to insect damage, leaf reddening and climate change are making the researcher to take stock of the situation before embarking on agronomic studies with higher yield goals. Hence, the review.

Introduction

The development of *Bt* cotton represents a significant technological evolution in the global cotton research. India adopted this technology during 2002. Commercial cultivation of *Bt* cotton in India began during 2002-03 with three hybrids viz., MECH-12 *Bt*, MECH-162 *Bt* and MECH-184 *Bt* (Anon., 2006) and during 2008 there were 274 hybrids officially approved by the Genetic Engineered Approval Committee (GEAC) and today the number is unimaginable. Today *Bt* cultivars cover almost entire cotton zones of India, the productivity has more than trebled over the initial level at the time of *Bt* introduction. However, of late the production is either stagnant or showing downward trend and therefore, it is imperative to take stock of key agronomic issues for integrated acceleration of cotton production across climate change particularly drought, changing pest scenario, leaf reddening etc. This is the key for furtherance of realization of crop potential and hence, this attempt.

Selection of cultivars

In India several studies have been carried out on the field performance of *Bt* hybrids since their release (Table 1). Initial multi-location trials conducted under the aegis of Indian Council of Agricultural Research for three hybrids (viz. MECH-12, MECH-162 and MECH-184) indicated increase in yield over the local popular non-*Bt* cotton, and among the *Bt* cotton hybrids, MECH 162 recorded significantly higher seed cotton yield (Anon., 2002). Venugopalan *et al.*, (2002) revealed that MECH-162 *Bt* fared better in central zone

(13.3 q ha^{-1}) while MECH-184 *Bt* did well in south zone (20.09 q ha^{-1}). Similarly, in Karnataka, Khadi *et al.,* (2002) revealed the superiority of MECH-184 *Bt*. In further south, on clay loam soil at Coimbatore MECH-162 recorded higher seed cotton yield, number of sympodials and number of bolls over non-*Bt* hybrids (Sankaranarayanan, 2004).

Under unprotected rainfed condition at Dharwad, Udikeri *et al.,* (2003a) recorded significantly lower damage to fruiting bodies in MECH-184 *Bt* (4.04%) followed by MECH-162 *Bt* (5.02%) and MECH-12 *Bt* (6.84%). Kengegowda (2003) also observed significantly higher good opened bolls and less bad opened bolls in *Bt* cotton hybrids in Raichur. Vennila *et al.,* (2004) revealed significantly lower square, green boll, open boll and locule damage in RCH-20, RCH-134, RCH-138 and RCH-144 *Bt*. Similarly, Bhosle *et al.,* (2004) reported significantly lower damage due to bollworms (14 to 17%) in *Bt* cotton hybrids compared to non-*Bt* and check hybrids (25 to 35%). Surulivelu *et al.,* (2004) reported that RCH-2 *Bt* and RCH - 20 *Bt* were effective in reducing the *H. armigera* incidence to the extent of 73.8 and 72.9 % over their non-*Bt* counterparts. Interestingly, Jagvirsingh *et al.,* (2003) noticed earliness nearly by 40 days in *Bt* hybrids. Mayee *et al.,* (2004) also had similar observation.

In the north eastern dry zone, at Research Farm, Raichur and on farmer's field incidence of bollworms in MECH-162 *Bt* and MECH-184 *Bt* cotton hybrids was negligible (Patil *et al.,* 2004). At Dharwad, Halemani *et al.,* (2004) found higher yield with RCH-2 *Bt* (2857 kg ha^{-1}) followed by RCH-144 *Bt* (2794 kg ha^{-1}), RCH-20 *Bt* (2585 kg ha^{-1}) and MECH-184 *Bt* (2575 kg ha^{-1}) while at College Farm, Dharwad, RCH-20 performed better (Yenagi, 2006). In Guntur district of Andhra Pradesh, Chandrasekhar Reddy *et al.,* (2005) observed higher overall average yield with MECH-12 *Bt* and MECH-184 *Bt* (1231 kg acre^{-1}) over commercial checks (1149 kg acre^{-1}) while Prasad and Rao (2008) reported superiority of RCH 20 *Bt* in terms of higher (2.5%) staple length (30.61 mm), 5% staple length (15.03 mm) and elongation (6.33%), however, *Bt* hybrids were comparable with respect to uniformity ratio, micronaire and fibre strength.

Similarly, JK-CH 99 *Bt* was outstanding (3323 kg ha^{-1}) while JK- Durga *Bt* (3302 kg ha^{-1}), MRC-6322 *Bt* (3230 kg ha^{-1}) and NCS-207 *Bt* (2927 kg ha^{-1}) were on par (Joshi, 2007). Bunny *Bt* was also found competitive (2672 kg ha^{-1}) with 30.96% higher seed cotton yield, 39% more number of bolls plant^{-1} and 9.02% more boll weight than the non-*Bt* cotton hybrids (Rekha, 2007). This was attributed to its close association with number of bolls per plant (r = 0.53). RCH-144 *Bt* had good micronaire value (3.9) and elongation (5.2) with higher (2.5%) SL (30.0) and high tenacity (22.8 g tex^{-1}) (Khadi *et al.,* 2008), while RCH 20 *Bt* had more UR (51%) and maturity ratio (0.77). At Raichur, significantly higher uniformity ratio (47.83) and bundle strength (24.43 g tex^{-1}) were observed with MCCH- 184 *Bt* (Anand *et al.,* 2009). However, significantly higher elongation percentage was noticed with Bunny (6.7) followed by RCH-2 *Bt* (6.1) and MECH-184 *Bt* (5.9).

In south-western districts of Punjab, MRC-6029 *Bt* (Pankaj *et al.,* 2009) and at Faridkot, RCH 314 *Bt* (2749 kg ha^{-1}), NCS 138 *Bt* (2311 kg ha^{-1}), NECK 6R *Bt* (2268 kg ha^{-1}) and JKCH 1947 *Bt* (2200 kg ha^{-1}) fared better. At Nagpur, Maharashtra, the highest fibre bundle strength (25.0 g tex^{-1}) was recorded by RCH 386 *Bt* hybrid and it had micronaire of 3.0 (Palve *et al.,* 2009). Phad *et al.,* (2009a) at Nanded revealed superior performances of MRC 7301 BG II, NCS 954 BG II, NCS 207 BG II, NSPL 999 BG I and NCS 145 BG I for fibre characters. Further, Ankur-651 BG-I and NHH-44 (non-*Bt*), and MRC-7301 BG-II *Bt* hybrids recorded superior staple length of 29.4 mm while, Ajeet-II BG-II recorded higher ginning percentage (37.0) over check and RCH-2 BG-I (36.66%) (Phad *et al.*, 2009b). While at Parbhani, Atal BG II, Ankur Akka BG II, Ankur Jai BG I, Dhruv *Bt* and Sigma *Bt* performed well (Chinchane *et al.*, 2009). Gitte *et al.*, (2009) observed higher seed cotton yield (1358 kg ha^{-1}) with Bunny *Bt.*

Gopalakrishnan *et al.*, (2009) observed better performance of Bunny and Mallika. The activity of the enzyme increased significantly from 2.11- 2.92 µ mol NO_2 g^{-1} fresh weight on 30^{th} day after sowing to 3.31-3.93 µ mol NO_2 g^{-1} fresh weight on 60^{th} day after sowing irrespective of the atmosphere in which the hybrids were grown. While, Poongothai *et al.*, (2010) at Chennai reported significantly higher chlorophyll content with MECH- 184 over RCH *2 Bt* cotton.

At Dharwad, Karnataka, Pawar *et al.,* (2009) reported significantly higher photosynthesis, relative water content, NRA and chlorophyll content with NHH-44 *Bt* while, Patil *et al.*, (2011) reported significantly higher photosynthesis, chlorophyll content, transpiration, conductance and SPAD value with MRC-6322 compared to RCH 2*Bt*. Sharma *et al.*, (2009) reported good fibre properties of 26.8 mm fibre length, 4.0 micronaire and strength of 21.8 g tex^{-1} with IT-905.

Bt cotton hybrids also depicted wide range ginning out turn for intra-*hirsutum* hybrids ranging from 28.17 to 39.22 % and 2.5% while span length ranged from medium (23.59 mm) to long (34.72 mm) and micronaire value between fine (2.9) to medium (4.78) (Sarang *et al.*, 2010). At Raichur, Bunny *Bt* BG-II had significantly higher ginning out turn (37.39%), mean fibre length (31.73 mm), uniformity ratio (48.67%) and bundle strength (24.08 g tex^{-1}) (Manjunatha *et al.,* 2010b). However, maturity ratio and micronaire value did not differ significantly among the genotypes. At Nanded, MRC 7301 BG II (2095 kg ha^{-1}) and Ajeet 11 13G 11(1928 kg ha^{-1}) were significantly superior to checks, Ankur 651 BG I and NHH 44 Non-*Bt* (Phad *et al.*, 2010).

At Coimbatore, Tamil Nadu, Rajarathinam *et al.*, (2011) reported that Lakshmi *Bt* recorded 34.34 mm of fibre length while, Tulasi 162, SP 7149, Tulasi 171 and VBCH 1543 recorded fibre length of more than 24 g tex^{-1}. At Dharwad, JK Durga (BG I) *Bt* recorded significantly higher fibre fineness (3.96 micronaire) (Hosmath, 2011). While, Neeraja *Bt* recorded higher bundle strength (25.60 g tex^{-1}) while JK Durga (BG 1) *Bt* (25.52 g tex^{-1}), DCH-32 non-*Bt* hybrid (25.42 g tex^{-1}) and JK Durga non *Bt* (25.12 g tex^{-1}) were on par. On farmers' field at Belgaum, Karnataka Sudha (2011) obtained significantly higher seed cotton yield (2385 kg ha^{-1}) with Bunny BG-II. She also observed significantly higher 2.5 per cent span length in RCH-708 *Bt* while, higher fibre fineness and fibre maturity were observed in JK-99 *Bt*. Genotypes, however, did not differ significantly with respect to bundle strength.

At Nagpur, CNHH 2 *Bt* recorded significantly high ginning out turn (GOT) (42%) while CNHH 13 *Bt* recorded highest 2.5% span length (27.3 mm) (Singh *et al.*, 2011). The fibre strength was the highest for CNHH 12 (20 g tex^{-1}) compared to other *Bt* cotton hybrids. Manjunatha *et al.,* (2010a) at Raichur, reported significantly higher seed cotton yield (2155 kg ha^{-1}) while in Upper Krishna Project at Bheemarayanagudi with KCH-135 *Bt*, Akka *Bt* and RCH-530 *Bt* (1938, 1859 and 1613 kg ha^{-1}, respectively) performed better (Venkateshalu, *et al.*, 2010).

At Ludhiana, RCH 134 was superior (Sukhbir singh, 2010), while at New Delhi on sandy loam soil, MRC-6304 (5.30 t ha^{-1}) (Ahlawat and Gangaiah (2010) and MRC-7017 *Bt* (2.7 t ha^{-1}) (Gujar *et al.,* 2011) were outstanding. At Coimbatore, SP7157 BG II (3104 kg ha^{-1}) and SP7149 BG II (2601 kg ha^{-1}) were promising. Further, Rajendran *et al.,* (2011) from same place reported highest seed cotton yield with MECH-162 (2459 kg ha^{-1}). At Banswara and Udaipur (Rajasthan), JCH 50005 *Bt* recorded higher yield (1952 kg ha^{-1}) (Saini *et al.,* 2011). At Faridkot, Kulvir Singh *et al.,* (2011) recorded significantly higher seed cotton yield (2795 kg ha^{-1}) and leaf area index with MRC 7361over Bioseed 6488 and RCH 134 hybrids. At Dharwad, Karnataka, Hosmath (2011) recorded significantly higher seed cotton yield (2483 kg ha^{-1}) with Neeraja (BG II). ACH-155 (3533 kg ha^{-1}), and Ankur Jai *Bt* (3380) and Tulasi 117 *Bt* (3353 kg ha^{-1}) also fared better in Maharashtra (Jatav and Shastry, 2011). At Nagpur, Venugopalan *et al.,* (2012) reported superiority of RCH 2 *Bt* (1130 kg ha^{-1}).

Thus, new cultivars are continuously evolved with greater potential, however, a single cultivar cannot perform equally well at all places and varied climatic conditions (Table 1). Therefore, it is essential to assess the potential of new cultivars under varied agro-climatic situations and under extended planting during the season for their plasticity in productivity and reaction to climatic parameters in terms susceptibility to leaf reddening.

Influence of date of sowing

Crops, cotton being no exception, particularly under rainfed condition need to be sown early in the season with the onset of monsoon to make better use of moist period. Similarly, under irrigated condition though moisture is not a constraint crop essentially need to be planted early in the season to make best use of growing conditions to realize potential yields. However, often due many unpredictable reasons cultivator is forced to sow the crop late and hence it becomes necessary to investigate how long the yields remain unaffected under delayed planting situation or how best yields still can be obtained through management techniques.

Out of five planting dates (April 20, April 30, May 10, May 20 and May 30) hybrids (RCH 134, RCH 314 and MRC 6304) sown on April 20 produced higher seed cotton yield (24.9 q ha^{-1}), the performance, however, was comparable to the crop sown on April 30 (23.5 q ha^{-1}) (Sukhbir Singh, 2010). Similarly, Rajesh Kumar *et al.,* (2014) recorded higher sympodial $plant^{-1}$, bolls $plant^{-1}$, yield $plant^{-1}$, seed cotton yield and lint yield ha^{-1} in early planting (20^{th} April and 6^{th} May). Zaheer *et al.,* (2014) also obtained significantly higher boll weight (3.18g), seed cotton yield (65.2g $plant^{-1}$, 2711 kg ha^{-1}), seed index (7.7g), staple length (27.60 mm), and seed oil content (20.58%) from 1^{st} May sown crop.

If Egyptian cotton, Elayan *et al.,* (2015) found that delaying planting pushed cotton plants for an early flowering and maturity with fewer number of days to first open flower and first open boll and the seed cotton yields decreased consistently with each 15-days' delay in planting due to a significant decrease in each open boll $plant^{-1}$ and boll weight. The response to delay of planting was negative with quadratic and linear functions in the first and second seasons, respectively. The delay of planting was associated with a significant deterioration in fibre length and strength and hence lea count strength product and yarn elongation during both seasons. In the TBP irrigation command Pyati (2016) obtained significantly higher dry matter accumulation in leaves, stems and reproductive parts with transplanting/dibbling *Bt* cotton during 1^{st}

fortnight of June due early and faster accumulation of heat units. Similar was the finding of other workers (Table 2).

Thus, the response to delayed planting was negative with reduction in seed cotton yield associated with a significant deterioration in fibre length and strength. Probably delayed planting pushed cotton plants for an early flowering and maturity expressed in less number of days to first open flower and first open boll and the seed cotton yields per plant. However, responses may vary among locations, and in regions where few heat units accumulate early in the season, earlier planting appears to be of little benefit, while earlier planting may increase yields when a significantly larger amount of heat units accumulate near planting.

Response to seedling transplanting

Transplanting is common in vegetables and cereals like paddy. But it is one important climate smart technique which helps to overcome the problems of late planting and also helps to make use of available resources at the disposal of grower. Therefore, only recently some researchers have studied the possibility of transplanting and its impact on cotton crop performance.

Dong *et al.,* (2005) found that the seed cotton yield and seed yield were significantly higher in transplanting system (3121 kg ha^{-1} and 1763 kg ha^{-1}, respectively) than under normal planting (2825 kg ha^{-1} and 1590 kg ha^{-1}, respectively) and early planting (2497 kg ha^{-1} and 1398 kg ha^{-1}, respectively). Therefore, they suggested that transplanting is a better technique of plant establishment. Rajakumar and Gurumurthy (2008) found that direct seeding recorded a boll setting percentage of 30.29 as against 33.43 per cent under planting through poly bag seedlings which resulted in higher seed cotton yield (2253 kg ha^{-1}). In UKP, Karnataka, Salakinkop (2009) obtained 17 to 25% higher seed cotton yield (3.86 to 4.26 t ha^{-1}) from transplanting of seedlings over farmers' practice of dibbling (3.27 t ha^{-1}). Further, leaf reddening also decreased (7.8 to 9.2%) under transplanting compared to dibbled crop (19%).

Transplanting of 20 days old polythene bag nursery grown in FYM: Soil (1:1 mixture) recorded highest yield (3 336 kg ha^{-1}), however, direct sown crop on April 24 (3 521.2 kg ha^{-1}) and May 5 (3 390 kg ha^{-1}) were comparable (Kulvir singh *et al.,* 2009). In UKP irrigation command, Karnataka, Honnali and Chittapur (2013) observed that transplanting at 90 cm X 90 cm spacing was advantageous (1840 kg ha^{-1}).

Thus, transplanting helps in making best use of pre-season growing time, other farm resources and labour. When such nursery raised seedlings are planted in the season/early in the season by making use of local water avenues, the seedlings take time lead of almost over a month's period over the crop sown with the onset of monsoon/release of canal water in the irrigation commands by continuing from where they have stopped in the nursery. This ensures best use of the time besides making a summer crop possible in irrigated areas. And, cotton also likely to escapes the impact of reddening.

Response to nutrition

Sound nutrition is one of the ingredients of high yields in cotton. Nutrition affects the yields of cotton to a greater extent than its quality. Fruiting efficiency (ratio of boll/dry weight of stems) is one important yield parameters influenced by the nutrients. P, K, Ca, Mg, B and Zn have direct influence on fruit growth while N, S, Mo and Mn have equal influence on vegetative and reproductive growth. In the country, all cotton growing areas are very poor in organic carbon and N, soils are also poor in available P and medium to high in available K, and hence, adequate fertilization based on crop requirement and soil supply capacity needs emphasis for profitable and sustained production.

At Dharwad, Hosmath *et al.*, (2004) revealed significantly higher cotton yield with RDF + FYM (1169 kg ha^{-1}) and FYM (1169 kg ha^{-1}) compared to RDF (938 kg ha^{-1}), vermicompost (854 kg ha^{-1}), vermicompost + RDF (829 kg ha^{-1}), RDF + green manure (785 kg ha^{-1}) and green manure alone (713 kg ha^{-1}) on black soils. While at CICR, Coimbatore, Sankarnarayan *et al.*, (2004) obtained significantly higher opened bolls $plant^{-1}$ and seed cotton (1710 kg ha^{-1}) with 150% RDF which was on par with 125 % of RDF.

Reddy and Kumar (2010) at Warangal, Andhra Pradesh, indicated that cv. Brahma responded positively with a higher level of 250 kg N ha^{-1} (3628 kg ha^{-1}) compared to lower levels of N (150 and 200 kg ha^{-1}), whereas application of 60 kg P_20_5 and K_20 ha^{-1} recorded significantly higher seed cotton yield over 30 kg ha^{-1} while, Saleem *et al.*, (2010) at Faziabad observed highest seed cotton yield (3002 kg ha^{-1}) with application of 180 kg N ha^{-1}.

Singh *et al.*, (2010) at Pali-Marvar revealed progressive increase in the nitrogen levels up to 200 kg ha^{-1} increased the bolls $plant^{-1}$ (73.0), boll weight (3.24) and seed cotton yield (3080 kg ha^{-1}) and it was on par with 160 kg N ha^{-1}. At Coimbatore, Nalayani *et al.*, (2010) observed significant response the graded levels of N and P while application of RDNP recorded significantly higher plant height, leaf area index, dry matter $plant^{-1}$, good opened bolls $plant^{-1}$, boll weight and seed cotton yield (2300 kg ha^{-1}). At New Delhi, higher seed cotton yield was observed with application of 35 kg P ha^{-1} compared to 17.5 kg P ha^{-1} (Saleem *et al.*, 2010).

Application of 240:150 kg NK ha^{-1} with plant density of 7.5 plants m^{-2} recorded significantly higher seed cotton yield (1545 and 2158 kg ha^{-1}, respectively) at low and high fertility fields (Dong *et al.*, 2010). While, Kaur *et al.*, (2010) concluded that the application of 125 % recommended dose of fertilizer (187.5:37.5:37.5 NPK kg ha^{-1}) produced significantly higher seed cotton yield (2813 kg ha^{-1}) compared to recommended fertilizer (150:30:30 NPK kg ha^{-1}). Tayade and Dhoble (2010) observed increase in growth attributes (plant height, sympodial branches $plant^{-1}$, leaf area and dry matter accumulation $plant^{-1}$) and seed cotton yield with the application of 80:40:40 and 100:50:50 kg ha^{-1} NPK.

At Raichur, Karnataka, Biradar *et al.*, (2010) observed significant improvement in seed cotton yield with increase in fertilizer levels up to 150% and it was 2195 and 2420 kg ha^{-1} at 100 and 150 % RDF, respectively with an increase of 10.2 % over RDF. While at Akola, Bhalerao and Gaikwad (2010) obtained significantly higher seed cotton yield (910 kg ha^{-1}), bolls $plant^{-1}$ (22.1) and stalk yield (1650 kg ha^{-1}) with 125% RDF (62.5:31.5:31.5 kg NPK ha^{-1}) than with 75% RDF.

Further, Bhalerao *et al.*, (2012) obtained maximum cotton yield $plant^{-1}$ and number of bolls $plant^{-1}$ with 150 % RDF which was at par with 125 % RDF.

Majid and Mohammad (2011) also reported increase in yield with increase in N level and they recorded the highest seed cotton yield (4363 kg ha^{-1}) with 200 kg ha^{-1} N, further increase to 300 N kg ha^{-1} was not useful. At Sriganganagar on loamy soil, Nehra and Yadav (2011) observed significantly higher number of bolls $plant^{-1}$ (129), boll weight (4.41g) and seed cotton yield (3213 kg ha^{-1}) with application of 125 % RDF (182.5:50 kg NP ha^{-1}) over 75 % RDF and RDF.

At Coimbatore, Rajendran *et al.,* (2011) observed that 150:80:80 NPK kg ha^{-1} induced significantly higher dry matter production (4624 kg ha^{-1}), number of bolls (34.06 plant^{-1}), boll weight (5.41 g) and seed cotton yield (2411 kg ha^{-1}) compared to 120:60:60 kg NPK ha^{-1} (2164 kg ha^{-1}). Similarly, Devraj *et al.*, (2011) reported highest seed cotton yield (3061 kg ha^{-1} and 3902 kg ha^{-1} at Hissar and Sirsa, respectively) with 125 % RDF (187.5:75:75 NPK ha^{-1}) compared to 75% RDF and RDF at both the locations. At Nagpur, Maharashtra, Amboti and Thakare (2012) reported that application of 150 % RDF produced significantly higher seed cotton yield (1.9 1 ha^{-1}) and biomass yield (2.46 t ha^{-1}) compared to lower levels of fertilizers. At Junagadh, Gujarat, seed cotton yield increased with application of 240:50:120 kg NPK ha^{-1} to the tune of 20.51, 6.90 and 13.27 % compared to 120:50:120; 180:50:120 kg NPK ha^{-1} and control, respectively (Modhvadia *et al.*, 2012). On vertisols, at Parbhani, Maharashtra Asewar *et al.*, (2013) recorded higher seed cotton yield (2864 kg ha^{-1}) with 200:100:100 kg NPK ha^{-1}.

In Tunga Bhadra irrigation command, Karnataka, Basavaneppa (2012) observed maximum plant height, monopodia, and sympodia per plant with 200:100:100 kg NPK ha^{-1} and it was at par with 160:80:80 kg NPK ha^{-1}. Corresponding to higher seed cotton yield (2515 kg ha^{-1}), higher yield per plant (135.8 g) and boll weight (5.09g) were recorded with 180:90:90 kg NPK ha^{-1}. While at Raichur in the same command, Hosamani *et al.*, (20l3a) obtained significantly higher seed cotton yield (1925 kg ha^{-1}and 106.92 g plant^{-1}), mean boll weight (4.13 g), total number of bolls (26.19 plant^{-1}), number of good opened bolls (22.15), and lowest bad opened bolls (4.02 plant^{-1}) with the application of 125 % RDF over RDF (17.04 q ha^{-1}, 94.86 g plant^{-1}, 3.89, 24.42, 20.14, 4.31g, respectively).

Table.1 Advantages of *Bt* cotton over other hybrids

Character	Place	Reference
Higher yield	All over India	Anon. (2002), Khadi *et al.*, (2002), Udikeri *et al.*, (2003a), Kengegoud (2003), Hosmath *et al.*,(2004), Sudha (2011)
	Coimbatore	Manikarn *et al.*,(2009)
	Nagpur	Venugopalan (2002)
	Ludhiana	Sukhbir Singh (2010)
	New Delhi	Ahlawat and Gangaiah (2010), Gujar *et al.,* (2011)
	Raichur	Manjunath *et al.*, (2010a)
	China	Qaim and Zilberman (2002)
	Australia	Fitt and Roush (2003)
Insect tolerance/resistance	China	Wu *et al.*, (2000),
	India	Udikeri (2003b), Hegde *et al.*, (2004), Vennilla *et al.*, (2004), Bhosle *et al.*,(2004), Surulivelu *et al.*, (2004)
Earliness		Jagvirsingh *et al.*, (2003)
		Mayee *et al.*, (2004)
Economic profitability		Patil *et al.*, (2004), Mehta *et al.*, (2009)
Better quality lint	Guntur	Chandrasekhar Reddy (2005)
	Dharwad	Khadi *et al.*, (2008), Udikeri *et al.*, (2011)
	Raichur	Anand *et al.*, (2009), Manjunath *et al.*, (2010)
	Punjab	Pankaj (2009)
	Nagpur	Palve *et al.*, (2009). Singh *et al.*, (2011)
	Nanded	Phad *et al.*, (2009a)
	Parbhani	Chinchane *et al.*, (2009)
	Coimbatore	Rajarathinam *et al.*, (2011)

Table.2 Response of *Bt* cotton to time of planting

Planting time	Location	Reference
20th April	Ludhiana	Sukhbir singh (2010), Rajesh kumar *et al.*, (2014)
May 3rd week	Semiarid and arid regions	Ikbal *et al.*, (2012)
June Ist fortnight	Raichur	Pyati (2016), Hosamani (2017)

Table.3 Response of *Bt* cotton to fertilizer doses at different locations in India

Location	Nutrient applied (N, P_2O_5 & K_2O kg ha^{-1})	Yield (kg ha^{-1})	Reference
Dharwad	150:75:75 + fym 10 t ha^{-1}	1160	Hosmath *et al.*, (2004)
Coimbatore	150% RDF	1710	Sankaranarayan *et al.*, (2004)
Ludhiana	187.5:37.5:37.5	3745	Kaur *et al.*, (2007)
Parabhani	120:60:60	2183	Doli *et al.*,(2009)
Raichur	150:75:75	2953	Ghongane *et al.*, (2009b)
Nandyal	150:75:75	1942	Aruna and Reddy (2009)
Warngal	150:60:60	3628	Reddy and Kumar (2010)
Akola	62.5:31.5:31.5	1650	Balerao and Gaikwad (2010)
Siganganagar	182.5:50:0	3213	Nehra and Yadav (2011)
Coimbatore	150:80:80	2411	Rajendran *et al.*, (2011)
Hisar/Sirsa	187.5:75:75	3061-3902	Devraj *et al.*, (2011)
Parbhani	200:100:100	2864	Asewar *et al.*, (2013)
Siruguppa	200:100:100	2515	Basavenneppa (2012)

Table.4 Response of *Bt* cotton to foliar nutrition

Location	Nutrient suggested	Reference
Guntur	KNO_3 (2%), 4 sprays	Kumar *et al.*, 2011)
Bangalore	DAP (2%) and KCl (2%) at 60 & 75 DAS	Chellaiah and Gopalswamy (2000)
TBP command	KNO_3 1% at flowering and boll development	Basavanneppa *et al.*, (2015)
UKP command	19:19:19 (1%) and $MgSO_4$ (1%) at 80,, 105& 130 DAS	Honnali and Chittapur (2017)
TBP command	1% KH_2PO_4 at 60, 80 &100 days after sowing	Basavaraj (2017)

Table.5 Yield targets set and nutrients applied at different locations in India

Place	Yield Target (t ha^{-1})	Fertilizer applied (N, P_2O_5, K_2O kg ha^{-1})	Reference
Rahuri	1.2-1.6	86:61:12 (STCR)	Sonar *et al.*,(1984)
Coimbatore	2.5	50:0:0 (STCR)	Basu (1995)
Siruguppa	2.5	130:70:120 (SSNM)	Biradar and Aladkatti (2005)
Dharwad	3	217:59:148 (SSNM)	Police Patil (2007)
Raichur	4	195:100:200 (SSNM)	Manjunath *et al.*, (2014)
	5	400:140:142.5 (SSNM)	Pyati (2016)
Raichur	5	400:105:190 (SSNM)	Hosamani (2017)
Yadagiri	6	480:168:171 (SSNM)	Shivaraja (2015)

At Dharwad under rainfed condition Gundlur *et al.,* (2013) revealed that growth, yield parameters and yield (2303 kg ha^{-1}) were significantly improved particularly with 175 % RDF compared to RDF (1986 kg ha^{-1}). While, Thimmareddy *et al.,* (2013b) obtained significantly higher ginning percentage (35.2%), lint index (5.6) and fibre length (32.82 mm) with 150 % RDF over RDF alone (32.77%, 4.05, 31.68 mm, respectively), however, it was at par with 125 % RDF.

Seed cotton yield was also significantly influenced by varied levels of potassium fertilizer. Application of 90 kg ha^{-1} recorded higher plant height (137 cm), dry matter per plant (401.2g), bolls per plant (85.9) and seed cotton yield (2554 kg ha^{-1}) compared to lower levels of potassium (Mohan Das *et al.,* 2013). Gangaiah and Ahlawat (2014) at New Delhi observed that application of 180 kg N ha^{-1} produced significantly higher plant height (127 cm), LAI (3.87), no. of bolls per plant (54.0) and seed cotton yield (2980 kg ha^{-1}) over other nitrogen levels. Munir *et al.,* (2015) also obtained higher seed cotton yield (2197 and 2032 kg ha^{-1} in 2007 and 2008, respectively) with 180 kg N ha^{-1} which was at par with 120 kg N ha^{-1}.

In all, under irrigated condition crop responded to fertilizer application exceeding 150 kg N and 50 kg each of P_2O_5 and K_2O ha^{-1} while under rainfed condition the doses could exceed 100:50:50 kg ha^{-1}NPK ha^{-1} (Table 3) with potential cultivars and on heavy/productive soils the responses would always be better.

Foliar Nutrition

Not much information is available on foliar nutrition. Roberts *et al.,* (1997) reported that foliar applied potassium (K) for cotton was profitable in Tennessee studies on low K soil with fast-fruiting, and high yielding cultivars. K deficiencies can be corrected by foliar KNO_3 and they found that lint yields responded to K in foliar KNO_3 rather than the N. Harris and Brown (2000) reported that foliar feeding of nitrogen, phosphorus, potassium and boron was most effective when done during peak bloom period. Similarly in Karnataka, Chellaiah and Gopalaswamy (2000) observed response to foliar spray of DAP (2%) + KCl (1%) solution at 60 and 75 DAS. Waraich *et al.,* (2011) reported that the foliar application of potassium resulted in increased number of bolls, boll weight and yield $plant^{-1}$.

Kumar *et al.,* (2011) suggested 4 foliar spray of KNO_3 (2%), whereas, at Guntur Narayana *et al.,* (2011) revealed that 2 sprays of KNO_3 (2%) each at flowering and boll development stage are enough. More recently, in TBP irrigation command, Basavanneppa *et al.,* (2015) found that foliar spray of KNO_3 (1%) each at flowering and boll development stages recorded significantly higher seed cotton yield (2178 kg ha^{-1}), net return (Rs.51182 ha^{-1}) and B: C ratio (2:50) compared to only water spray (1903 kg ha^{-1}) or split application of MOP at 25 % each at sowing, thinning, flowering and boll development stage. While, in UKP irrigation command at Bheemarayanagudi, Karnataka, Honnali and Chittapur (2017) observed that three foliar sprays each of 1.0 % $MgSO_4$ and 19:19:19 at 80, 105 and 130 days after sowing coinciding with square formation, peak flowering and boll development alongwith application of 150:75:75 kg ha^{-1} N, P_2O_5 and K_2O and soil application of 25 kg ha^{-1} $MgSO_4$ at planting recorded higher seed cotton yield (2.07 t ha^{-1}), sustainability yield index (90.59%) and economics (Rs. 73 630 ha^{-1} and 2.65 net returns and B:C ratio, respectively) in comparison to application of recommended dose of fertilizer (0.87, 1.63, 70.41%, Rs. 57 380 and 2.38, respectively). Very recently, reduction in leaf reddening and improvement cotton yield was reported with foliar spray of 1% 4 at 60, 80 &100 days after sowing (Basavaraj, 2017).

All these workers attributed yield responses to better absorption and utilization of foliar applied nutrients at critical stages of cotton growth (Table 4).

Nutrient management for targeted yields

Cotton, particularly the hybrids are soil exhaustive and, therefore, require heavy nutrient supplementation. Nutrient requirement varies with cultivars, growing conditions and management practices, crop response and yield target. Of late, in the era of precision agriculture the concept of 'fertilizing the crop' is much important than 'fertilizing the soil' which has led from blanket recommendation to soil test based (Soil Test based Crop Response/STCR) or site specific (Site Specific Nutrient Management/SSNM) nutrition for preset target yields is gaining momentum. For achieving a definite yield target of a crop, a definite quantity of nutrients must be applied to the crop and this requirement of nutrients can be calculated by taking into consideration the contribution of soil available nutrients and fertilizer nutrients for total uptake. This forms the basis for the fertilizer recommendation for targeted yield of crops (Subba Rao and Srivastava, 2001). While, SSNM approach focuses on balanced and crop need-based nutrient application (Johnston *et al.,* 2009).

Site specific nutrient management is an approach for the timely application of fertilizers at optimal rates to fill the deficit between the nutrient needs of a high-yielding crop and the nutrient supply from naturally occurring indigenous sources, including soil, crop residues, manures and irrigation water. Hence, the results of experiments of target yield based nutrition are briefed hereunder.

Mizaev and Mamadaliev (1980) at Andizhan region of Uzbekistan indicated that average seed cotton yields of cotton were 3.68 t ha^{-1} without NPK, 5.08 t ha^{-1} with recommended rates of NPK and 5.7 t ha^{-1} with NPK rates calculated for a targeted yield of 6 t ha^{-1}. The uptake of 60 kg N, 20 kg P_2O_5 and 60 kg K_2O ha^{-1} seed cotton was the basis for calculating fertilizer rates together with a consideration of the coefficient of utilization of nutrients from soil and the fertilizer.

In India, fertilizer adjustment equations have been developed for cotton based on soil test crop response (STCR). Studies at Rahuri, Maharashtra with yield targets of 1.2 to 1.6 t ha^{-1} (Sonar *et al.,* 1984) revealed higher returns and comparable yields with 86:61:12 N, P_2O_5 and K_2O kg ha^{-1}. On the other hand at Coimbatore target yield of 2.5 t ha^{-1} was obtained with 50:0:0 NPK kg ha^{-1} based on fertilizer adjustment equation against blanket recommendation of 90:45:45 NPK kg ha^{-1} (Basu, 1995). This reveals the possibility of saving in chemical fertilizer if contribution of soil is taken into consideration.

On medium to deep black soil at, Parbhani, Maharashtra targeted yields of cotton were in close agreement with actual yields of cotton (Khandare *et al.,* 2002). Therefore, it was concluded that fertilizer prescription equation would be useful to adopt balanced fertilizer dose based on target yield concept in cotton. At Central Cotton Research Farm, Sreepur and, Jagdishpur, Bangladesh, Islam and Mian (2004) developed potassium fertilizer prescription equation for making fertilizer recommendations using data on cotton yield, soil available potassium and potassium fertilizer applied for calculating contribution from soil and applied fertilizer. Kalaichelvi and Chinnusamy (2004) studied the influence of STCR based fertilizer nutrients and potassium humate on cotton productivity and reported that application of 100 % STCR recommended NPK fertilizers recorded more number of sympodial branches, fruiting points, boll setting percentage and boll number over other levels. Higher seed cotton yield was recorded with 100 % STCR recommended NPK fertilizer combined with the soil application of potassium humate either 30 kg or 40 kg ha^{-1}. Bronson *et al.,* (2006) at Texas, USA, reported that nitrogen management effect on lint yields was highly significant, but the magnitude of the response was less than that of irrigation. Variable rate of N resulted in more consistent (1100 kg lint ha^{-1}) lint yield response than did blanket rate N.

Critical nutrient from the point of nutrition for an area is identified through omission plot technique which helps in ascertaining the key nutrient which greatly influences plant performance in a particular area and specific crop so that its supply could be considered on priority under resource constraints. Further, SSNM helps in nutrient supply based on soil supply, fertilizer contribution and crop requirement for a pre-defined crop yield and thereby helps in efficient utilization of both natural and fertilizer resources and also ensures production economy. Therefore, this technique which is superior to blanket recommendation is being used in different crops and farming situations of late.

Doberman *et al.,* (1999) reported that SSNM improved the plant uptake of N, P and K by 10 to 20 % and N use efficiency by 40 %. Similarly, SSNM approach was developed to increase mineral fertilizer use efficiency and to achieve balanced plant nutrition (Doberman *et al.,* 1999; Witt *et al.,* 1999; and Doberman and Fairhurst, 2000). SSNM approach is one such option which focuses on balanced and crop need-based nutrient application (Johnston *et al.,* 2009). Gill *et al.,* (2008) opined that by adopting the principles of SSNM in India, the present food grain production could be achieved from half of the current irrigated area and rest could be better utilized in crop diversification efforts. This remains true for cotton also. Further, SSNM which advocates need based supply of nutrients ensures application of nutrients at right time in desired quantities by the crop for obtaining set yield targets.

Gonias *et al.,* (2005) observed that leaf phosphorus concentration declined significantly for the P-deficient cotton treatment within 1 week after P was omitted from the nutrient solution. Membrane leakage also increased significantly by 1 week for the P-deficient treatment compared to the P-sufficient plants. At Tamil Nadu Agriculture University, Coimbatore, Rajan *et al.,* (2005) revealed that the omission of P application did not affect the seed cotton yield. However, the omission of N and K significantly reduced the seed cotton yield. Biradar and Aladakatti (2005) from ARS, Siraguppa, Karnataka, reported that 130:70:120 kg ha^{-1} plus the stand suite for secondary and micronutrients produced 2.3 t ha^{-1}. The NPK based RDF and PR treatment produced 2 t ha^{-1} and 1.9 t ha^{-1}, respectively.

Police Patil *et al.,* (2009) at Dharwad reported improvement in seed cotton yield with increase in the fertilizer levels targeted from 2.0 to 3.0 t ha^{-1}. Improvement in seed cotton yield was in the order of 63.90, 15.60 and 7.30 per cent over their respective target yield levels. Significantly higher seed cotton yield was recorded with 217:59:148 kg NPK ha^{-1} (3219 kg ha^{-1}) level over 145:39:99 NPK kg ha^{-1} (2738 kg ha^{-1}) level. However, 217:59:148 NPK kg ha^{-1}(2891 kg ha^{-1}) level was on par with 217:59:148 kg NPK ha^{-1} level.

At ARS, Siruguppa, Karnataka, Biradar *et al.,* (2011) observed that N omission reduced the seed cotton yield and net income by about 41 and 50 %, respectively followed by omission of K and P. Omission of N also resulted in lower net income compared to other nutrients. Similar was the finding of Chittapur *et al.*, (2017) in TBP command. However, omission of secondary nutrients such as Ca, Mg, S, and micronutrients such as Zn, Fe, and B had no drastic negative effect on cotton yields. Hence, they concluded that N followed by K and P were the major nutrients contributing to higher yield of *Bt*-cotton.

At Raichur, Karnataka, Manjunatha *et al.*, (2014) reported that application of nutrients under assured rainfed condition as per the target yield of 4.0 t ha^{-1} (195:100:200 NPK kg ha^{-1}) recorded significantly higher seed cotton yield (3940 kg $ha^{-1}$and 234.7g $plant^{-1}$). Aladakatti *et al.*, (2012) reported that soil organic carbon decreased in absolute control where no nutrients were applied (0.50 % to 0.38 %) and also in the N omission plot (0.50 % to 0.35 %). But there was no significant impact of omission of P, K and other nutrients on soil organic carbon. Soil available N, P and K were reduced from the initial soil status after first and second crop of cotton in the respective treatments where these nutrients were omitted. The soil available N, P and K were reduced to the extent of 61, 7.1 kg and 161.9 kg ha^{-1}, respectively in respective nutrient omission treatments at the end of second crop of cotton. Omission of N, P and K also reduced the seed cotton yield by 41, 9.3 and 27.3 %, respectively.

On farmers' fields in TBP irrigation command while validating SSNM, Chittapur *et al.*, (2017) obtained significantly higher number of bolls $plant^{-1}$, average boll weight and seed cotton yield (4384 kg ha^{-1}) was recorded with SSNM (for 4 t ha^{-1} yield target) treatment. Lower values for these attributes were recorded in nitrogen omission treatment (3707 kg ha^{-1}) followed by K and P omission treatments.

Thus, the foregoing review reveals that soil testing and fertility management is of great importance to any country for sustained crop production. The STCR or SSNM approach or targeted yield approach is a step ahead in fertilizer recommendation over the prevailing blanket recommendation as these approaches are based on soil fertility class (low, medium and high) and crop requirement (Table 5). Further, it is also clear that with the evolution on new and highly responsive and potential cultivars for commercial use the set yield target has also almost seen four-fold increase over the targets set initially (1.2 to 5.0 t ha^{-1}). So far efforts to achieve up to 5 t ha^{-1} targets were met with success in UKP and TBP commands of Karnataka (Shivaraja, 2015, Pyati, 2016 and Hosamani, 2017). They stressed early planting and supplementation of nutrition through $MgSO_4$, 19:19:19 and KNO_3 through foliage to manage leaf reddening during critical flowering to boll development period alongwith required NPK it is essential through to realize the set target. Therefore, it is pragmatic to fix yield target looking into the genetic potential of the crop/variety and other factors.

The fore-going review, no doubt, emphasizes the invigoration of Indian cotton production and industry with the advent of *Bt* cotton since 2002. The potential of these hybrids has witnessed quantum jump from one to over six tonnes per ha over years with broadened insect resistance/tolerance due to concerted efforts in biotechnology and plant breeding. However, continued monocropping practice by farmers driven by market is draining soil resources greatly. Besides, the changing climate particularly the delayed monsoon with its impact on soil moisture and heat units is also affecting production. Consequently, crop yields are either stagnating or decreasing. Under these circumstances, screening new cultivars, advancing sowing with available water or transplanting and crop nutrition based on soil supply capacity and crop removal for a pre-set yield target 5 t ha^{-1}) either through STCR or SSNM hold promise.

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