AMELIORATION OF SOIL RELATED CONSTRAINTS FOR IMPROVING EXTRA LONG STAPLE COTTON PRODUCTION

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The National productivity of cotton (503 kg lint/ha) is far below the world average (715 kg lint /ha). This low productivity may be attributed to the fact that major area of cotton cultivation (65 per cent) is under rainfed condition, where there is no control over distribution of water. Further soil management has not been paid adequate attention as deserved compared to the cotton growing countries where the productivity is quite high. It is pertinent in this context, to review the soil management practices according to soil properties and constraints and follow site-specific ameliorative measures to improve the National productivity of cotton. This aspect needs urgent attention to meet the production target of 350 lakh bales by 2010 as demanded by the Confederation of Indian Textile Industries.

Soils of cotton growing zones

Cotton is predominantly grown three distinct agroecological zones (North, Central and South) besides in negligible areas in the East zone (Mannikar and Venugopalan, 1999).

The North zone comprises of Punjab, Haryana, Rajasthan and Western Uttar Pradesh. It occupies only 15.9 per cent of the total cotton area but contributes to more than 18.5 per cent of the total cotton production. This zone almost totally irrigated. The soils of this zone are alluvial (Entisol), sierozem (Entisol and Inceptisol) and sandy soils (Aridisol).

The Central zone is spread over Maharastra, Madhya Pradesh and Gujarat. It occupies more than 67.7 per cent of the total cotton area but contributes to less than 60 per cent of the total production. This is predominantly a rainfed area with only 23 per cent is under irrigation. The soils of this zone are shallow to deep black (alluvial soil) and alluvial (Entisol).

The South zone covers the states of Andhra Pradesh, Karnataka and Tamil Nadu. It occupies only 15.3 per cent of the total cultivated area and contributes nearly 16.3 per cent of national cotton production. Nearly 40% of the cotton growing areas in this zone is irrigated. The soils in this zone are black (Vertisol), red (Alfisol), alluvial (Entisol) and to a negligible extent laterite soil (Oxisol).

Besides these three zones cotton is also grown in a small proportion (<1 per cent) in the Eastern states like Assam, West Bengal and Orissa under rainfed condition. The soils of this zone are predominantly red (Alfisol) and laterites (Oxisol).

Soil characteristics and constraints for ELS cotton production

For any crop, soil characteristics are very important as environment provided by soil and climate govens the growth of the crop. Cotton being a commercial crop, its soil site suitability characteristics have been worked out (Sehegal et al., 1989) and presented in Table 1. Soils are graded from most suitable to unsuitable based on the characteristics.

ELS cotton is predominantly grown in the southern zone states viz., Andhra Pradesh, Karnataka and Tamil Nadu and in some pockets of Maharastra and Madhya Pradesh. The soils of ELS cotton growing areas are Black (Vertisol), red (Alfisol), alluvial (Entisol) and to a less extent laterite soil (Oxisol). The characteristics and constraints for cotton production in these soils are discussed here under.

(i) **Black soil:** The soils developed on gneisses and schiests and are moderately shallow (50-75 cm) to moderately deep (75-100 cm) where as those developed on basalt are deep (100-150 cm) to very deep (>150 cm). These soils are highly argillaceous with clay content varying from 30-80%. The clay is dominantly smectitic in nature, which has high coefficient of expansion and contraction, which leads to the development of typical features such as gilgai micro-relief, deep and wide cracks and closely intersecting slicken sides. The members developed on calcareous clay parent material have high $CaCO_3$ content that increases irregularly with depth. These soils have pH values ranging from 7.8 to 8.7, which may reach up to 9.4 in sodic soils. These soils have cation exchange capacity (35-55 c mol (p+) kg^{-1}) and rich in base status. Although the black soils have relatively high moisture holding capacity (150-250 mm/m), yet water is not available to plants because the water is held tenaciously by the smectitic clay. These soils are extremely sticky when wet and extremely hard when dry. These soils have low permeability and the bulk density of these soils is generally high (1.5 to 1.8 Mg m^{-3}) because of shrinkage on drying.

The main constraints in this soil to cotton production are due to their narrow range of workable moisture, low infiltration and poor drainage when wet leading to water logging and high runoff and soil loss during heavy downpour. Otherwise these soils suffer from moisture stress during drought. These soils are poor in organic carbon, nitrogen, sulfur and phosphorus. Water holding capacity is a major problem in shallow soils. Whereas deep soils when irrigated are very much prone to salinity and sodicity particularly in the subsoil. The calcareous nature of these soils affects the availability of many micronutrients.

(ii) **Red soil**: These soils are mostly derived from crystalline granite and metamorphic rocks, such as gneisses, schists, mainly of archaean period. Occasionally, the red soils are developed on micaceous schiests, sandstone, limestone and shales. Morphologically the red soils are divided into two broad subgroups i.e. (a) Red loam and (b) Red earth

Red loams are characterized by argillaceous, clay-enriched profiles with a cloddy structure and having only a few concretionary materials.

Red earths are characterized by loose and friable topsoils but rich in secondary concretions as a consequence sesquioxide type of clay.

The colour of the red soils varies from red to yellow due to coatings of ferric oxides on the soil particles, rather than to a very high proportion of the iron content. It is red when the ferric oxide occurs as haematite or anhydrous FeO and yellow when the ferric oxide occurs in hydrated form eg. Limonite. These soils are highly variable in texture from loamy sand to heavy clay, but generally they are loam to clay loam. The soil depth varies from shallow in uplands to very deep in valleys. Most of the red soils are well drained. The pH of these soils (6.0-7.5) varies from slightly acidic to neutral (or alkaline). These soils are low in CEC and base saturation. The CEC of clay fraction varies from 25 to 42 cmol (p+) kg $^{-1}$. These soils are low in N and P but high in K. These are poor in organic matter and lime content.

The main constraints in these soils include surface crusting and low soil depth under upland conditions. These soils are low in water holding capacity and have high soil-erosion potential and surface runoff. They have compacted subsurface layer due to illuviation, which may lead to restricted root development. These soils have low CEC and high P fixing capacity. These soils are low in N,P, Ca, Zn and S.

(iii) **Alluvial soil:** These soils are mainly developed from coastal alluvium or deltaic alluvium. These soils are generally variable in colour depending on the source of parent material and are calcareous. The depth of this soil depends on the geomorphic position of landscapes. Their texture varies from very coarse to fine. These soils are rich in P and K but low in N and organic carbon. These soils are generally alkaline in reaction but may be acidic when rainfall exceeds potential evapo-transpiration. These soils are best agricultural soils.

The main constraints in these soils include low content of N,P,S,Zn and organic matter and development of salinity and/or sodicity under injudicious use of irrigation water.

(iv) **Laterite soil:** These soils are deeply weathered soils and the depth of weathering may extend up to several meters. They have high clay content (especially in the B horizon) which is not due to migration of clay but due to insitu alteration of weatherable minerals. With depth and between a pH range of 6.0 to 6.8, there is a decreasing intensity of red colour and clay content. With pronounced leaching, they lose bases (Ca, Mg, Na, K) and silica with relative accumulation of sesquioxides and the soils develop acidic reaction. Kaolinite is the dominant clay of these soils. In laterite soil the base saturation is less than 40% whereas in lateritic soils it is more than 40% with CEC of clay less than 16 c mol (p+) kg^{-1}.

The major constraints of these soils are deficiency of P accentuated by high P fixing capacity of Fe and Al phosphates, high acidity, toxicity of Al and Mn and deficiency of K, Ca, Mg, Zn and B.

Amelioration of soil related constraints for improving the productivity of ELS cotton

Soil constraints refer to a situation where the soil environment in not at optimum condition to produce high yield of crops. Soil constraints may be physical, chemical and biological in nature. Unless these constraints are ameliorated the genetic potential of a crop cannot be realized even when all other inputs like water and nutrient are supplied in adequate quantity. Soil characteristics also influence the fibre quality parameters (Table 2) of cotton (Johnson et al., 2002). Thus maintenance and improvement of soil health is indispensable for sustaining the agricultural productivity at higher level. The term soil health and soil quality are often used interchangeably in the scientific literature. Soil quality is defined as the capacity of soil to function within ecosystem and land use boundaries, to sustain biological productivity, maintain the environmental quality and promote plant, animal and human health (Doran and Parkin, 1994). Soil quality includes three groups of mutually interactive attributes i.e. soil physical, chemical and biological quality, which must be restored at its optimum to sustain productivity at higher levels in the long run. It is estimated that out of the 328.8 m ha of the total geographical area in India, 173.65 m ha are degraded, producing less than 20% of its potential yield (Govt. of India, 1990). Some of the soil related constraints encountered in the ELS cotton growing zone and technologies for ameliorating and managing these constraints are discussed below.

i. Soil erosion: Soil erosion is defined as detachment of soil particles, their transportation from one place to another and deposition elsewhere through, water, wind, coastal waves, snow, gravity and other forces. Under normal physical, hydrological and biotic equilibria, the natural erosion or removal of soil is balanced with soil formation process. If the balance gets disturbed due to biotic interference, human intervention or natural factors, the eroding agencies become more active and cause accelerated erosion. Soil erosion is a complex historic phenomenon governed by several factors (including wind and water) and causes tremendous damage to cropland. In India about 86.9% soil erosion is caused by water and 17.7% soil erosion is caused by wind. Out of the total 173.6 Mha of total degraded land in India, soil erosion by wind and water accounts for 144.1 Mha (Govt. of India, 1990). The surface soil is taken away by the runoff causing loss of valuable topsoil along with nutrients, both native and applied. In India about 5334 miliion tones (16.35 tonnes/ha/year) of soil is being eroded annually due to agriculture and associated activities and 29% of the eroded materials are permanently lost into the sea (Dhruva Narayana, 1993). Since erosion causes loss of finer fraction of soil, the soil fertility declines. The loss of soil fertility and topsoil makes the land unsuitable for biomass production. The mountainous regions and slopping lands are especially more prone to severe erosion following excessive deforestation, faulty cultivation, over grazing and developmental activity. Soil erosion by water can be minimized by following preventive measures like soil management, crop management and control measures like slope management and runoff management.

Basic principle involved in minimizing soil erosion by wind includes mellowing the wind speed, particularly nearer to soil surface. This can be achieved through perennial vegetation or site-specific cultural practices including shelterbelts, wind strip cropping, stuble mulching, tillage etc.

ii. Highly permeable soil: Light textured laterite and fluffy soils show high permeability, which causes losses of water and nutrients. Two technologies can be followed for management of highly permeable soils in the ELS cotton zone *viz*., compaction and clay addition (Painuli and Yadav, 1998).

a. Compaction technology: It involves repeated passes of a roller of sufficient weight drawn by animal or tractor at optimum soil moisture content (proctor moisture) to attain the desired level of compaction i.e. bulk density. The level of compaction is specific for specific soil-climate crop combination.

b. Clay addition technology: Addition of clay @ 2% in red sandy loam of Andhra Pradesh increased crop yield by more than 10 per cent. Continuous addition at the same rate is recommended for 2-3 years. This is possible due to formation of stable aggregates and increase in water and nutrient retention due to clay. This technology is viable where fine textured soil is available either from ponds or nearby fields.

iii. Soils with subsurface mechanical impedance: Subsurface mechanical impedance restricts root growth and movement of air, water and nutrients, which affects crop yield. Three technologies have been developed to alleviate this problem viz., chisel technology, chisel plus amendment technology and Ridge technology (Painuli and Yadav, 1998).

a. Chisel technology: It has been observed that deep tillage/chiseling breaks the subsurface compacted layer or hardpan and thereby facilitates vertical and horizontal growth of roots. Depending upon soil and crop requirement, chiseling up to 30-50 cm depth at 50-60 cm intervals has been recommended. Though the residual effect of chiselling up to seventh successive crop has been significant in red soils, the effect diminished more rapidly in light textured soils. Hence chiseling in every kharif season in light textured soil and once in 2-3 years in red soils is useful.

b. Chisel plus amendments technology: Subsurface compacted layer in black soils broken by chiseling rebuild compaction due to rapid swelling upon wetting of montmorillonitic clays. Addition of amendments like gypsum @ 5 t/ha or FYM @ 20 t/ha reduced the rate of compaction.

c. Ridge technology: By construction of ridges, rooting volume above the compacted layer increases and thus the crop yield increases.

iv. Slowly permeable black soils (Temporary water logging): Various tillage and land form treatments viz., ridges and furrow, broadbed and furrow and raise and sunken beds of different widths were found effective in black soils of low rainfall and high rainfall areas to avoid waterlogging during rainy season (Painuli and Yadav, 1998). These practices have been found effective to various extents depending on topography, crop and rainfall.

v. Shallow soils: Insufficient soil volume limits root growth and supply of water and nutrients to the crop in required amount. Construction of 10 cm high ridge on shallow soils of depth ranging from 15 to 35 cm was found beneficial for root growth. Addition of clay or paddy husk further improves the physical condition and crop growth. In the sloppy red soils of Andhra Pradesh farmers face the twin problems of shallow depth and erosion. Formation of ridges and furrow on contour along with khus (vertiver) barrier at a vertical interval of 1 m reduced runoff and soil loss by 88 and 92 per cent, respectively. This also helped in maximum moisture retention during crop growth and higher crop yields.

vi. Crusting soils: Soil aggregates are easily dispersed in soils of low organic matter under the impact of rain drops, thus forcing a thin layer of dispersed soil (clay) on the soil surface which on drying develops high strength and form crust. This reduces the exchange of gases between soil and atmosphere and also injures the tips of emerging seedlings, resulting in drastic reduction in plant population and thus forcing farmers for resowing. A technology called "Seed line mulch technology" has been developed to alleviate this problem (Nagarajarao and Gupta, 1996). This involves application of FYM @ 3 t/ha or chopped wheat straw (bhusa) on the seeded rows immediately after sowing. This prevented the disintegration of aggregates and dispersion of soil and maintained 3% higher soil water in the crusted soil in the upper 5 cm layer during seedling emergence.

vii. Hardening soils: Rapid and irreversible hardening of red 'chalka' soils upon drying is a major constraint in crop production. Addition of slow decomposing residues like paddy husk, coir pith etc. followed by appropriate tillage has proved very useful (Painuli and Yadav, 1998). The efficiency of various amendments at different rates was evaluated for major crops of the area and their efficiency was found in the order FYM @ 10 t/ha > coir pith @ 20 t/ha > powdered groundnut shell @ 5 t/ha > gypsum @ 4 t/ha > paddy husk @ 5 t/ha (Nagarajarao and Gupta, 1996).

viii. Salt affected soils: In salt affected soils, salts accumulate in the crop root zone in amounts detrimental to crop growth. These are broadly categorized into saline, sodic and saline-sodic soil based on pH, EC and ESP (exchangeable sodium percentage) of soil. Salt affected soils are generally formed due to insitu weathering of parent material, overland flow of salt bearing sediments, subterranean flow of salts, rain and wind borne salts, use of saline water for irrigation and sea water intrusion.

Management and reclamation of sodic soils involves replacement of a large part of the exchangeable sodium with calcium using a suitable amendment. Gypsum and Phosphogypsum are used as direct source of calcium to reduce the ESP. The work at the Central Soil Salinity Research Institute, Karnal shows that gypsum application sufficient to meet 50% of gypsum requirement is needed to start with rice as the first crop. Combined application of FYM @ 20t/ha and gypsum (25% gypsum requirement) was more effective than application of gypsum equivalent to 50% gypsum requirement. As part of the package deal this is achieved by following a set of agronomic practices like bunding, land shaping, choice of suitable crops and judicious irrigation and fertilization.

Reclamation of saline soils involves leaching of excess soluble salts from the root zone, lowering of water table below the critical depth, selection of suitable crops and their varieties and agronomic practices conforming to the need for keeping a low saline root environment.

ix. Acid soils: Soil acidification is caused by natural as well as human interventions. The main source of soil acidity are acidifying parent material, leaching of bases under heavy rainfall, acid rain, use of acidifying mineral fertilizers, acidifying industrial byproducts, sewage waters, urban wastes, dumping of wastes of mines and low buffering capacity of soils to neutralize the detrimental effects of acidifying process. The main constraint in this soil includes Al and Mn toxicity, low availability of P, Ca, Mg, Mo, low pH values and poor nutrient status.

Liming is done to neutralize soil acidity. Several liming material such as calcite lime stone, dolomite limestone are used for amelioration of acid soils. Several industrial wastes such as lime sludge of paper mill, press mud from sugar industries, basic slag from steel industry has great potentiality of liming. Singh and Singh (1985), Sahu and Pal (1987) and Panda (1987) found that limestone at one-fourth of lime requirement is optimum for getting a good crop yield. Patiram (1990) recommended lime application at the rate of 1 to 2 times the exchangeable Al^{3+} to raise the pH to more than 5.5. Application of lime as fertilizer in furrows than as amendment was found to be more economic.

x. Soil fertility decline: Soil fertility is defined as the inhernt capacity of soil to supply nutrients for plant growth. Intensive agricultural practices in the post green revolution era involving multiple cropping of high yielding fertilizer responsive varieties has resulted in substantial removal of plant nutrients compared to that added through fertilizers. This has resulted in excessive nutrient mining and negative soil nutrient balance. The nutrient gap between crop removal and fertilizer addition in India during 1988-89 is estimated to be 9.75 million tons (Biswas and Tewatia, 1991). Imbalanced use of high analysis straight inorganic fertilizers has resulted in large-scale deficiencies of major, secondary and micronutrients causing decline in crop yield. Deficiency of S and Zn was recorded by Rao and Ghosh (1981) even though recommended dose N, P, K was applied. Deb (1989) reported deficiency of Fe, Mn, Zn and Cu in many areas. These deficiencies should be addressed by applying appropriate nutrients in appropriate quantity, method and time to enhance crop yield. Nutrient deficiency cause the following disorders in cotton viz., Tirak disease due to N deficiency, Red leaf disease due to Mg deficiency and lower N content in leaves, bud and boll shedding due to lower nutrient and moisture status of soil etc. In addition to excessive mining of nutrients an appreciable decrease in organic matter content takes place because of non-use or low use of organic matter. Experience from long-term fertilizer experiment has revealed that use of recommended dose of NPK + FYM resulted in higher crop yield. So adoption of integrated nutrient management including judicious combination of organic manures and inorganic fertilizers on soil test basis holds the key for improving soil health and sustaining the crop yield at higher level. Integrated nutrient management aims at maintenance or adjustment of soil fertility and of plant nutrient supply to and optimum level for sustaining the desired crop productivity through optimization of benefit from all possible sources of plant nutrients in an integrated manner (Roy and Ange, 1991). This integration should be made in the soil and plant system over time and has to take care of all other factors of production and make allowances for residual effect of fertilizer application, biological nitrogen fixation etc. and to ensure that there is no toxicity or deficiency of any element (Goswami, 1998).

xi. Soil moisture stress: Soil moisture is an important component for any crop production and is governed by soil texture, structure, soil depth and organic matter content of soil. Under irrigated conditions, irrigation methodologies including water economy, irrigation at critical growth stages, irrigation as per crop demand, irrigation in alternate furrows and drip and sprinkler irrigation help in saving water and improving the water use efficiency, thus producing more crop for drop. However, under rainfed condition suitable moisture conservation practices like following ridge and furrow method, broad bed and furrow method, planting on 0.2% contour, deep ploughing, tying ridges in September, applying organic and inorganic mulches should be followed for achieving higher crop yield.

Cotton is a semi-xerophytic plant, which requires adequate drainage for achieving better growth and higher yield. Water logging in tracts of heavy soil during incessant rains creates excess water stress and hampers crop growth. Cotton roots, like other plants stop functioning when soil oxygen level falls below 10%. Water logging during fruiting stage induces shedding of small flower buds and small bolls. This also causes loss of N in soil as observed by yellowing of leaves. Hence provision of good internal as well as surface drainage is therefore essential in areas of water logging for better performance of the crop.

The technologies discussed above for ameliorating different soil related constraints should be followed on site-specific basis. Adoption of these technologies by farming community require concerted effort by scientists, state agencies, extension workers and NGOs. These technologies help in maintaining soil health and sustaining the productivity of ELS cotton at higher level. Further research is required to carry out the impact assessment of these technologies, identifying and delineating any other new soil related constraints and refinement of these technologies in a farmers' participatory approach to alleviate these constraints and improving the productivity of ELS cotton in India.

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Table 1. Climatic and soil-site suitability characteristics for cotton at different degrees of limitations

Soil site characteristics	Degree of limitation				
Climatic characteristics					
	0	1	2	3	4
	S1	S2	S3	S4	N1
Total Rainfall (mm)	1200-1000	1000-850	850-700	700-550	≤550
Rainfall during growing season	1000-850	850-750	850-700	700-550	≤550
Mean temperature during growing season (^{0}C)	28-26	26-24	24-22	22-20	≤20
Mean maximum temperature during growing season (^{0}C)	35-32	32-28	28-26	26-24	≤24
Mean RH during growing season	50	50-60	60-70	70-80	≥80
Site characteristics					
Slope (%)	0-1	1-3	1-3	3-5	≥ 5-8
Erosion	0	1	2	2-3	3
Drainage (Internal and External)	Well	Well	Mod. Well	Imperfect Excess	Excess
Ground water table (m)	3	2-3	1-2	1	1
AWC (mm/m)	200	150-200	100-150	50-100	≤50
Stoniness (%)	3	3-15	15-40	40-75	≥75
Soil characteristics					
Texture	Clayey, sandy clay	Clay loam, silty clay loam, sandy clay	Loamy, Silty loam, clayey, sandy loam	Sandy loam, loamy sand	Sandy
Coarse fragments (%) Within 50 cm Below 50 cm	 5 5-15	 5-15 15-40	 15-40 40-75	 40-75 75	 75 -
Effective depth (cm)	120	120-80	80-50	50-25	≤25
Ca CO3 (%)	2	2-4	4-8	8-15	≥15
ESP Loamy texture Fine texture	 10 5	 10-15 5-10	 15-25 10-15	 25-40 15-25	 40 25

Table 2. Peason's correlation coefficient between soil and fibre properties

Soil property	Micronaire	Length (mm)	Elongation	Uniformity	Strength	Rd	+b
Moisture	ns	-**	-***	-***	-***	**	-***
P	**	-***	-**	ns	-*	***	-***
Na	ns	ns	ns	ns	ns	*	ns
K	ns	ns	ns	ns	ns	***	ns
Ca	ns	ns	*	ns	*	ns	***
Mg	ns	**	*	ns	ns	ns	*
PH	-***	***	*	ns	ns	-***	ns
Organic matter	*	-**	-*	ns	-*	***	-**
CEC	ns	ns	**	**	*	ns	***

*, **, *** indicate significance at 0.05, 0.01, 0.001% respectively

Rd = degree of reflectance (colour) and b+ = Hunters