Improvement in Agro-Technologies for a Pest Free Quality Cotton Production – A Review on Indian Context

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Abstract

Cotton is grown commercially in India under Asiatic, American or Egyptian cotton groups and is primarily used for its natural fibre. The current scenario in cotton revolves round increased cost of cultivation not commensurating with the out put, spread of Bt (Bacillus thuringiensis) cotton, change in pest status as a result of Bt cotton cultivation, application of new molecules and deterioration of quality of ecosystem. Since the major emphasis in its cultivation has been the cost-cutting and low energy intensive farming with very low biotic pressure to harvest the better produce, improved agronomy has been in the forefront both from the point of integrated crop management and higher yield/quality. Of late there is a growing interest towards realization of millennium developmental goals through promoting green agriculture aimed at successful management of both natural and manmade resources while maintaining or enhancing the quality of environment and conserving natural resources. With new role in agriculture, recent agronomic approaches encompass appropriate & effective amalgamation of crop management tools that involves the blending of traditional knowledge with modern science. It is only such a blend that will empower the farming community in meeting the challenges posed by climate change and transboundary pests, as well as shrinking per capita land and water availability and expanding biotic and abiotic stresses. Thus, many of the agronomic practices that lower down the production costs assist in diminishing the pests load, increasing output and having better acceptability; are certainly adopted by the farmers. The details of improved agro-technologies for quality fibre production in Cotton on the context of India are discussed.

Cotton, *Gossypium* spp., popularly known as "white gold" being a premier cash crop of the country enjoys a superb status in economic and trade related activities besides sustaining substantial employment generation. Grown in all the three distinct agro-ecological regions (north, central and south), India produces all the cultivated species throughout the year. The ever increasing demand and premiums for the commodity have resulted in quantum jump in its production over the years from a meager 53 lakh bales (1 bale = 170 kg) during 1966-67 to a staggering 315 lakh bales in 2007-08 from 95.5 lakh hectares (AICCIP, 2008) with an average yield of 560 kg/ha and the contributing factors are many including high yielding varieties/hybrids, best crop management practices (BMPs) and current spurt in Bt (*Bacillus thuringiensis*) hybrid acreage. Yet, the productivity realized under existing agro-ecology in India is again low as against the world average of 760 kg/ha and is mostly constrained to its cultivation in unfavourable/rainfed areas because of other

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alternative crops that compete with it socio-economically.

Cotton is widely cultivated in both tropics and subtropics as a semi-xerophytic forced annual. With 65 % cotton acreage under rainfed in India where water management is critical and conservational management of stored soil moisture is crucial for realization of its yield potential. Moreover, high external input based cropping systems have also degraded the soil-water system, depleted soil organic carbon (SOC) stocks, fertility of soils and have led to an extension of new/secondary problems including multiple nutrient deficiencies, and salinization and water logging in many canal-irrigated tracts of India. In a cotton-wheat belt in Hisar (Haryana), 76 and 28 per cent of the soil samples analyzed were deficient in Zn and Fe. Deficiency of B in Nagarjuna Sagar Project area of A.P. and that of Zn in Faridkot and Firozpur (Punjab), Morena (M.P.) and Coimbatore (T.N.) has been widespread (Venugopal *et al.*, 1999). Therefore, role of integrated nutrient management (INM) and additions of organics *in situ* and *ex situ* is stressed upon.

Thus, best management practices are mandatory for attaining a stable and higher yield of the crop. Suitable agro-techniques *viz.*, proper planting schedules, optimum plant population and crop geometry, judicious and balanced fertilization/fertigation, use of improved and stable HYVs/hybrids, conservation of Bt in popular varieties, timely control of emerging pests and diseases including weeds, red leaf symptoms especially in Bt and hybrids, and effective irrigation scheduling for irrigated crop and proper water harvest cum management strategy for rainfed crop play a crucial role for achieving the above twin objectives (Rajendran *et al.*, 2005). Thus, cost-cutting and low energy intensive farming with very low biotic pressure to harvest clean pest free cotton with better quality is being stressed (Kairon 1998 and Kairon *et al.*, 1998).

Restoring quality of fibre is even more challenging than productivity *per se*. For long and extra-long staple cotton (ELS), ideally micronaire should be 3.8-4.2 instead of existing 3 or slightly above. Much of short staple but high micronaire and coarse cotton renders it difficult for spinning. Fibre strength in Indian cottons also needs a fill up. Moreover, short staple varieties *viz.*, diploids need improvement in length and micronaire to be spun easily leaving aside the inherent weaknesses. Thus, efficient cotton production technologies from the stand point of sustainability enable in realizing the potential yields with improved quality. Since there is a paucity of information in one place in relation to agro-technologies for quality fibre production on Indian context, an attempt is made here to spell out the development in research on these aspects.

Crop adaptation

The climate and soils are the pre-requisites for successful and profitable raising of a crop in an agroecoregion. Requiring a minimum of 15°C for germination and 21-27°C for vegetative growth, cotton can withstand temperature as high as 43° C yet doesn't favour temperature below 21° C for its growth and development. Moreover, warm days and cool nights with large diurnal variations are conducive during the fruiting for boll and fibre development. Prevalence of temperature stress beyond 42°C for long periods coupled with dry winds and prolonged dry spell cause physiological reddening of leaves disturbing N and its utilization and lead to yield reduction (Bonde, 1992 and Venugopal *et al.*, 1999). The above stress can be modified by irrigation and additions of organics for a profitable crop husbandry. Although cotton crop is hardy and semi-tolerant to salinity, yet it is sensitive to water stress at critical stages especially water logging at the early stage (CICR, 2008).

With the possibility of profitable intercropping systems in a rainfall range of 600-750 mm and 100-150 mm soil moisture storage (SMS), relay and sequential cropping are adopted only in a rainfall up to 900 mm and SMS of 200 mm with some exceptions. Thus, given the soil and climatic condition, choice of suitable genotypes and its intercrop and their proportion, fertilizer economy by a legume/cover crop, moisture conservation through live mulches and adoption of suitable weed control measures are the critical considerations for realizing higher fibre quality and yield (Rajendran and Jain, 2004). In a pH range of 5.5-8.5, loamy sand to sandy loam soil with effective drainage in north, deep vertisols in central and south, and loamy soils in south Indian pockets are preferred for American cottons while desi cotton is preferred in the above pH range even in marginal and shallow soil in central and south zone.

Tillage options

Optimum tillage under a given set of condition is detected by soil and crop characteristics; and it provides an optimum environment for a best possible start followed by a good carry over (through crop life cycle). In presence of a surface crust/subsurface hard pan, deep tillage is better over other tillage options (Brar and Kaur, 2007). Similarly, tillage plus wheat residues in cotton wheat system are advantageous over minimum tillage (Jalota *et al.*, 2008). However, on many occasions under normal condition, reduced tillage, a resource conserving technology, is also having its additional advantages in terms of moisture and nutrient conservation and carbon sequestration. Reduced tillage also controls some of key pests spending a major part of their life cycle in soils, e.g., pink bollworm (Dhawan and Sidhu, 1988, Russel, 2004).

Improved genotypes as planting materials

Selection of specific varieties/hybrids adopted for a region tested for stability over the years is the key for realizing the potential productivity as many varieties released for commercial cultivation in India have lost their relevance in terms of quantity and quality (Rajendran and Jain, 2004) although mostly Asiatic ones (*G. arboreum* and *G. herbaceum*) are inherently tolerant to pests. Cultivated varieties *viz.* CO-2, SRT-1, Khandwa-2, G. Cot-12, Badnawar, B-1007, NH-54 and MCU-5 are resistant to pests (Sundaramurthy and Chitra, 1992). PKV Hy-2 is tolerant to sap sucking pests in Vidarbha region of Maharashtra in India (Rajendran and Jain, 2004). Sucking pests tolerant ones viz., MCU 5, MCU 5 VT, SVPR 2 and Surabhi, whitefly resistant ones like Kanchana, Supriya and LPS 141 and the bollworm tolerant variety like Abhadita have also been preferred (Surulivelu, 2006).

Bt transgenic hybrids representing the state of art in bollworm management reduce the frequency in insecticide use by at least 50-75 % by ensuring favourable ecological, economical and sociological returns (Kranthi 2002, Kranthi *et al.*, 2002 and Halemoni *et al.*, 2004). Bt has a characteristic insecticidal activity due to crystal protein produced by the soil bacterium *Bacillus*. With more than 66% area under Bt cotton in India, the management and other criteria have to be modified accordingly for realizing sustained productivity and quality (CICR, 2008).

Adopted cropping systems

Cropping System is the intensification of crops in space and time dimensions. Being a more exhaustive and pest ridden one, cotton demands high energy intensive external inputs associated with environment safety. Suitable crop rotations involving cotton are given in Table-1. Host plants like sorghum, ragi and maize can also be grown after cotton to reduce the incidence of white fly and Helicoverpa (Rajendran and Jain, 2004) in addition to yield advantages. Increasing

Table 1. Major cotton based cropping systems prevalent in India

Zone/Region	States	Cropping Systems
North Zone	Punjab, Haryana and Rajasthan	Cotton-Wheat, Cotton-Mustard
Central Zone	M.P., Maharashtra and Gujarat	Cotton, Cotton-*Sorghum* (2-3 yrs), Intercropping of Black gram, Green gram, Soybean, Ground nut and Red gram in Cotton
South Zone	A.P.	Cotton, Cotton-Rice, Cotton-Chilli or Cotton-Tobacco (2 yrs)
	Tamil Nadu	Cotton, Cotton-Rice, Rice-Rice-Cotton, Cotton-*Sorghum*, Cotton-Pulses-*Sorghum*, Intercropping with Onion, Black gram & Ground nut in Cotton
	Karnataka	Cotton, Cotton-Wheat, Cotton-Maize, Intercropping with Chilli, Onion/garlic + Chilli, Intercropping of Ground nut, Black gram and Green gram in cotton

problems of currently emerged minor pests e.g. white grubs, termites and scale insects are expected along with nematode problems unless appropriate crop rotation is practiced (Rajendran and Basu, 1999). Moreover, removal and destruction of unopened bolls from cotton sticks also helps in reducing the carry over effect of pests like pink boll worm (Jayaswal and Sundaramurthy, 1992).

On the contrary, mixed crops are primarily designed under contingency crop planning for insurance against crop failure (Table-2). While grain legumes, sorghum, maize and sesame are mixed with cotton in central India, the crops like ragi, groundnut and millets are grown with cotton in Karnataka, parts of A.P. and T.N. These are planted on a regular pattern viz., 1-2 rows of pegion pea sown after every 8-10 rows of cotton; 3-5 rows of ragi or 2 rows of groundnut alternated with a single row of cotton and single row of castor after a few rows of cotton (Bonde, 1992). Short duration crops (70-100 days) with low canopy cover and quick growth viz., green gram, black gram, groundnut and dwarf soybean are also suitable as intercrops in cotton.

Experimental trials at western Maharastra (Rahuri) revealed that sunnhemp grown as green manure and incorporated *in situ* improved productivity of widely spaced hybrid cotton (Venugopal and pundari-kakshudu, 1999). Sunnhemp started decomposing following incorporation *in situ*, and in the process releasing nutrients especially N for better growth and performance of the crop. In addition, strip cropping of cotton and alfalfa/pigeon pea practiced now regulates the plant bugs by preventing the emigration and synchronizing the relationship between pests and natural enemies (Jayaraj *et al.*, 1990, Parajulee *et al.*, 1997, Geetha 1994 and Swaminathan *et al.*, 1999). However, drought tolerant species viz. castor in Gujarat and vegetable cash crops like cowpea, onion and chili are also taken up in assured rainfall areas of Dharwad, Karnataka.

Table 2. Effective intercropping systems for integrated pest management

Insect Pest	Intercropping Systems	Reference
Sucking pests	Cotton + Soybean	Balasubramanin *et al.*, 1996; Natarajan and Seshadri, 1988
Whitefly	Cotton + Sunflower & Cotton + Coriander	Mallapur *et al.*, 2004
Stem borer	Cotton + Chilli & Cotton + Bhendi	Mallapur *et al.*, 2004
American serpentine leaf minor	Cotton + Groundnut	Panchabhavi and Basavarajappa, 1994; Kennedy *et al.*, 1990
Jassids	Cotton+ Cluster bean Cotton + Onion Cotton + Bhendi & Cotton + Sunflower	Suresh *et al.*, 1993 Panchabhavi and Basavarajappa, 1994; Chakravarthy, 1997 Mallapur *et al.*, 2004
American bollworm	Cotton + Setaria Cotton + Maize Cotton + Clusterbean	Venugopala, 1994 Subiyakto and Sahid, 1990; Puri *et al.*, 1999 Suresh *et al.*, 1993
Spotted bollworm	Cotton +Ground nut Cotton + Rice Cotton+Bhendi (border)	Das, 1987 Thimmaiah, 1979

In a study at Georgia, USA, plots inter-seeded with legume cover crops (green manure) had higher number of predators requiring fewer insecticide sprays (Tillman *et al.*, 2002). Study at Coimbatore also reveals that the nematode, Rotylenchus sp. population was reduced significantly while beneficial microbes like Diazotrophs, facultative methylotrophs, Azospirillum, PSB and Mycorrhiza were higher due to polyethylene mulching (Nalayini *et al.*, 2004). Thus, the prudent utilization of all these techniques at opportune situation necessitates increased expertise which has to be created in cotton farming. Success of these strategies could be attained only by a missionary approach for targeted increase in cotton fibre.

Planting windows

Time of planting being the most critical non-monetary input, is highly influenced in an agro-climatic region since yield formation as a result of delayed planting would not be realized fully by other agro-techniques. Thus, optimum sowing time is a function of growth dynamics, moisture need and heat unit that varies with the growing conditions (irrigated/ rainfed). Sowing of dry land crops following onset of monsoon, dry seeding in rainfed areas of Maharastra, M.P. and Gujarat in

India before onset of monsoon have yielded dividends through increased yield and quality (Rajendran and Jain, 2004). Advancing planting time either through dry seeding or raising seedlings in nursery or polyethylene bags and transplanting these seedlings at 3-4 weeks with the onset of rain or by crow bar method under Akola, Maharashtra has also increased yield by 15-35 % (AICCIP, 2004).

Similarly, environmental modification of fibre maturity by temperature was most often identified in planting and flowering dates studies, and delayed planting usually lowered micronaire values (Porter *et al.*, 1996) leading to variable sowing time (Bonde, 1992 and AICCIP, 2008). Moreover, high incidence of pink boll worm and sucking pests especially jassids are associated with late sown condition (Rajendran and Jain, 2004). In north, staggered planting continued for 2 months due to water shortage leads to completion of 1-2 more generations by the pests leading to crop loss. Similarly, in south zone of India, high incidence of pink boll worm was observed in both early and late sown cotton crop (Dhawan *et al.*, 2004).

Plant rectangularity

Optimum crop spacing varies with genotypes, its architecture, soil type and its nutrient status and soil available moisture. Closer spacing is advantageous in many cotton-growing countries including India (CICR, 2008). Pest population is also controlled by optimum spacing (Puri *et al.*, 1999 and Surulivelu, 2006) and was also influenced by closer spacing (50x20 cm) *versus* wider spacing (75x30 cm) (Jayaswal and Sundaramurthy, 1992). American bollworm is significantly higher in 15-30 cm spacing than in 45 cm spacing. Hence, appropriate seed rate ensuring proper stand, spacing and crop canopy that ultimately enables in adoption of proper pest control measures to be followed in the season (Dhawan *et al.*, 2004).

Integrated weed management

Because of slow initial growth from emergence to around 60 DAS (25-60 DAS, the critical period), susceptibility to competition due to weeds was more apparent in cotton. Hence, effective weed control strategy involves an integrated approach where chemical method of weed control is blended with mechanical or cultural methods. Application of Fluchloralin @ 1 kg/ha or pendimethalin @ 1.25-1.5 kg/ha or butachlor @ 1 kg/ha as pre-plant followed by one interculture at 35 DAS has consistently performed better in control of weeds and increased yield in many areas of the country (AICCIP, 2004). For interculture, tractor drawn harrows in north zone and bullock drawn blade harrows in south and central zone are handy for control of weeds.

Pendimethalin @ 2.5 l/ha followed by a hoeing at Faridkot (Punjab), pendimethalin or prometryn @ 1.5 kg/ha at Sriganganagar (Rajasthan), pendimethalin or trifluralin @ 1.5 kg/ha as pre-plant along with one hand weeding (HW) at 35 DAS for controlling *Trianthema* spp at Sriganganagar (Rajasthan), Galaxy 45 EC @ 2 l/ha (a ready mix of clomazone @15 % w/w + pendimethalin @30 % w/w) along with one HW and two intercultural operations with *dora / kulpa* at Indore (M.P.) and hand weeding alone at Khandwa (M.P.) and Rahuri (Maharastra) were optimum for higher yield and net return (AICCIP, 2004).

In south, fluchloralin as pre-plant incorporation @ 1 kg/ha along with an interculture and HW at 25 DAS or two HW at 25 and 50 DAS under Lam, Guntur condition, HW or diuron @ 1-1.25 kg/ha along with HW at 30 DAS at Dharward, and two HW at 25 and 50 DAS or pendimthalin or fluchloralin @ 1.5 kg/ha along with two intercultural operations at 30 and 45 DAS at Raichur (KTK) are optimum. At Coimbatore (T.N.), HW twice at 20 and 40 DAS and galaxy @ 2 l/ha or fluchloralin @ 1 kg/ha as pre-emergence are effective. Thus, keeping weed free particularly during early stages for reducing crop-weed competition and managing reduced tillage and residues are the best as these are more energy efficient and have an ameliorative effect on soil quality (AICCIP, 2004).

Under rainfed condition (e.g., Kovilpatti in Tamil Nadu), intercropping of cowpea in cotton, with pendimethailin or butachlor applied as pre-emergence @ 2 l/ha along with single HW at 40 DAS was effective for controlling weeds and getting higher yield. Manual collection and removal of weeds like Abutilon indicom, Datura metal, Acanthospermum hispidum and Gynandropsis gynandra is also essential under an effective weed/pest control strategy (Rajendran and Jain 2004, Dhawan *et al.*, 2004).

Soil parameters and fibre quality

Study on the pattern of relations between fibre properties *versus* soil parameters reveals that micronaire, fibre length, elongation, uniformity and strength are more strongly correlated with soil moisture and soil P. Soil pH and organic matter also enhanced fibre quality parameters. Fibre length, micronaire, strength and elongation were also influenced by water supply for e.g. moderate moisture stress increased length but did not increase strength and maturity (Venugopalan *et al.*, 2004). Similarly, increasing the salt concentration in a soil with 1.6 dS/m using 70, 140, 210 mol/m^3 NaCl increased GOT and fibre fineness where as staple length, fibre maturity and fibre strength decreased at higher salt concentration i.e., 140 and 210 mol/m^3. Fibre strength and fineness decreased when salinity was lower than 5.43 dS/m. Soil salinity results in differential uptake of cations, causing changes in cationic ratios in the plant tissues and alteration in fibre properties.

Improved crop nutrition

Improved crop nutrition aims at maintenance or adjustment of soil fertility and of plant nutrient supply to an optimum level for sustaining the desired crop productivity (FAO, 1998) through optimization of benefit from all possible sources of plant nutrients in an integrated manner (Roy and Ange, 1991). Thus, balanced dose of N, P and K is usually applied to the soil in the ratio of 2:1:1 or 3:1:1 (in terms of N: P_2O_5:K_2O) and proper and judicious management of nutrients is helpful for higher yield by influencing pest control (Basu, 1992, Venugopal *et al.*, 1999 and Rajendran and Basu, 1999).

Nitrogen, the major growth nutrient is known to positively interact with irrigation, plant population, optimum sowing window, other nutrient elements especially P and K, absence of weeds/pests and presence of organics in soil. In-situ/ex-situ determination of Plant-N status through petiole analysis of terminal fully unfolded leaf (with 2000 ppm as critical level) is required for controlling incipient/acute deficiencies in plant for its application (Venugopal et al., 1999). Since the index of efficient use of fertilizer-N is higher yield per unit N applied and greater B: C ratio, splitting N needs of the crop to earthing up/thinning (50%) and flowering (50 %) have yielded better results over that at planting and earthing up operations. However, fibre quality is said to have adversely affected by N beyond optimum although improved GOT with N supply is observed (Venugopalan *et al.*, 2004). Studies show that uniformity ratio, GOT, lint index and maturity co-efficient were usually not influenced by the variation in N additions (Nehra, 2005) although span length was increased significantly up to 120 kg N/ha. In a 5 yr study, micronaire decreased with increasing N rates from 101 to 202 kg/ha (Reddy *et al.*, 2004).

Management of P and K, however, requires long term strategy as biological and chemical transformations don't add or deplete P and K from the rhizosphere easily. Thus, basal placement of P within the active root zone is advocated (for less contact and less fixation) over broadcasting on top soil or splitting. Moreover, crop response to P varies with species of cotton (less with desi/ variety and higher with hybrid) and growing condition (usually less with rainfed). Water-soluble sources of P are more efficient over others especially when P is applied as foliarly, and along with N it increases nutrient use efficiency. However, antagonistic effect of P on Zn, Fe and Cu is noticed. Plant-P contents at reproductive stages (70 to 150 DAS) are also related to yield (Venugopal *et al.*, 1999).

Crop response to K is also highly inconsistent and variable due to inherent soil K status and dynamic K-transformations. Cotton being a subsurface feeder, K extraction from lower depth in the soil profile also influences K balance and its uptake from soil. K application possibly increases the micronaire and the values of 3.5-4.9 are regarded the most desirable in respect of fibre strength. Thus, moderate K supply not only improved boll size but also its fibre strength and micronaire. Study at Coimbatore shows that application of 1/3 of the total K through foliar during flowering and the remaining through soil at sowing maintained 30-306 % increase in K in the leaves during the reproductive stage, improved 2.5 % span Length, uniformity ratio, fibre fineness, maturity coefficient and fibre strength over control (Shanmugam and Bhatt, 1991). Application of 2/3rd of K dose through soil and the remaining as foliar spray improved fibre quality parameters compared to control (no K) as well as application of the entire quantity (45 kg/ha) through soil (Bhatt, 1996).

Besides NPK, integrated nutrient management (INM) involving organics and inorganic nutrients plays a pivotal role in long term sustainability in cotton. Three years data collected from 267 sites in India under different crops convincingly show a 22 % increase in yield by following INM rather than farmer's practice (Govil and Kaore, 1997). Since secondary and micronutrients, S and Zn deficiencies are also on the rising trend (Rattan *et al.*, 1999), an integrated plant nutrient system (IPNS) is the most efficient and practical way to mobilize all the available, accessible and affordable nutrient sources for optimizing crop(s) productivity and economic return (Praharaj and Rajendran, 2007).

Blaise and Ravindran (2003) reported that leaf or leaf + stalk amended plot yields were equal to that in control; and stalk alone amended plots had the least seed cotton yield. However, in a field trial at Coimbatore, when GM was applied alone or in combination with FYM (with or without CR), it resulted in a release of nutrients following mineralization of organic sources, and probably inhibiting immobilization (Praharaj *et al.*, 2006). Similarly, Venugopal *et al.*, (1999) also revealed that application of 12-18 t/ha of FYM or green manure increased yield of cotton by 16-20 % at Coimbatore.

Study at Coimbatore (Tamil Nadu) reveals that an integration of organics i.e. combined application of FYM @ 5t/ha (15 days before sowing, DBP) and sunnhemp seeded @ 15 kg/ha simultaneously in inter-rows of cotton as green manure (GM) and buried at 45 DAP produced significantly higher seed cotton yield and lower pest population over the RDF of fertilizers (Praharaj *et al.*, 2006). With similar yield to that under FYM+GM, fibre Quality Index (an index of span length, bundle strength and micronaire value) was maximum (386) under FYM + GM + crop residues (viz., FYM @ 5 t/ha + cotton whole crop residues @ 2.5 t/ha (60 DBF) + sunnhemp buried at 45 days as GM) which proved the role of *in situ* management of inputs on quality fibre under irrigated condition (Praharaj *et al.*, 2006).

In a two year rotation, although cotton residue alone resulted in yield decline (Basavaneppa and Biradar, 2002, Praharaj, et al., 2005 and Praharaj, et al., 2006), yet when applied in combination with FYM and Vermicompost, the yield was similar to FYM + Vermicompost + fertilizers. Seed cotton yield were higher with low pressure of pests under more than two components of INM (FYM, GM, Phosphorus solublizing bacteria (PSB), 2% DAP spray) than chemical fertilizers in a study across three locations (Nagpur, Nandyal and Dharwad) in India (Singh, 2003).

Secondary and micronutrients

Limited studies reveal the positive response of micronutrient on yields, oil and protein content in seed. Foliar sprays of SO_4 viz., $MgSO_4$ @ 0.5-1 % twice on 60th and 80th day (at flower and boll development) increased the yield. Spraying of $ZnSO_4$, $FeSO_4$ and Borax @ 0.5% at 45, 60 and 75 DAS were found to increase the yields in deficient soils (Nehra, 2005). Problematic soils *viz.*, salinity and alkalinity result in differential uptake of cations, causing changes in cationic ratios in the plant tissues, thereby resulting in alteration in fibre properties.

The symptoms of micronutrient deficiency include reddening of leaves due to deficiency of Mg while Fe and Mn deficiency leads to chlorosis of leaves. To the contrary, Zn and B deficiency lead to the problem of improper bud and boll opening and subsequently in boll rotting. For foliar deficiencies, Mg as 1% $MgSO_4$ as aerial spray while others @ 0.3-0.5 % SO_4 of Fe, Mn and Zn or 25-50 kg sulphates of these cations to soil per hectare is useful. For correction of a deficiency, 0.1 % boric acid is beneficial (Mannikar and Venugopalan, 1999).

Nutrient recharge and interactions

A better example of nutrient recharge involves application of organic materials/ complexes for higher efficiency with lower nutrient loss from soil. Evidently, application of FYM, GM mulching, Glyricidia green foliage loppings and sun hemp as GM recorded 15-32 % increase in yield over control and there was considerable build up of soil available nutrients following these (Bonde, 1992). Besides direct addition of N to the available pool of the soil, organics addition resulted in the greater multiplication of soil microbes following microbial decomposition that could convert organically bound N to inorganic form thereby help restoring soil N status. Organics reduces P fixing capacity of soil through organic complexes with sesquioxides. Enhancement in K availability is also fortified and release of K to soil pool due to organic matter-clay interaction and reduction in K fixation following mineralization of organic matter. Thus, INM or IPNS has a tremendous role in soil nutrient recharging.

Leaf reddening

Red leaf systems (RLS) appearing towards peak flower and boll development cause reddening of leaves and cracking of bolls leading to lower yields. *RLS* is usually attributed to Mg deficiency, lower leaf N content, sudden fall in night temperature and low soil N supply (Bhatt et al., 1982 and Khader, 2008). leaf reddening is due to the sudden lowering of night temperature in the month of October and afterward, prevalence of water logged conditions for a prolonged period, moisture stress, excessive boll load, synthesis and accumulation of anthocyanin pigment lead to the appearance of red leaf symptoms and N deficiency in the leaves, genetic make up of variety during early to late boll developmental stage. This disorder is different from the normal senescence. Senescence need not necessarily lead to the appearance of leaf reddening symptoms (Sarlach et al., 2008). Potassium deficiency frequently has been mentioned as a primary suspect. Plant age, fruit set and load, earliness in fruiting and maturity, and high yield potential also effect symptom severity (Khaskhali, 2008).

Biochemically, the polyphenol complex of cotton leaves, expressing an abnormal red colouration under abiotic stress, when analysed by using high performance liquid chromatography (HPLC) and separating out different polyphenol types viz., cinnamic acid derivatives (C6-C3), flavonoids (C6-C3-C6) and anthocyanins (C6-C3-C6') revealed that reddening of cotton leaves was related to an increased formation of anthocyanin pigments, mainly cyanidin glycosides, while cinnamic acid derivatives and flavonoids were not significantly changed. The plausible protective role of anthocyanins is also there; particularly taking into account the shift from malvidin to cyanidin aglycones, i.e. to o-dihydroxy substitution in the B-ring of the anthocyanins during cotton leaf reddening that may determine a higher antioxidant and antiradical capacity (Edreva *et al.*, 2006).

Thus, reddening of leaves is a physiological disorder in cotton mainly induced by different abiotic stresses. Dramatic biochemical changes occurred in reddening leaves such as strong accumulation of anthocyanins and drop of chlorophyll content, important increase of proline content and peroxidase activity. The lipid peroxide content indicative of membrane fragmentation was decreased. In this way a multicomponent system encompassing anthocyanins, proline, and peroxidase may act coordinately to overcome abiotic stress in cotton (Edreva *et al.*, 2002). The reddening of cotton leaves has also been associated with low leaf N concentrations in F1 hybrids with heavy fruit loads (Bhatt *et al.*, 1982) and reduced amino acid levels of prematurely reddened cotton leaves. The red color has been identified as anthocyanin (Ant), which is unmasked by chlorophyll breakdown (Combrink, 1988).

Reddening in Bt cotton leaves was reduced by 30-40% with foliar application of urea @ 2 % + DAP @ 2% + $MgSO_4$ @ 1 % given at full boll formation stage (CICR, 2008). Since varieties of G. hirsutum and G. barbadense as well as hybrids including Bt hybrids manifest reddening of leaves, a combination of magnesium sulphate (2%), urea (1 %) and zinc sulphate (0.1 %) as foliar sprays on 50th and 80th day corrects the RLS malady. These sprays prevent further development of reddening as well (Karivaradarajau *et al.*, 2008).

Biofertilizes

Biofertilizers *viz.*, *Azotobacter* and *Azospirillum* play a useful role in reducing cost of cultivation by way of increasing fertilizer use efficiency especially that of N. Seed inoculation with *Azotobacter* has resulted in saving of fertilizer to the tune of 20 kg N/ha. In cotton-chick pea sequential crop at Rahuri, India maximum yield was realized in the combination of FYM @ 5 t/ha, GM (*Sesbania* sp.) buried *in situ*, Azotobacter, Azospirillum and seed treatment with PSB; followed by that of FYM @ 5 t/ha and Sesbania buried in situ (AICCIP, 2008). However, in absence of a biofertilizer, loose seed can be treated with thiram 75-D @ 3 g + 1 g carboxin + 3 g captan or 1 g carbendazim + 3 g thiram/captan per kg of delinted seed. Even simple pre-soaking of seed in water for 6 hours improves germination to a great extent and is equally effective both for rainfed and irrigated conditions. Usually, *Azospirillum* @ 3 packets (600 g) per hectare and 2 kg *Azospirillum*/ha mixed with 25 kg FYM and 25 kg soil and applied on the seed line saves 25 % N besides increasing the yield (CICR, 1997).

Nutrient management in cotton based cropping systems

Differential crop(s) uptake pattern is the deciding factor for nutrient additions in a cropping system. In irrigated north, wheat is applied with recommended NPK (120:60:60 kg/ha) and the following cotton is only given N @ 80-120 kg/ha without P and K. The residual effect of high N to wheat increased strength and maturity ratio in cotton (Venugopal *et al.*, 1999). Under central zone (Nagpur) in India, application of NPK @ 60:30:30 kg/ha along with 7.5 tonnes of FYM was beneficial for stable fibre yields (Mannikar and Venugopalan, 1999). In cotton-*sorghum* system in central (Nagpur) and south zone (Coimbatore), both P and N supply prevented the decline both in cotton yield and sorghum yield. No yield benefit however, was observed with K supply; and yield was highest when pooled or part of the nutrient requirements was replaced with bulky organic manure (FYM). Application of organics to cotton is preferred over sorghum when it is in short supply and for getting optimum response and output although NPK @ 60:30:30 kg/ha is sufficient in vertisols under existing conditions.

In rice fallows of south zone in India, short duration cultivars can be grown immediately after paddy. Since P and K applied to paddy also takes care for cotton, only N is to be given to it (Mannikar and Venugopalan, 1999). In cotton-*sorghum* cropping system, cotton should be given full dose of NPK while P and K may be skipped to succeeding summer *sorghum* crop (Praharaj and Rajendran, 2007). However, in most cases, summer cotton and its ratoon may be avoided for the pest menace. Crop rotation involving restorative and exhaustive crops including varied depth feeders *viz.*, cotton-*sorghum*/ragi is necessary for higher nutrient use efficiency (NUE) and desired sustainability.

Irrigation scheduling

Crop requires about 1/3rd of seasonal water use (of 70-120 cm) during initial growth till flowering and the rest during flower and boll development. The break up of water use per day at different phases of the crop under normal condition is a) up to 1st flower, 3.8 mm water/day, b) up to peak bloom, 8.9 mm water/day and c) at the last bloom up to harvest, 5.1mm water/day (Bonde, 1992). Since germination, square formation, flower opening and boll developments are the critical stages for irrigation in cotton, thus, normal irrigation schedule includes a pre-sowing irrigation, life irrigation at 3-5 DAP and subsequent irrigations in 10-12 days interval till arrival/continuance of monsoon and withholding irrigation after 35% of bolls are opened (Venugopal *et al.*, 1999). Scheduling on irrigation based on IW/CPE (irrigation water/cumulative pan evaporation) ratio showed that a ratio of 0.6 with 6 cm depth of irrigation was optimum for cotton at Hyderabad. However, at Rahuri, the ratio of 0.45 was better during pre-monsoon period as irrigation is not usually required during peak activity of monsoon. On depletion basis, cotton performs optimally if irrigated at 50-75 % depletion of available soil moisture.

With application of precision technology, drip irrigation shows its superiority over conventional system with water saving (by 40 %) besides higher productivity and WUE. With recovery of installation cost within 2 years, other key benefits of irrigation thro' drips include uniform maturity with optimum fibre quality, culturability of sloppy and lighter soils and partial use of saline water are envisaged. More economically, paired row planting (60/120 cm) with drip irrigation was the most profitable over conventional planting with furrow irrigation. Fibre quality parameters of LRA 5166 like 2.5 % S.L and fibre quality index were influenced significantly due to polyethylene mulching up to 30 micron thickness (Nalayini *et al.*, 2004).

Irrigation water as a controllable factor influences on both status and pests' spread as pest incidence is usually low in the crop irrigated at optimum rate and time. Excess soil available moisture leads to excess vegetative growth and often attacked by white fly and other pests and may also shift the balance between the vegetative and reproductive growth, thus delaying maturity, reducing yield and GOT and promote boll shading, disease and insect damage (Surulivelu, 2006). Moreover, infection continues since excessive growth of plants hamper effective and uniform spray of the control chemical. Study under south zone reveals irrigation beyond September 30th and N beyond 100 kg/ha encourages whitefly buildup and diapausing population of pink boll worm without raising cotton yield (Jayaswal and Sundaramurthy, 1992).

Use of growth regulators and defoliants

Defoliants *viz.*, dropp and Ethrel have also no adverse effect on the quality of cotton. Dropp @ 150-200 g/ha in 600 litres of water applied at 60 % boll opening increased opened bolls by 39-45 % in North India (Ganganagar, Hisar and Ludhiana) thereby hastening crop maturity and vacated the cotton fields 2 weeks earlier for sowing of winter crops (AICCIP, 2004). For reducing physiological shedding of squares, flowers and bolls, two sprays of NAA @ 10 ppm (planofix @ 100 ml in 450 litres of water) be given at 15 days' interval at 45 and 60 days after sowing. NAA (planofix/fuitofix) @ 30 ppm at flower primordial initiation followed by that @ 20 ppm applied after 15 days of 1st spray could retain 35 % more bolls and 300 kg more *kapas* yield per hectare. Cytokinin @ 10 ppm delays senescence and promote fruit setting. Application of ascorbic acid @ 40 ppm and that of Zn, B and Mg @ 10 ppm improve boll retention and yield. In addition, sucrose @ 5 % along with ascorbic acid @ 40 ppm and NAA @ 10 ppm check severe square shedding (AICCIP, 2004).

Species specificity reveals that American upland cultivars (*viz.*, F 846, LH 2002 and F 886) have higher leaf conductance and leaf transpiration, lower sugar content, osmotic potential and sodium content in the sap under salinity than the desi varieties (LD 327, LD694 and LD927) indicating tolerance to salt stress in American and susceptibility in desi varieties of cotton (Kumari and Gill, 2007).

Manual removal of alternate leaves from lower most branches reduced incidence of pests and diseases (and decay of bolls) through facilitating free air circulation. For control of excessive vegetative growth, topping/nipping of branches/main stem at 70-80 DAP is beneficial. However, CCC/cycocel @ 4.4 ml or linocin @ 4 ml mixed in 50 litres of water applied at 65-70 DAP (@ 40 ppm) will replace desired manual topping with no harmful effect besides improving yield (AICCIP, 2004).

Conclusion

Although fibre quality is primarily governed by the genetic make up of the cultivar, yet strong genotype and environment (including management options) interactions exist in terms of fibre yield which modify the ultimate quantum and expression of fibre properties. Fibre property modulations due to the application of agronomic practices are not confirmatory and even contradictory to the complex interactive effects of genotypes, climate and soils. However, best crop management practices is likely to complement and supplement the quality with the optimum output i.e., fibre production.

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