INTEGRATED NUTRIENT MANAGEMENT STRATEGIES FOR INCREASING COTTON PRODUCTIVITY

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Introduction

Cotton, a crop of both tropics and subtropics, is widely grown as a semi-xerophytic forced annual. Today, greater emphasis in cotton cultivation has been on the cost-cutting and low energy intensive farming/organic farming with very low biotic pressure to harvest the better produce since improved crop management especially its nutrition has a key role on both yield and quality. In addition, deterioration of the soil quality as a natural resource is also pertinent in the traditional cotton belt. Since high external input based cropping system has also degraded the soil-water system, depleted soil organic matter/carbon (SOM/SOC) stocks and fertility of soils, these have also led to associated secondary problems *viz.* salinization and water logging in some canal-irrigated tracts of the country. Consequently, imbalanced fertilization, soil erosion and exclusion of organic sources coupled with overuse of acid forming N fertilizers especially urea compels the crop/cropping systems to exploit soils reserves for other nutrients, thereby creating multiple nutrient deficiencies. Current survey in the cotton-wheat belt in Hisar (Haryana) reveals that 76 and 28 per cent of the soil samples analyzed were deficient in Zn and Fe. More recently, B deficiency has been noticed in Nagarjuna Sagar Project area of Andhra Pradesh and that of Zn in Faridkot & Firozpur (Punjab), Morena (M.P.) and Coimbatore (T.N.). Therefore, there is an urgent need for appropriate crop nutrition - a key component for higher yield realization and better quality - through integrated approach, called Integrated Nutrient Management (INM) or INM system for supplying crops the essential nutrients.

INM - the concept

The basic concept underlying the integrated nutrient management system (INMS), nevertheless, remains the maintenance and possible improvement of soil fertility for sustained crop productivity on long term-basis and also to reduce inorganic (fertilizer) input cost. The three main components of INMS as defined by FAO, 1998 are:

1. Maintain or enhance soil productivity through a balanced use of fertilizers combined with organic and biological sources of plant nutrients
2. Improve the stock of plant nutrients in the soils
3. Improve the efficiency of plant nutrients, thus, limiting losses to the environment.

Thus, integrated nutrient supply/management (INS) aims at maintenance or adjustment of soil fertility and of plant nutrient supply to an 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).

Requirement of a crop for a nutrient is decided by the rooting behavior and its mining ability, the native soil status, the potential yields as decided by the soil-agro-climatic situations, the targeted yields and nutrient management. Since cotton crop forages deeper (45 cm) into the soil and are thus, efficient in availing the native soil nutrients like P & K. Yet, universal crop response to applied-N is reported in many locations in India. Amongst secondary and micronutrients, S & Zn deficiency is on the rise.

Therefore, an INMS is the most efficient and practical way to mobilize all the available, accessible and affordable plant nutrient sources in order to optimize the productivity of the crops/cropping systems and economic return to the farmer. 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).

Scope of INM practice

Looking back on the history, the concept of INM was realized in green revolution cereals due to higher nutrient turn over in soil-plant system. In addition, today, development of short duration tetraploid varieties and hybrids including the Bt hybrids have also led to increased cropping intensities leading in heavy mining of nutrients from soil. This resulted in increased reliance on INM and accepting it as a practice for sustaining crop productivity.

Soil fertility can only be sustained if the nutrients removed from soil are replenished following the basic principle of Liebig's Law of Restitution. With the existing cotton production of 27 M bales, the requirement of N, P, K has gone up to 1.4, 1.3 and 2.1 M tones respectively and supplying this through fertilizers may not be practicable due to demands from the competing crops and gap in demand-supply of fertilizers (around 55 kg NPK ha^{-1}) and lower utilization efficiencies in case of inorganics only. Therefore, an integration of organic and inorganic sources of nutrients is the need of the hour to meet the nutrient requirement of cotton appropriately.

In addition, other soil related constraints viz, depletion of SOM, multinutrient deficiencies under intensive agricultural practices, decline in soil health, unsustainable crop productivity and environmental pollution due to imbalanced use of chemical fertilizers has developed renewed interest on use of organic sources of nutrients. On the contrary, use of organics alone may not yield enough to meet the growing demand for cotton. Moreover, similar to fertilizers, competition does exist with regard to its use for other enterprises and its limited availability to fulfill the entire nutrient demands which again justifies for integrated use of fertilizers and manures.

INM should also cater to the contributions of all other factors of production and make allowances for residual effect of fertilizer application, biological nitrogen fixation (BNF) and other fixations and must ensure free of toxicity or deficiency of any element.

Besides decline in yield, imbalanced fertilization and its linked soil quality deterioration could have been the probable reason for reduced quality of cotton fibre since integration of nutrient supply through INM ensures optimal crop growth & development, and resists plant against pests and diseases. Both reduced and excessive supply of many plant nutrients could possibly aggravate its susceptibility to pests and diseases.

Approach/components in INM

Besides inorganic fertilizers as the major component, others include farmyard manure (FYM), composts, green manure, crop residues, crop rotation and biofertilizers. These are discussed here along with the details of fertilizer practices in cotton in various zones (Table-2).

Balanced fertilization

Improved crop nutrition aims at maintenance of soil fertility and of plant nutrient supply to an optimum level for sustaining the desired crop productivity through optimization of various plant nutrients in an integrated manner. Balanced dose of N, P and K is usually applied to the soil in the ratio of 2:1:1 or 3:1:1 ($N:P_2O_5:K_2O$). However, imbalanced one viz, high available N possibly shifts the balance between the vegetative and reproductive growth towards excessive vegetative development, thus delaying maturity, reducing yield & ginning per cent (GOT) and promote boll shedding, disease & insect damage. Others reported higher incidence of jassids and spotted bollworm (*Earias vittela*) under NPK of 160:80:80 and 120:60:60 kg ha^{-1} over those in 80:40:40 kg ha^{-1} (Jayaswal and Sundaramurthy, 1992). Thus, application of N as basal will have to be reduced under a successful pest's prevention strategy since schedule and method of application of nutrients, have a lasting influence on the threshold population of pests in cotton.

Nitrogen, a growth nutrient is known to positively interact with irrigation, plant density, optimum sowing window, other nutrient elements especially P & K, absence of weeds/pests for higher growth and presence of organics in soil. *In-situ / ex-situ* determination of Plant-N status through petiole analysis of terminal fully unfolded leaf (with critical level of 2000 ppm) is required for controlling incipient/acute N deficiencies in plant for its application. 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 than that at planting and earthing up operations.

Fibre quality is said to be adversely affected by N beyond optimum although improved GOT with N supply is observed. Studies show that uniformity ratio, GOT, lint-index and maturity co-efficient were usually not influenced by the variation in N although span length was increased significantly up to 120 kg N/ha. In a 5 year study, micronaire decreased with increasing N rates from 101 to 202 kg ha^{-1} (Reddy et al. 2004). Leaf N during boll maturation stage had also a significant positive correlations with mean fibre length, fine fibre fraction and immature fibre fraction and negative correlations with fibre diameter, short fibre content, fibre cross sectional area. Thus, full potential (fibre quality) of any genotypes is only realized in optimum atmospheric & nutritional environments.

Table-2. Fertilizer management practices for cotton in different zones

Management practices	**Northern Zone** (Punjab, Haryana , Rajasthan)	**Central Zone** (Gujarat, M.P. and Maharastra)	**Southern Zone** (Karnataka, A.P. and T.N.)
1. Fertilizer Dose	N @ 50-100 kg ha^{-1} (100-150 kg ha^{-1} for hybrids) and P & K as per soil test.	NPK varies from 40:20:20 to 240:120:120 depending on genotype/hybrid/agro-ecology.	NPK varies from 40:20:20 to 150:75:75 depending on genotype/ hybrid/ agro-ecology.
2. Time and Method	½ at thinning & ½ at 1st flower with supplementation of foliar-N if needed. Full P at sowing and K as per soil test.	N in 3 equal splits at sowing, squaring & pick flowering stages. P and K as per soil test.	½ N at squaring & ½ at peak flowering and P & K at sowing. Full N, P & K at planting in rainfed areas of Karnataka.
3.Schedule of foliar NPK supply	2-3 sprays of 2 % urea/DAP/ KNO_3 (flowering onwards at 7-10 days intervals).	2 % urea at flowering & 2 % DAP at boll development.	2 % urea/ DAP at flowering & at boll development.
4. INM	50 % of NPK + FYM @10 t/ha & foliar sprays. Full N & P ± FYM @10t/ha (Mathura,U.P.).	50-100 % of NPK+ FYM @ 5-10 t/ha ± vermi compost @ 1.25–5 t/ha.	50-100 % of NPK+ FYM @ 5-10 t/ha (or poultry manure @ 5 t/ha) + DAP/urea sprays.
5. Bio-inoculants	*Azotobacter/Azospirillum* for seed along with 40-50kg Nha^{-1}.	*Azotobacter* for seed.	*Azospirilum* (seed + soil) in T.N.

Management of P & K, however, requires long term strategy for working out the required P & K inputs as biological and chemical transformations don't add or deplete P & K from the rhizosphere easily. This (strategy) ensures adequate soil P & K supply so that the crop growth is not limited and NUE for N is not reduced. Study reveal that basal placement of P within the active root zone is advocated (for less surface contact & less fixation) over broadcasting on top soil or splitting. Similar to N, crop response to P varies with species of cotton (less with *desi* or variety & 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 through foliage, and P with N increases use efficiency of N. Yet, 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.

Crop response to K is also highly inconsistent and variable due to inherent soil K status & dynamic K-transformations. Cotton being a subsurface feeder, K extraction from lower depth in the soil profile also influences K balance & 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. In a few cases, K supply increased both fibre length & strength besides enhancing maturity ratio.

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 % K in the leaves during the reproductive stage, improved 2.5 % span Length, uniformity ratio, fibre fineness, maturity coefficient & fibre strength (Shanmugam & Bhatt 1991). Application of 2/3rd of K dose through soil & 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^{-1}) through soil (Bhatt 1996). Moreover, NPK + K foliar at early and peak boll formation stage @ 5 kg K_2O/ha gave slightly increase in 2.5 % staple length and strength, where as elongation % and micronaire were higher in NPK + K foliar at peak boll formation stage @ 5 kg K_2O/ha. Uniformity % was slightly higher in NPK soil applied. In addition, yield could also be enhanced by the application of slow release NPK tablets prepared by incorporating phosphogypsum urea at the recommended level of NPK.

With limited works on secondary and micronutrients, studies reveal positive response of S on yields, oil and protein content in seed at Hisar, India and soil application of both S & Zn was beneficial for cotton at Sriganganagar. Although S @ 20-40 kg ha^{-1} is recommended for S deficient soil, yet moderate dose of it is found to have enhanced the oil content in seed and fatty acid profile although the response varies widely with soil status. Foliar sprays of SO_4 *viz,* $MgSO_4$ @ 0.5- 1 % twice on 60th and 80th day (at flower & boll development) increased the yield. Similarly in other locations, spraying of $ZnSO_4$, $FeSO_4$ and Borax @ 0.5% at 45, 60 & 75 DAS were found to increase the yields in deficient soils.

Leaf reddening (red leaf systems, RLS) appearing towards peak flower and boll development cause reddening of leaves & cracking of bolls leading to lower yields. RLS is usually attributed to Mg deficiency, lower leaf N content, sudden fall in night temp and low soil N supply. For this 1% $MgSO_4$ and 1-2 % of urea or DAP is beneficial. Deficiency of Mg results in mostly reddening of leaves while Fe and Mn deficiency leads to chlorosis of leaves. On the contrary, Zn and B deficiency lead to the problem of improper bud & 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 B deficiency, 0.1 % boric acid is beneficial.

Farm yard manure

Although the manure is the source of all nutrients, crop response is more evident in presence of fertilizers. However, in a long-term study conducted for eight years since 1985 at Sriganganagar, Rajasthan indicated no benefits following application of FYM or a combination of both FYM & NPK fetrtilizer. Yield of both cotton and succeeding wheat were the highest in the NPK fertilized plots due to deficiency in N & P in alluvial soils of North zone as nutrient uptake under partial substitution of fertilizer by FYM could not commensurate with the immediate crop demand.

In central India (Nagpur), however, at the end of eight cycles of cotton-sorghum two-year rotation, seed cotton yield was enhanced by 20.2-22% in the NPK + FYM plots compared to NPK alone plots (Blaise et al. 2003). Similarly, in the cotton monocropped plots, cotton yield was the highest in the INM plots compared to that receiving mineral fertilizer alone. Although yield in the NPK + FYM @ 5 t/ha was as good as that in NPK (60:13:25) till 8^{th} year of cotton farming and beyond that micronutrients and secondary nutrients deficiencies might have been the yield-limiting factors following continuous cropping and supplying mineral fertilizers alone. However, this was overcome by FYM supply which also improved the physical & biological soil condition besides improving soil moisture holding capacity (especially true in rainfed areas). Thus, influence of FYM or compost is of long term nature since it restores the sustainability of the soil-plant system.

At many locations in South India, FYM supplemented plots had higher yields, improved organic & inorganic N & P fractions, microbial biomass C, decreased P sorption and enhanced micronutrient status than the plots with mineral fertilizer alone (Praharaj et al, 2005a, Swarup and Wanjari 2001). Significant improvement in organic C and available P were seen in the NPK + FYM compared to NPK alone plots after a 10-year of cotton cropping on Vertisols (Venugopalan and Pundarikakshudu, 1999).

Besides improvement in fibre yield and soil properties, soil microflora was also improved following FYM or INM practice. Significantly greater populations of actinomycetes, fungi, Rhizobia and bacteria in the INM plots compared to that in mineral fertilizer plots which may, in part, attributed to higher moisture holding capacity and favourable environment under it. Better retention of squares and bolls because of improved soil nutritional status and moisture might be the causal factor for higher yields realization in INM plots.

Green manure

With the increase in usage of fertilizers and intensification of agriculture, alternative source of organics besides FYM like green manure (GM), crop residues/wastes etc. have been increased. Although N additions through GM is in the range of 30-40 kg ha^{-1}, yet this practice is not prevalent even in rainfed areas because of unavailability of sufficient soil moisture and no direct visual/economic benefits.

Although a general trend of yield decline is noticed when a GM crop was grown *in situ* and incorporated as such because of immobilization factor yet yield increases were observed in many locations following its fortification/enrichment. At Nagpur, seed cotton yield increased to an extent of 24% with *in situ* GM incorporation when supplemented additionally with subabul loppings and FYM. On-farm trials conducted at several locations have indicated the viability of *in situ* GM if GM crop is sown after establishment of cotton with enhancement in temporal compatibility. Yet, the practice of growing a GM crop in a standing cotton crop is difficult to adopt. Therefore, a system of growing cotton along with GM at the same time and burying it before flowering with supplemented N or FYM proved effective. A study at Coimbatore (T.N.) reveals that a GM combination *viz,* application of FYM @ 5t/ha, sunnhemp seeded @ 15 kg ha^{-1} simultaneously in inter-rows of cotton as GM and buried at 45 DAP produced significantly higher seed cotton yield and lower pest population over the NPK fertilizers (Praharaj *et al.* 2005b).

In a study at Georgia, USA, Tillman *et al*. (2002) observed that plots inter-seeded with legume cover crops had higher number of predators. Therefore, fewer insecticide sprays were needed. Though differences in yield were not statistically significant, cover crops benefited growers by reducing insecticide inputs and thus increasing returns.

Crop residues

The bulk of available crop residues constitute cotton, wheat and mustard in the north, cotton and pigeon pea stalks in central India, and cotton, legume & rice straw in the South. Usually cotton stalks are poor for quality composting because of their high lignin content, wide C/N ratio, low nutrient especially N content causing N immobilization and often allelopathic effect on the applied crop. Therefore, crop residues need to be converted to bio-composts for its effective conversion and utilization by crop plants.

Study revealed that incorporation of cotton and wheat residues improved the productivity of these crops at Sirsa, Sriganganagar and Ludhiana in the North zone since improvements in the soil fertility might stabilize long-term yields. Thus, cotton and wheat crop residues can be safely incorporated as an eco-friendly practice. Since limited application (due to low crop response) of K leads to an accelerated depletion of other nutrients in addition to K in North zone, crop residue incorporation (with high in K) can alleviate these problem here besides improving long-term nutrient balances of cations and restoring SOC. Shredding and incorporation of cotton stalks and wheat straw were again found more suitable. The tremendous potential of the residues was also assessed over 3 years at Sirsa and Ludhiana in the North zone.

Yet, since there is very little turnaround time between harvest and sowing of the subsequent crop in the cotton-wheat & cotton-mustard systems and inherent detererent nature due to residues in field operations, management of residues poses a stupendous task in the North. Thus, a majority of crop residues are burnt resulting in health and environmental problems in additiuon to loss of N, P, S and B. On the other hand, restoration of soil fertility is possible by incorporating the crop residues since the practice itself conserves/sequesters carbon as residue having wider C/N ratio possibly leaves more carbon in the soil.

In rainfed central India however, cotton residue incorporation may decline yield over legume (usually very low in availability) because of continuation of prolonged dry periods leading to immobilization of N. Thus, an integrated approach is mandatory for residue incorporation in central India.

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

Biofertilizers

In cotton, *Azotobacter* and *Azospirillum* were found useful in effecting N economy. Studies revealed that *Azotobacter* inoculation along with 40 kg N ha^{-1} was similar to application of 60 kg N ha^{-1} (a saving of 20 kg N ha^{-1}, CICR 1985). Though the N fixing potential ranged from 40-60 kg N $ha^{-1}y^{-1}$, yet saving to an extent of 20-40 kg N ha^{-1} y^{-1} was observed under field condition .The principle involves in rendering unavailable sources of atmospheric N & bound phosphates in decomposed plant residues and other organics into available forms, thus, help enhance soil fertility and crop yields. Crop response to biofertilizers is positive, and there exists a potential to integrate biofertilizers with inorganic fertilizers. Apart from unreliable quality and poor availability in the market, their effects are not consistent as with the fertilizers explaining the reason for unpopularity of these amongst farmers.

For increased availability of P, PSB (*Bacillus megatherium* var. phosphaticum) as soil application @ 5 kg ha^{-1} in combination with vermicompost (2 t ha^{-1}) and rock phosphate was as good as supplying P through SSP. The cheaply available rock phosphate can therefore, be efficiently utilized and should be an incentive to reduce the costs.

VAM (vesicular arbuscular mycorrhiza), an obligate symbiont, are also known to improve the availability of P and micronutrients .However, its use is limited because of unavailability in adequate amount and limitation in commercial production. Yet, integration of these biofertilizers proved very useful in cotton based cropping systems. In cotton-chick pea system at Rahuri, maximum yield was realized with FYM @ 5 t/ha + dhaincha buried *in situ* + *Azotobacter* + *Azospirillum* + seed treatment with PSB; followed by FYM @ 5 t/ha + dhaincha.

Rotational crops

More often ignored in an INM strategy, crop rotation is a very important tool in sustaining nutrient supply. Legumes in rotation restore soil fertility in more than one way *viz*, some of the N fixed is left in the soil after harvest, improvement in soil properties, lesser disease and pest problem and better weed control. Legumes rotation can fix atmospheric N to an extent of 135-488 kg ha^{-1}. It is estimated that cotton following a non-legume rotation crop required an application of 179 kg N ha^{-1}, while following the grain- and GM-legume system it required only 90 and 52 kg N ha^{-1}

respectively (Rochester et al. 2001). Therefore, legumes in a cropping system certainly provide a link towards INM.

Non legume crop *viz*, jowar grain crop was highly remunerative and requires less inputs especially N following a cotton crop. In cotton-*sorghum* cropping system at Coimbatore T.N.), cotton should be given full dose of NPK while P & K may be skipped to succeeding *sorghum* crop (Praharaj and Rajendran, 2007). Therefore, effect of INM practices on cropping system is mostly positive (AICCIP findings, Table-3).

Table-3. Effect of INM practices on seed cotton yield increase (%) over RD-NPK

Location	Cropping systems	INM package	% Increase
Delhi	Cotton-mustard	FYM, Acotobactor & 50% RD-N	10
Akola	Cotton-cotton	Municipal seed waste, Neem seed cake & 50% NPK	8.3
Akola	Cotton-sorghum	FYM, biofertilizer & RD-N	0.7
Nanded	Sole cotton	FYM, Neem cake & NPK	-5.7
Rahuri	Sole cotton	FYM, Azotobacter, PSB & 50% RD-N	18.3
Guntur	Sole cotton	FYM & Crop residues	-13.7
Siuguppa	Cotton-maize-gram	FYM, vermicompost & crop residues	16.2
Nagpur	Sole cotton	FYM, GM, PSB & 2% DAP	17.9
Nandyal	Sole cotton	FYM, GM, PSB & 2% DAP	55.6
Dharwad	Sole cotton	FYM, GM, PSB & 2% DAP	23.6

Integration of components of INM

As discussed earlier, integration of INM components are useful in many ways. In a two year rotation, combined application of cotton crop residue, FYM and vermicompost were equivalent to FYM + Vermicompost + fertilizers in terms of yield (Basavaneppa and Biradar, 2002). At Coimbatore (T.N.), an integration of organics *viz,* FYM @ 5t/ha (15 days before planting), cotton residues @ 2.5 t/ha (30 days before sowing) and sunn hemp seeded @ 15 kg ha^{-1} simultaneously in interrows of cotton as GM and buried at 45 DAP produced significantly higher seed cotton yield and lower pest population over the recommended dose of fertilizers (Praharaj et al., 2005b).

Fertilizer equivalents of INM components

The fertilizer equivalent of different INM components varied in different agro-ecological regions based on crop response. On an average, 20 to 45 t of FYM or 16.6 t of GM were needed to produce 1 t of seed cotton ha^{-1} (Blaise, 2004). However, it differs a lot since crop response varies with varying nutrient content of manures, management practices and agro-ecological regions. Thus, its application in huge quantity is not a regular due to its unavailability and nonremunerative nature which calls for an appropriate integration of several organic components along with mineral fertilizers for getting the best results.

Nutrient recycling

A better example of nutrient recycling in INM for sustainable cotton farming involves application of a set of organic materials/complexes for higher production efficiency with lower nutrient loss from soil (nutrient recharge). It is evident that application of FYM, green gram 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 (Blaise et al, 2004). Besides direct addition of N to the available soil pool, organics facilitates in the greater multiplication of soil microbes that could convert organically bound N to inorganic form there by help maintaining/restoring soil N status.Similarly, microbial decomposition of organics could form organic complexes with sesquioxides and thus, reducing the P fixing capacity of this soil.Moreover, enhancement in K availability is fortified following mineralization of organics and release of K to soil pool due to organic matter-clay interaction & reduction in K fixation.Thus, INM or IPNS has a tremendous role in soil nutrient recharging.

Crop nutrition versus fibre quality

Fibre property modulations due to the application of nutrients are often contradictory because of the complex interactive effects of genotypes, climate and soils. Yet, with few exceptions (Table-4), fibre parameters are not normally differed with optimum/balanced crop nutrition vis-à-vis INM (Praharaj et al, 2005a).

Table-4. Fibre quality under INM treatments (3 yrs pooled) (Praharaj et al. 2005a)

Treatments	SCY q/ha (10 yrs)	2.5 % SL. (mm)	Micronaire value (ug/inch)	Strength (g/tex)	Elongataion (%)
N P K					
FYM*	11.59	31.9	3.69	23.3	5.80
0 0 0	11.99	32.1	3.67	23.5	5.79
60 0 0	12.52	32.2	3.70	23.4	5.80
60 13 0	11.71	31.9	3.74	23.4	5.77
60 0 25	12.38	32.5	3.66	23.4	5.83
60 13 25	12.97	32.3	3.75	23.3	5.82
30 13 25 5	0.753	0.47	NS	NS	NS
C.D. (0.05)					

N, P, K in kg ha^{-1} on nutrient basis & FYM in t/ha

The fibre quality is adversely affected by the application of N alone. Contrary to it some observed improved GOT following N application up to optimum level. Successive decrements in fibre strength and fibre fineness were observed due to increase in N levels. In contrast, P didn't influence on fibre quality. So far K is concerned, when it is combined with NP, is largely effective. Reports suggests that K when applied foliarly at early and/or peak boll formation stages increased 2.5 % SL & strength and elongation % because of higher K (3.0-3.6 %) in the leaves during the reproductive phase.

Nutrient balance and its use efficiency

The efficiency of fertilizer use (FUE) in a crop/cropping system would be further enhanced through GM, biofertilizers, nitrification inhibitors and even by splitting the fertilizer (mostly N & K) dose. As demonstrated in long term experiment under intensive cropping, the responses to a fixed dose of NPK also decrease with time unless the fertilizer application is balanced by adding other bulky organics in high doses to correct the imbalances.

Problematic soils and salinity

For problematic soil and water especially in saline and sodic tracts of vertisols where poor hydraulic conductivity with high degree of shrink-swell potential of soil, compact and dense subsoil, incomplete leaching of salt from soil due to impairment of drainage resulting in decline in yield and deterioration of soil properties, are the major problems. In addition to INM, incorporation of gypsum or such soil amendments with increasing levels (up to 50 to100 % gypsum requirements) without and with alkali water (through sprinkler) is helpful for getting good yields. Even with alkali water, sprinkler irrigation gave higher benefit.

Irrigation scheduling has to be modified as per soil and water salinity and this condition warrents certain precautions not followed under normal condition. Majority of yield and fibre parameters were increased up to moderate EC of 4 dS/m and declined beyond. It is confirmed from a typical trial involving *desi* hybrid AAH -1 that quality parameters such as 2.5 % span length, mean length, effective length, seed cotton yield, seed & lint indices were enhanced up to EC 4 dS/m and thereafter gradually decreased. However, linear density and maturity parameters were declined even at moderate salinity and higher at zero salinity. But there was significant reduction in linear density and maturity parameters of fibres with increasing strength of water salinity. However fibre bundle strength increased up to 8 dS/M. FQY [(2.5 % span length x bundle strength)/ square root of micronaire], an index of fibre quality declined after a maximum value at EC 6 dS/m.

It is convincingly proved in many trials that beyond 8 dS/m there is decline in physical characteristics of fibre and its yield that might play a key determinant for application of poor quality of water to cotton crop.

Constraints in adoption of INM technology

Despite impressive results of INM technology (on-station experiments), it has not yet been widely adopted among the farming communities as per expectation. Farmers have different priorities because of variation in topography, circumstances and variable access to nutrient sources and markets. The low nutrient content, slow nutrient availability and bulky nature of organic manures, other competing demand for the organics and easy availability of mineral fertilizers are some of the constraints in adoption of INM. Increasing cost of mineral fertilizers in the future and changes in the global demand, new norms of quality cotton and economics may generate renewed interest in adopting various components of INM. Developing awareness among the farmers about the deterioration of soil health under non use of organics leading to unsustainability may help in adoption of technology.

Conclusion

A comprehensive concerted effort in utilization of locally available components of INM involving rational and appropriate use of fertilizers and organics will go a long way in providing a sustainable crop nutrition management in cotton. Moreover, more and more nutrient elements *viz*, Mg, S, Zn & B are likely to be critical nutrient element of cotton in future due to multiple cropping, inadequate use of organic manures and application of chemical fertilizers devoid of secondary/trace elements. In addition, fertilizer management should be based on cropping systems rather than sole crop for higher nutrient use efficiency and economics. Therefore, Integrated Plant Nutrient System has emerged as a necessity for sustainability of agriculture.

Looking onto the future

- Assessment of INM technologies (with secondary/micro nutrients) should be made only after a thorough inventory of the resources available in a region including the components of production *viz,* water management, tillage practices, moisture conservation practices, managing crop with site specific technology, biotic & abioic stresses and cropping/farming system.
- Agrotechnologies maximizing input use efficiency must form an integral part of the INM package.
- Adaptive research trials conducted on large scale to assess the INM technology with respect to agronomic productivity, ecological compatibility, economic profitability and social acceptability is necessary.
- Developing awareness among the farmers by extension agencies about the deteriorating soil health, unsustainable production and environmental pollution due to non use of organics.

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