Indian Journal of Fertilisers **15** (4) : 450-464, April 2019

AICRP on Cotton – Fifty Years of Tireless Research on Nutritional Management for Sustainable Cotton Production

A.H. Prakash*, K. Sankaranayaranan and M. Sabesh
ICAR- All India Coordinated Research Project on Cotton,
ICAR-Central Institute for Cotton Research, Regional Station, Coimbatore, Tamil Nadu

Received : 04/03/2019 Accepted : 03/04/2019

Abstract

All India Coordinated Research Project on Cotton (AICRP on Cotton) is recognised for its pioneering work in nutrient management and fertilizer use in cotton production research since its inception in 1967. The amalgamation of newer cultivars and improved nutritional management strategies not only proved to be productive and remunerative but also made it possible for going in for double cropping. On the other hand, after the introduction of Bt cotton, nutrient consumption by this crop increased in the country and also put pressure to enhance the nutrient use efficiency and go in for matching the productivity level of other leading countries. Cotton is cultivated under diverse agro-ecological conditions including varied soil fertility, making uniformity in developing strategies and techniques in nutrient management a more difficult and complicated task. Location-specific environmentally benign agro-techniques have been developed over the years by AICRP on Cotton, especially on nutrient management to increase the cotton productivity. This review is a critical assessment of work done on nutrient management in cotton.

Keywords: Cotton, AICRP on Cotton, soil fertility, split application, foliar application, nitrogen use efficiency, micronutrients, macronutrients, fertigation, nano-fertilizers, INM

Introduction

Cotton plays an important role in the Indian economy as the country's textile industry is predominantly cotton-based. India is the largest producer as well as second largest exporter of raw cotton. The Indian textile industry contributes around 5% to country's gross domestic product (GDP), 14% to industrial production, and 11% to total export earnings. The industry is also the second-largest employer in the country after agriculture, providing employment to over 51 million people directly and 68 million people indirectly, including unskilled women (IBEF, 2017). Area- and production- wise, India ranks first (11.8 Mha) with about 34.0% of world cotton area and production of 356 lakh bales. Concomitant with the vertical increase in adoption of Bt cotton hybrids, favourable government policies and vigorous promotion of technological adoption in certain regions, its average productivity exhibited an increase from 302 kg ha^{-1} in 2003 to 568 kg ha^{-1} in 2016-17 (CAB, 2017). However, the cotton productivity has plateaued in recent years, hovering around 500 to 550 kg ha^{-1} and is far behind with productivity of leading countries like Australia (2,320 kg ha^{-1}), Brazil (1,706 kg ha^{-1}), China (1,765 kg ha^{-1}) and world average (783 kg ha^{-1}) (ICAC, 2018).

The All India Coordinated Cotton Improvement Project (AICCIP) was launched by ICAR in 1967 with its headquarters at Coimbatore (Tamil Nadu) to improve both quality and quantity of cotton considering the needs of domestic textile industry and export in the country. Now rechristened as the All India Coordinated Research Project on Cotton (AICRP on Cotton), it has done pioneering work in soil fertility and fertilizer use in cotton production system with specific mandate of developing viable and economical area-based agro-techniques for realizing maximum yields for both irrigated and rainfed conditions. Besides, AICRP on Cotton

***Corresponding author:** cicrcbe@gmail.com

concentrated on the location-specific crop production technologies like spacing requirement for varieties/ hybrids, low cost production technologies for marginal and rainfed conditions, optimal sowing time and ideal plant geometry for specific genotypes/hybrids, integrated nutritional management, agro-packages of practices for Bt hybrids in different locations of three zones, irrigation scheduling for drip irrigation practices, soil moisture conservation techniques for rainfed conditions, agro-package of practices for organic cotton and plant protection techniques like IPM and IDM.

Prior to launching of AICRP on Cotton, cultivars were of longer duration, not very responsive to high level of agro-management especially nutritional management and the fertilizer use was almost negligible. It was possible to take up only single crop of cotton in a year. As a result of massive genetic improvement programme taken up at various AICRP centres in the country, number of high input responsive short duration high yielding varieties and hybrids suited for both rainfed and irrigated conditions have been made available. The amalgamation of newer cotton cultivars and improved nutritional management strategies have not only increased the cotton productivity and made cotton cultivation more remunerative but also made it possible for going in for double cropping.

After the introduction of Bt cotton hybrids in 2002, per hectare fertilizer-nutrient consumption, especially that of nitrogen (N), in cotton increased. In Andhra Pradesh, Maharashtra and Gujarat, the major Bt cotton growers, fertilizer consumption increased by around 30% between 1999-2000 and 2009-10 (Sabesh et al., 2014a). In view of the rising cost of inputs including fertilizers, there is an urgent need to increase the cotton productivity from the present level to 1000 and 500-600 kg lint ha^{-1} under irrigated and rainfed conditions, respectively to enhance the profitability (Kranthi, 2013). Adequate and balanced nutrition holds the key to sustain the yield and quality of cotton. While sub-optimal nutrition reduces the yield potential of crops, excessive application of nutrients adversely impacts the profitability due to increase in cost of cultivation; contamination of groundwater; excessive vegetative growth in the crop; and associated insect, disease and harvest problems.

Fertilizer Consumption Scenario in India

In the pre-independence period, use of chemical fertilizers in India was confined to plantation and few cash crops. Organic manures were generally recommended and used for food crops. In the aftermath of world war II and Bengal famine in 1943, country faced a large scale shortfall in the food availability and this deficit made the Indian Government initiate/take policy decisions to meet the country's growing food grain requirements. Various programmes were initiated to enhance the food grain production in the country with the increased use of agrochemicals including fertilizers and these attempts proved to be successful in the subsequent years. Indoria et al. (2018) reported that the fertilizer consumption increased in direct proportion to the population growth and country could meet its food and fibre demand (**Figure 1**). In addition to fertilizers, assured irrigation facilities,

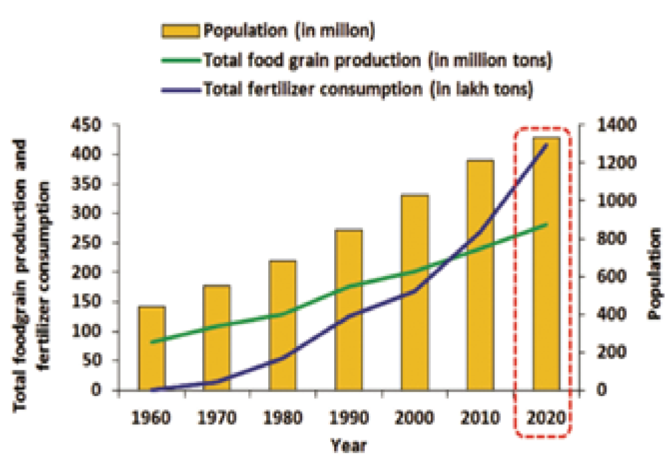

Figure 1. Relationship between the population of India, fertilizer consumption and food grain production (Adopted from Indoria et al. (2018)

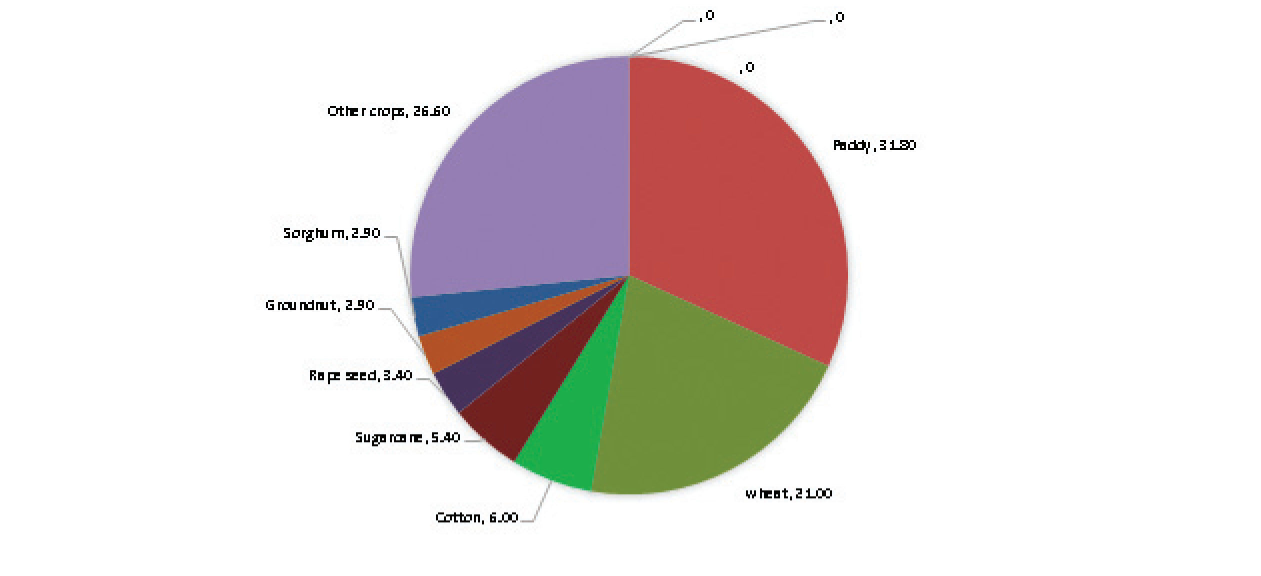

Figure 2. Per cent fertilizer consumption for crops (2003-04) (Data source: FAO, 1998)

improved crop varieties and plant protection measures contributed in a big way in increasing the agricultural production in the country.

In a report submitted to IFPRI, Sharma (2014) observed that during the initial phase of the Green Revolution, per hectare fertilizer consumption more than doubled in five years *i.e.*, from about 7 kg in 1966-67 to about 16 kg in 1971-72, and by the mid-1980s it stood at 50 kg. Average fertilizer consumption was 100 kg ha^{-1} in 2005-2006, and reached a record level of 146.3 kg ha^{-1} in 2010-11. Fertilizer consumption was highest in the northern (192.3 kg ha^{-1}) region followed by eastern (161.1 kg ha^{-1}) and southern (153.2 kg ha^{-1}) regions and lowest in the western (84.6 kg ha^{-1}) (FAI 2012). Average fertilizer consumption on gross cropped area basis was highest at 139.74 kg ha^{-1} on marginal farms and lowest on large farms at 67.64 kg ha^{-1} in 2006-07. Although there was a significant increase in the fertilizer use intensity on all the farm size holdings between 1991-92 and 2006-07, the increase was largest on small farms (95.9%), followed by marginal farms (93.5%) and it was the lowest (47.0%) on large farms (Sharma, 2014).

Paddy was the largest consumer of fertilizer (consuming 1/3rd of the total nutrients) in 2003-04, followed by wheat (21.0%), cotton (6.0%) and sugarcane (5.4%) (FAO, 2004). Fruit, vegetable and other crops consumed about 35% of fertilizer nutrients (**Figure 2**). Fertilizer input enhanced tremendously the productivity of Indian agriculture system. For example, data from the AICRP on Long-Term Fertilizer Experiments (LTFE)

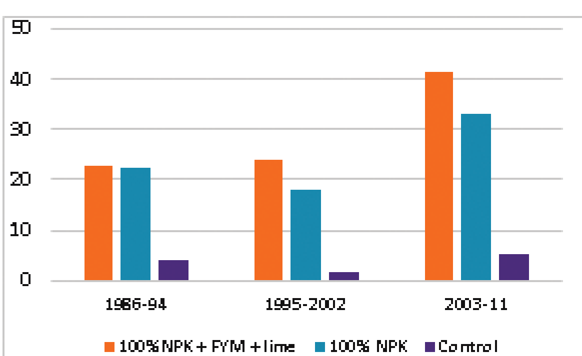

Figure 3. Maize yield (q ha^{-1}) under long term fertilizer experiment (Data source: AICRP on LTFE)

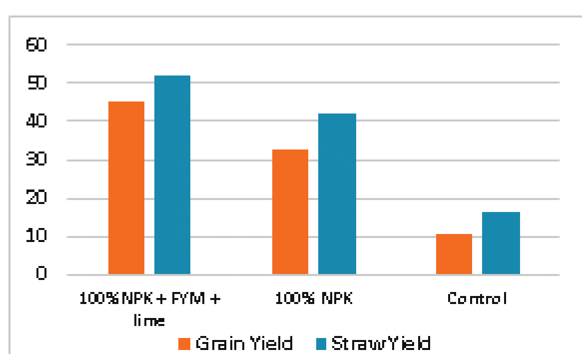

Figure 4. Rice and straw yield (q ha^{-1}) under Long Term fertilizer experiment (Data source: AICRP on LTFE, 2006)

showed that compared to control, maize yield increased on an average 6.5 and 8.5 times under optimal fertilizer use (100% NPK) and 100% NPK + FYM + lime, respectively during the period 1986 and 2011(**Figure 3**). In case of rice, increase in the grain yield was 206 and 327% more under 100% NPK and 100% NPK + FYM + lime, respectively, over control in 2006 (**Figure 4**).

Fertilizer Consumption Scenario in Cotton

Cotton, a major fibre crop in the county, consumes 6% of the total nutrient applied. Per hectare NPK consumption in cotton was estimated at 176 kg ha^{-1} during 2015-16. Between 2004-05 and 2015-16, around 52% increase in average fertilizer NPK consumption was observed in major cotton growing states *i.e.*, Andhra Pradesh, Gujarat, Maharashtra and Punjab **(Table 1)**. Maharashtra alone accounted for 35% of the total cotton area of the country. Between 2000 and 2010, with large scale use of nutrients along with optimum irrigation facility, the cotton production and productivity increased by 15.28 and 12.40%, respectively (Sabesh et al., 2014b). Expenditure per hectare on fertilizer for cotton cultivation during this period was around 9 to 11% of the total operational cost and 6 to 7% of the total cost of cultivation.

Soil Fertility and Fertilizer Use

In India, the major soil types in which cotton is grown are black, alluvial, red, laterite, and coastal saline and alkali soils. Black soils are widely distributed in the states of Maharashtra, Gujarat, Madhya Pradesh, Andhra Pradesh and parts of Karnataka and Southern Tamil Nadu. Inherent potential of the soil to support plant growth and development and production of seed cotton yield in different locations of cotton production system varies because of diverse soil fertility, different genetic potential of the genotypes cultivated, prevailing agro-climate resources available and crop management practices followed. The national mean average of 869 kg ha^{-1} of seed cotton yield was estimated truly based on soil potential (where no fertilizer was applied) under ICAR- All India Coordinated Research Project on Cotton (AICRPC, 2018). The mean contribution of soil and external application of nutrients arrived was 57 and 43%, respectively with respect to seed cotton yield (**Table 2**). Production potential of soil registered under absolute control varied from 486 to 1631 kg ha^{-1}. The highest yield potential of 1631 kg ha^{-1} was realised at Sri Ganganagar on irrigated sandy loam alluvial soil of pH 7.4 with status of low, medium and high with respect to soil availability of N, P and K. Entire north zone of cotton production system is supported on alluvial soils. Cotton-growing soils are mainly clay-loam in Punjab and loamy and sandy loam in Haryana and Rajasthan. Alluvial soils are known for their texture being favourable to cotton production, workability and also for their depth. The lowest contribution in term of absolute quantity of seed cotton yield (486 kg ha^{-1}) was from alkaline (pH 8.1) Vertisol of Nandyal under scarce rainfall conditions.

Results showed that the application of recommended dose of NPK enhanced the mean seed cotton yield at different AICRP centres from 869 kg ha^{-1} under absolute control to 1524 kg ha^{-1}.

Table 1. State-wise consumption of fertilizer (kg ha^{-1}) in cotton cultivation

Year	Andhra Pradesh	Gujarat	Haryana	Karnataka	Madhya Pradesh	Maharashtra	Punjab	Rajasthan	Tamil Nadu	Average
2004-05	224	103	76	74	70	93	129	80	197	116
2005-06	144	142	101	83	143	90	160	73	195	126
2006-07	226	125	107	92	173	106	146	79	210	140
2007-08	191	149	108	98	157	123	153	91	154	136
2008-09	240	177	127	131	102	135	185	142	308	172
2009-10	245	188	156	92	73	155	192	118	331	172
2010-11	262	204	153	152	80	218	212	133	361	197
2011-12	237	215	134	164	92	273	231	119	276	194
2012-13	255	158	128	121	88	237	203	121	193	167
2013-14	269	218	136	170	84	257	192	129	173	181
2014-15	229	216	127	146	166	216	161	94	257	179
2015-16	223	197	130	140	145	206	184	98	266	177

Compiled by authors; Data source: Directorate of Economics and Statistics, GOI

Table 2. Seed cotton yield (kg ha^{-1}) as influenced by soil fertility and recommended level of fertilizer nutrients

AICRP centre	Absolute control	Recommended nutrients	Per cent increase over control	*CD (P = 0.05)*
Sri Ganganagar	1631	2163	32.6	300.0
Kanpur	829	1847	122.8	142.8
Akola	1302	1847	41.9	216.3
Bhawani	902	1572	74.3	156.5
Indore	581	985	69.5	124.8
Khandwa	915	1487	62.5	95.4
Nanded	557	892	60.1	125.9
Rahuri	713	1509	111.6	259.5
Dharwad	870	2031	133.4	259.0
Guntur	1036	1736	67.6	212.7
Nandyal	486	810	66.7	143.0
Srivillipudur	874	1339	53.2	288.0
Coimbatore	598	1590	165.9	129.5
Mean	869	1524	81.7	

Source: AICRPC (2018)

Statistical analysis revealed that external application of major nutrients influenced significantly the seed cotton yield. Yield obtained with external application of nutrients along with soil potential in absolute term ranged from 810 to 2163 kg ha^{-1}. Percentage of yield increase over absolute control ranged from 32.6 to 165.9%. The highest per cent yield increase was observed at Coimbatore and it was the lowest at Sri Ganganagar. The overall average of 81.7% yield increase was observed across all the centres with external application of the major nutrients.

Application of fertilizers for realising high cotton yields is an accepted practice. Recommendations of major nutrients application in different states are presented in **Table 3**.

Integrated Nutrient Management in Cotton

Three main components of integrated nutrient management system (INMS) as per FAO (1998) include: i) Maintenance or enhancement of soil productivity through a balanced use of fertilizers combined with organic and biological sources of plant nutrients; ii) improving the stock of plant nutrients in the soils; and iii) improving the efficiency of plant nutrients, thus, limiting losses to the environment. Thus, integrated nutrient supply/ management 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 benefits from all possible sources of plant nutrients in an integrated manner. Cotton, being a C3 plant, releases CO_2 during photorespiration. High external input and over-use of N fertilizers in cotton lead to more emissions of nitrous oxide. For management of climate change, mitigation strategies should aim to reduce inorganic input utilization with more emphasis on nitrogen by following of integrated nutrient management practice (Sankaranarayanan et al., 2010a).

Integrated nutrient management studies conducted under AICRP on Cotton (AICCIP, 2007) are presented zone wise. In north zone, application of 50% of the recommended NPK + 10 t of FYM ha^{-1} with foliar spray registered significantly highest seed cotton yield (2230 kg ha^{-1}) (**Table 4**). The integration of different sources of nutrients, which included fertilizers, farmyard manure and foliar application, delivered the enhanced effect and produced significantly higher seed cotton yield. Further, inclusion of foliar application of nutrients could save 50% on recommended dose of nutrients to cotton. Muthukrishnan et al. (2017) observed that integrated nutrient management consisting of RDF (80:40:40 kg ha^{-1}) along with 12.5 t FYM ha^{-1} registered the highest seed cotton yield of 2,252 and 1,752 kg ha^{-1} during *rabi* 2012-13 and 2013-14, respectively; yield was statistically on par with application of recommended NPK + 5 t of FYM ha^{-1} (2230 kg ha^{-1}), 50% recommended of NPK + 10 t FYM ha^{-1} (2215 kg ha^{-1}) and recommended NPK+10 t of FYM ha^{-1} (2130 kg ha^{-1}). In central (1716 kg ha^{-1}) and south zones (1904 kg ha^{-1}), application of recommended dose of NPK with 10 t FYM ha^{-1} produced the highest seed cotton yield, which was

Table 3. Major nutrient doses recommended for cotton in different regions

Zone	State	Recommended doses in kg ha^{-1} of			Recommended for
		N	P_2O_5	K_2O	
North	Punjab	150	30	0	Non-Bt hybrids and Bt hybrids
		75	30	0	Varieties
	Haryana	175.5	60	0	Non-Bt hybrids
		87.5	30	0	Varieties
		150	60	60	Bt hybrids
	Rajasthan	160	40	20	Non-Bt hybrids
		80	40	20	Varieties
		150	40	0	Bt hybrids
Central	Gujarat	240	0	0	Non-Bt hybrids (Irrigated)
		160	0	0	Non-Bt hybrids (rainfed)
		80	0	0	*Herbaceum* (rainfed)
	Maharashtra	100	50	50	Non-Bt hybrids (Irrigated) and Bt hybrids
		50	25	25	Non-Bt hybrids (rainfed)
		50	25	0	Varieties (rainfed)
	Madhya Pradesh	100	50	30	Non-Bt hybrids (rainfed)
		80	40	30	Varieties
South	Andhra Pradesh	120	60	60	Non-Bt hybrids and Bt hybrids
		90	45	45	Varieties
	Karnataka	150	75	75	Non-Bt hybrids (Irrigated) (HxB)
		80	40	40	Varieties (Irrigated)/Non-Bt hybrids (Rainfed)
		30	15	15	Varieties (Rainfed)
		120	60	60	Non-Bt hybrids (Irrigated) (HxH)
		188	94	84	Bt Hybrids
	Tamil Nadu	80	40	40	Varieties (Irrigated) and *barbadense* varieties
		60	30	30	Rice fallow cotton
		40	20	0	Rainfed *desi* cotton
		90	45	45	Non-Bt hybrids (Irrigated) (HxH)
		120	60	60	Non-Bt hybrids (Irrigated) (HxB)
		112.5	56	56	Bt hybrids

on par with application of NPK + 5 t FYM ha^{-1} and 50% of recommended NPK + 10 t of FYM ha^{-1} + foliar spray. Brar et al. (2008) reported that the recommended dose of fertilizer (N 150 kg, P 22 kg, K 25 kg and Zn 3 kg ha^{-1}) and substitution of 25% of the above RDN through FYM were significantly superior to RDN alone for Bt cotton in north zone.

Nitrogen Use Efficiency

Generally high amounts of N fertilizers are applied to cotton crop. Estimated efficiency of applied fertilizer N ranges from 15 to 65% (Pilbeam, 1998), which means that the rest is lost through either volatilization as NH_3, or leaching as NO_3^- or NO_2^- or emission as N_2O/N_2. So, in order to increase the crop production and conserve energy as well reduce the costs and minimize the adverse impact on environment, it is a must to maximize the plant use efficiency of applied N (John, 2007). Results of experiments (AICRPC, 2017) on enhancing N use efficiency revealed that the application of 75% of RDN as spot application in 4 splits (at basal, squaring, flowering and boll development) along with foliar application of 1% urea (3 times: squaring, flowering and boll development) produced the highest nitrogen use efficiency of 13.65 and 27.84 kg kg^{-1} N, respectively at Junagarh and Guntur (**Table 5**). At Dharwad, application of 75% of RDN as spot application in 4 splits (at basal, squaring, flowering and boll development) along with foliar application of 1% urea at squaring, flowering and boll development and raising of sunnhemp/fodder cowpea between rows incorporated before flowering recorded significantly higher nitrogen use efficiency 23.32 kg kg^{-1} N. Nitrogen fertilization recommended in three different times corresponded to the phases of plant growth *i.e.*, pre-plant

Table 4. Seed cotton yield (kg ha^{-1}) as influenced by integrated nutrient management practices

Pooled	North Zone	Central Zone	South zone	Mean
T_1. Absolute control	1,569	1,066	1,257	1,297
T_2. 10 t FYM ha^{-1}	1,926	1,242	1,498	1,555
T_3. Recommended dose (RD) of NPK	2,140	1,488	1,690	1,773
T_4. RD of N alone	1,968	1,272	1,601	1,614
T_5. RD of NP	1,847	1,377	1,669	1,631
T_6. RD of NPK + 5 t FYM ha^{-1}	2,230	1,561	1,822	1,871
T_7. 50% RD of NPK+10 t FYM ha^{-1}	2,215	1,479	1,712	1,802
T_8. 50% RD of NPK+ FYM ha^{-1} + foliar spray	2,413	1,564	1,701	1,893
T_9. RD of NPK + 10 t FYM ha^{-1}	2,130	1,716	1,866	1,904
T_{10}. 50% RD of NPK + 15 kg sunnhemp ha^{-1}		1,343	1,570	1,456
CD (P = 0.05)	283	170	255	

application, first bloom application and peak bloom application (Hallikeri and Gershenzon, 2006) to enhance the efficiency.

Micronutrients

Intensive cultivation, highly fertilizer-responsive hybrid cultivation and limited use of organic manures has led to the accelerated appearance of micronutrient deficiencies in cotton-based cropping systems. Zinc (Zn) is a metal component of several enzymes (carbonic anhydrase, aldolase etc.). It is also involved in the auxin production and synthesis of RNA. Iron (Fe) plays an important role in photosynthesis, nitrate and sulphate assimilation and synthesis of chlorophyll. Boron (B) plays a significant role in the fertilization, flowering and fibre development and its deficiency has been reported to increase the boll shedding (Venugopalan et al., 2009). On per hectare basis, cotton (*Gossypium hirsutum* L.) crop accumulates an average of 36 kg Mg, 890 g Fe, 340 g B, 130 g Zn and 51 g Cu. Micronutrient deficiencies in Indian soils estimated

Table 5. Nitrogen use efficiency (kg kg^{-1} N) as influenced by method of N application

Treatments	Bathinda	Junagarh	Guntur	Dharwad	Mean
T_1. Nil N control	0	0	0	0	0.0
T_2. 100% of RDN (band application in 2 splits at basal and flowering)	19.5	8.8	20.2	16.9	16.3
T_3. 75% of RDN (band application in 2 splits at basal and flowering)	21.4	11.2	23.3	21.9	19.4
T_4. 75% of RDN + Placement (spot application in 2 splits at basal and flowering)	23.3	11.6	23.6	21.9	20.1
T_5. 75% of RDN + Placement (spot application in 4 splits: basal, squaring, flowering, boll development)	24.9	11.7	23.8	22.2	20.6
T_6. T_5 + Foliar application of 1% urea (3 times: squaring, flowering, boll development)	24.7	13.7	27.8	22.4	22.1
T_7. T_6 + Raising of sunnhemp / fodder cowpea between rows incorporated before flowering	22.4	13.0	27.6	23.3	21.6
CV (%)	9.0		1.5	0.9	
S.Ed.$_\pm$	1.7		3.2	2.7	
CD (P = 0.05)	NS				

at 49% for Zn, 37% for B, 12% for Fe, 4% for Mn and 30% for Cu call for their external application (Singh, 2009). Soil application of Zn, B, Fe, Mn and Cu on calcareous soils is less efficient, as these nutrients remain inaccessible to plant roots due to the higher soil pH (Rashid and Ryan, 2004). The first signs of micronutrient deficiencies and their supplementation as a corrective measure in cotton were observed in the irrigated north zone, where cotton-wheat cropping system was extensively followed after introduction of short duration cotton varieties. After the introduction of the Bt hybrids, need for external micronutrient application became more essential. Application of Mg, Zn, Fe, B and Cu in combination with recommended dose of macronutrients improved cotton productivity under irrigated conditions as compared to the application of macronutrients alone.

Micronutrient application had significant effect on production of seed cotton yield in all the three zones (AICCIP, 2008). Foliar application of 1% $MgSO_4$ + 0.5% $ZnSO_4$ registered the significantly highest seed cotton yield of 2191, 1754 and 2058 kg ha^{-1} in north, central and south zones, respectively (**Table 6**). Foliar application of either 1% $MgSO_4$ or in combination 0.5% $ZnSO_4$ at flowering and boll development stages could be exploited for enhancing productivity of Bt cotton in north-western India (Kulvir Singh et al., 2015). Spraying of 1% $MgSO_4$ alone produced seed cotton yield of 2037,1571 and 1748 kg ha^{-1} in north, central and south zones, respectively. Foliar sprays of 0.5% $MgSO_4$ at 60, 75 and 90 days after planting raised the seed cotton yield by more than 18% *i.e.* 1630 kg ha^{-1} against control 1380 kg ha^{-1} (Sankaranarayanan et al., 2010b). The next best results were obtained with 0.5% $ZnSO_4$ spray in which the seed cotton yields registered were 1954, 1599 and 1892 kg ha^{-1}, respectively in north, central and south zones. Kumar and Gupta (1989) reported that the foliar application of 0.5% $ZnSO_4$ alone and in combination with 2% urea + 0.25% lime recorded seed cotton yields varying from 1.31 to 1.33 t ha^{-1}.

Nano-Fertilizers in Cotton Cultivation

Use efficiencies of conventional fertilizers seldom exceed 30-35, 18-20 and 35-40% for N, P, and K, respectively in spite of the several years of sustained research. Nano-fertilizers are intended to improve the nutrient use efficiencies by exploiting unique properties of nano-particles (Suppan, 2017). Moreover, it is imperative to optimize the use of chemical fertilizers for meeting the nutrient requirements of crops to minimize the risk of environmental pollution by exploring the use of new novel technologies such as nanotechnology (Manjunatha et al., 2016). Nano-fertilizers are absorbed by plants rapidly and completely, save on fertilizer consumption and minimize the risk of environmental pollution (DeRosa et al., 2010).

Effect of nano-fertilizer on cotton was tested under AICRP. Highest seed cotton yield was recorded under recommended dose of NPK + foliar application of 0.2% $ZnSO_4$ at 45 and 60 DAS (T_7); it was on par with recommended dose of NPK + foliar application of 2 g nano-zinc 10L^{-1} of water at 45 and 60 DAS (T_8), recommended dose of NPK + soil application of 25 kg $ZnSO_4$ ha^{-1} (T_6), recommended dose of NPK + foliar application of 2 g nano-zinc 15L^{-1} of water at 45 and 60 DAS and all these treatments were significantly superior to the rest of the treatments (**Table 7**). Foliar application of P either in normal or nano form

Table 6. Effect of foliar feeding of micronutrients on seed cotton yield (kg ha^{-1}) of cotton

Treatments	North zone	Central zone	South zone	Mean
Control	1,688	1,272	1,520	1,493
0.1% boric acid	1,769	1,477	1,796	1,681
0.5% zinc sulphate	1,954	1,599	1,892	1,815
1.0% managanese sulphate	1,851	1,511	1,831	1,731
1.0% magnesium sulphate	2,037	1,571	1,748	1,785
1.0% magnesium sulphate + 0.5% zinc sulphate	2,191	1,754	2,058	2,001
0.5% ferrous sulphate	1,923	1,446	1,775	1,715
2% urea at flowering and 2% DAP at boll developing stage	2,185	1,570	947	1,791
CD (P = 0.05)	228	293	195	

Source: AICCIP (2008)

Table 7. Effect of nano-fertilizer application on seed cotton yield

Treatments	Seed cotton yield (kg ha^{-1})
T_1. Reccommended dose (RD) of NK	1,307
T_2. RD of NPK	1,363
T_3. T_1 + Foliar application of KH_2PO_4 @ 2% at 45 and 60 days after sowing (DAS)	1,344
T_4. T_1 + Foliar application of nano P @ 2 g 10L^{-1} of water at 45 and 60 DAS	1,345
T_5. T_1+ Foliar application of nano P @ 2 g 15L^{-1} of water at 45 and 60 DAS	1,370
T_6. T_2 + Soil application of 25 kg $ZnSO_4.7H_2O$ ha^{-1}	1,459
T_7. T_2 + Foliar application of 0. 2% $ZnSO_4.7H_2O$ at 45 and 60 DAS	1,531
T_8. T_2 + Foliar application of 2 g nano Zn 10L^{-1} of water at 45 and 60 DAS	1,447
T_9. T_2 + Foliar application of 2 g nano Zn 15L^{-1} of water at 45 and 60 DAS	1,438
CD (P = 0.05)	59

Source: AICRPC (2017)

did not show any impact on growth and development of cotton.

Method of Application of Nutrients

Broadcasting refers to spreading fertilizers uniformly all over the field and is suitable for crops having dense stand, where plant roots explore the whole volume of soil for nutrients. Main disadvantage of application of fertilizers through broadcasting is that the nutrients cannot be fully utilized by plant roots as they have to move laterally over long distances. Placement refers to the applying the fertilizers in soil at a specific place. Row placement of fertilizers is normally recommended in cotton and works well when the phosphatic and potassic fertilizers have to be applied in small quantities in the soil having low level of fertility. Foliar application refers to spraying of fertilizer solutions containing one or more nutrients on the foliage of growing plants. Several nutrient elements are readily absorbed through leaves when they are dissolved in water and sprayed on plant leaves. However, the nutrient absorption by leaf is poor at later stages in cotton because of the cessation of root growth after flowering. Foliar feeding is an efficient means of supplying essential nutrients to the crop during critical stages.

Nitrogen (N) is the most important among macronutrients and is the most commonly applied fertilizer to many crops. Studies on method of N application in Bt cotton showed that significantly higher cotton seed yield (2983 kg ha^{-1}) was recorded in north zone under the treatment comprising of 75% of RDN applied as spot application in 4 splits along with foliar application of 1% urea at 3 times (AICRPC, 2018). The same method of N application yielded the highest net profit (Rs. 77,732 ha^{-1}) also in the north zone (**Table 8**). These results indicate the possibility of reducing 25% N to Bt cotton. Spot application of N fertilizer at the base of each pair of crop plants delivers better residual effect than the broadcasted fertilizer (Swagata, 2018).

In the central zone, highest seed cotton yield of 2799 kg ha^{-1} and net profit of Rs. 50,073 ha^{-1} was obtained under the treatment comprising of 75% of RDN in spot application in 4 splits with foliar application of 1% urea 3 times along with raising of sunnhemp/ fodder cowpea between rows incorporated before flowering. Plant growth needs nutrients continuously but plants absorb nutrients in different quantities at different growth stages as per requirements. Therefore, multi-split application of fertilizer, especially N, is a beneficial strategy for plant growth and yield enhancement (Yang et al., 2012).

Split Application of Nutrients

Split application of fertilizer, as a nutrient management strategy, is productive, profitable and environment-friendly under given soil moisture conditions. Dividing total nutrient application into two or more treatments in different growth periods can help growers enhance nutrient efficiency, realise optimum yields and reduce the loss of nutrients. Nitrogen, needs to be supplied at appropriate time and in right quantities. Split application of N becomes important as it is supplied ideally at a time when crop critically requires it (Mahmood-ul-Hassan et al., 2003). For *desi* cotton under rainfed condition, application of N in a single dose at sowing was found to be the best option. Application at later stages or split application was found to adversely affect the cotton growth and seed cotton yields, especially if the crop faced moisture stress

Table 8. Seed cotton yield (kg ha^{-1}) and net return (Rs ha^{-1}) as influenced by method of application of nitrogen

Treatments	North zone		Central zone		South zone	
	SCY	Net return	SCY	Net return	SCY	Net return
T_1. No N (Control)	1,902	38,549	1,412	19,794	1,824	29,504
T_2. 100% of RDN (band application in 2 splits at basal and flowering)	2,973	73,489	2,317	35,795	2,493	55,852
T_3. 75% of RDN (band application in 2 splits at basal and flowering)	2,547	58,467	1,952	31,254	2,285	48,158
T_4. 75% of RDN + Placement (spot application in 2 splits at basal and flowering)	2,627	62,446	2,108	35,187	2,302	49,000
T_5. 75% of RDN + Placement (spot application in 4 splits: basal, squaring, flowering, boll development)	2,738	65,690	2,280	37,216	2,325	49,122
T_6. T_5 + Foliar application of 1% urea (3 times: squaring, flowering, boll development)	2,983	77,732	2,585	47,305	2,450	52,719
T_7. T_6 + raising of sunnhemp/ fodder cowpea between rows incorporated before flowering			2,799	50,073	2,433	51,600
CD (P = 0.05)	366	12,357	290		346	5,268

SCY = Seed cotton yield in kg ha^{-1}; NR = Net return in Rs. ha^{-1}
Source: AICRPC (2018)

conditions. Nitrogen in two split doses was recommended for *hirsutum* cotton. More numbers of split applications are recommended for Bt and non-Bt hybrid cotton at different stages of plant growth as the fruiting stage takes longer duration in hybrid cotton.

Potassium (K) is another major essential plant nutrient along with N and P. Quantity of potassium required differs at different stages of plant growth. The plant would respond better to split application of K at critical stages of plant growth. Before the arrival of Bt cotton, the application of K fertilizer was negligible since most of the cotton-growing soils were medium to high in available K and response to K application was either low or inconsistent. With large-scale cultivation of the Bt cotton hybrids, demand for external application of K fertilizer is incraesing. Recently, Bt cotton hybrid grown on Vertisols in Adilabad, Andhra Pradesh, was found to respond to K dose as high as 90 kg ha^{-1}. It is due to the fact that the K requirement is high during boll-formation stage and its uptake is limited during this phase, particularly under rainfed conditions.

Experiment was conducted under ICAR – AICRPC to find out the effect of split application of N, P and K (AICRPC, 2004). The schedules of splits consisted of i)) Basal (50%) + 60 DAS (50%); ii) basal (50%) + 30 DAS (25%) + 60 DAS (25%); iii) basal (25%) + 30 DAS (50%) +60 DAS (25%); iv) 30 DAS (50%) +60 DAS (25%) +75 DAS (25%); and v) basal (50%) + 1/3rd each of the rest 50% at 50, 80 and 110 DAS. Split application of nutrients and scheduling of NPK significantly affected the seed cotton yield. Amongst the treatments, combined split application of NK produced highest mean seed cotton yield (1016 kg ha^{-1}) which was superior to the other combinations (**Table 9**). Split application of NPK combined resulted in significantly lower seed cotton yield (819 kg ha^{-1}) as compared to all the other combinations. These results indicate on the necessity of basal P application. Phosphorus normally exists in two "pools" in the soil, *i.e.*, slow and fast release pools. One is the slow release pool where the P is relatively immobile and resides in compounds such as calcium phosphate. The slow release pool delivers P to the other pool, called the fast release pool and in this way the slow release pool gets depleted over time. The fast release pool delivers P into the soil solution from where the plants meet their P requirements. Due to immobility of P, it is a must to go in for basal application of P fertilizer (Anonymous, 2019). Deepa and Aladakatti (2016) reported that application of N and K in four splits *i.e.*, 25% N and K_2O + 100% P_2O_5 as basal and 25% N and K_2O each at 30, 60 and 90 DAS recorded significantly higher seed cotton yield (4061 kg ha^{-1}) as compared to the present practice of application of 50% N + 100% P_2O_5 and K_2O as basal and 50% N at 60 DAS (3692 kg ha^{-1}). Chandrashekara and Halemani (2004) reported that application of 25:50:25% of the recommended dose of N at the planting time, 30 and 60 DAS along

Table 9. Seed cotton yield (kg ha^{-1}) as influenced by split application of nutrients

Scheduling of NPK	Split of nutrient				Mean
	N	NP	NK	NPK	
Basal (50%) + 60 DAS (50%)	735	828	949	694	802
Basal (50%) + 30 DAS (25%) + 60 DAS (25%)	957	916	982	806	915
Basal (25%) + 30 DAS (50%) + 60 DAS (25%)	1,084	1,071	1,176	850	1,070
30 DAS (50%) + 60 DAS (25%) + 75 DAS (25%)	1,067	1,088	1,149	815	1,030
Basal (50%) + 1/3rd each of the rest 50% at 50, 80 and 110 DAS	974	853	825	830	871
Mean	964	951	1,016	819	942

CD (P =0.05)	Split of nutrients	57
	Scheduling of NPK	32
	Interaction	74

Source: AICCIP (2004)

with P and K at planting produced higher cotton yield against the recommended practice for hybrid cotton under irrigated tract of Karnataka. Patil et al. (2004) reported that split application of N and K through fertigation in 19 equal splits at five days' intervals from 30 to 120 to intra *hirsutum* hybrid cotton produced consistently higher yield as compared to conventional method of fertilizer application. Increase in split numbers was accompanied by the increase in seed cotton yield.

Evaluation of different schedules of nutrient application revealed that the basal (25%) + 30 DAS (50%) + 60 DAS (25%) produced significantly highest mean seed cotton yield (1070 kg ha^{-1}); which was on par with schedule of 30 DAS (50%) + 60 DAS (25%) + 75 DAS (25%) (1030 kg ha^{-1}). The interaction effect was significant and scheduling of combination of NK applied as basal (25%) + 30 DAS (50%) + 60 DAS (25%) was associated with the significantly highest seed cotton yield (1176 kg ha^{-1}).

Foliar Application

Nutritional deficiencies often occur for a variety of reasons, most of which can be rectified by timely application of the deficient nutrient(s). Recently evolved cotton cultivars have growth period such that these fruits in a shorter period of time mature earlier (Oosterhuis and Weir, 2010). These require application of nutrients at appropriate time part of the plant. Bt-cotton is said to have a higher nutrient demand during the boll-filling period (between flowering and maturity). During this period, nutrients are transported from leaves to bolls, foliar fertilization could be used as an effective tool for raising the nutrient status of the leaves at this critical period, and increasing the yield and fibre quality of the cotton crop (Errington et al. 2007). Therefore, foliar application is instrumental in correcting nutrient deficiencies during the reproductive phase, as and when required. Foliar application of nutrients is highly beneficial under conditions where the plant roots are unable to meet the nutrient requirement of the crop at a critical stage (Ebelhar and Ware, 1998). Foliar fertilization has many advantages over traditional soil fertilisation as in the former, i) the plant response is fast, and therefore deficiencies may be rectified quickly; ii) there is no soil fixation; iii) is independent of root uptake, and so may be applied when root functioning is declining or impaired; and iv) fertilizer to be sprayed may be mixed with other agrochemicals (Ebelhar and Ware, 1998).

AICRP on cotton conducted a variety of foliar application experiments across its centres. Foliar spray of 0.5% $ZnSO_4$ +1% $MgSO_4$ at 45 and 60 DAS registered higher seed cotton yield at Coimbatore. Foliar spray of 2% urea during flowering, 1% $MgSO_4$ spray at 90 days and 2% DAP enhanced the yield at Dharwad. Boron @ 0.1% as foliar spray at Khandwa, 1% $MgSO_4$ + 0.5% $ZnSO_4$ at Nanded and Rahuri, and 0.5% $FeSO_4$ at Coimbatore have been suggested for yield gains in cotton. Application of 2% KNO_3 (4 sprays) may be taken up for inclusion in package of practices on cotton for Nanded and Siruguppa, while 3% KNO_3 (3 sprays) may be recommended for Akola and Junagadh conditions. At Indore, foliar nutrition gave significantly higher seed cotton yield over control; the tune of increase in yield was 15 to 25% over control. So far as net income is concerned, application of 2% each of urea and DAP at flowering and boll development stage was found to be more remunerative (Rs. 10864 ha^{-1}) against the lowest income of Rs. 8523 ha^{-1} under control. Foliar feeding of 1% $MgSO_4$ along with 0.5% $ZnSO_4$ produced higher seed cotton yield in a four years' trial at

Indore. At Coimbatore and Srivilliputtur, combined application of RDF along with micronutrients was also beneficial for sustained higher productivity.

Potassium Nitrate as Foliar Application Option

Potassium remains in an ionic form in the plant cells and tissues and controls osmoregulation. It plays an important role in fibre development and the turgor-driven expansion of fibre cells and ultimately determines the fibre length. Equally important is its role in enzyme activation. There are more than 50 enzymes which either completely depend on or are stimulated by K. Cotton bolls accumulate 50% of K. Moreover, most of the applied K remains in the top soil, and cotton root systems fail to adequately exploit it. Further, the nutrient absorption is poor at later stages in cotton because of the cessation of root growth after flowering. Hence foliar applications of K offer the opportunity of correcting deficiencies quickly and efficiently, especially late in the season when soil application of K may not be either effective or possible. Foliar feeding of a nutrient may also actually promote root absorption of the same nutrient. Field evaluation of effectiveness of nitrate, sulphate, thiosulphate, chloride and carbonate salts of K as foliar fertilizers showed a clear trend with KNO_3 causing maximum yield increase followed closely by potassium thiosulphate and potassium sulphate. Need-based foliar spray of KNO_3 (3%) is more effective than the formulation (speciality fertilizer) available in the market. Howard et al. (1998) observed that yields from the four K sources averaged 10% higher than the untreated check and yields with KNO_3 were 4% higher than the other K sources

Response of foliar application of KNO_3 in cotton was studied under AICCIP (2009). The significant increase in seed cotton yield was observed with application of KNO_3 in different concentrations in all three zones as compared to control. However, between soil (MOP) and foliar application (KNO_3), foliar application of KNO_3 was not found to be significantly superior in any of the zones. In central zone, soil application of full dose of potassium in the form of MOP recorded significantly highest seed cotton yield of 2586 kg ha^{-1} (**Table 10**). Soils of major cotton production zones had higher soil available potassium; however, external application of potassium influenced significantly the seed cotton yield in north and central zones. Amongst different concentrations and schedule of application of KNO_3, four sprays of 2% KNO_3 harvested significantly higher seed cotton yield in north and south zones. Plants receiving both soil and foliar-applied K or foliar-applied K alone gave higher seed yields than the control. Foliar application of KNO_3 also increased the cotton fibre length and uniformity (Oosterhuis and Jernstedt, 1999).

Drip Fertigation

Cotton, commonly known for its response, is one of the crops identified for adoption of drip irrigation (Sankaranarayanan et al., 2010c). Under drip-fertigation, where fertilizer is applied through an efficient drip irrigation system, nutrient use efficiency could be as high as 90% with losses through leaching, etc., dropping down to as low as 10% against 50% in the conventional one. Since fertigation permits application of a nutrient directly at the site of a high concentration of active roots as per crop requirement, scheduling fertilizer application offers the possibility of reducing

Table 10. Seed cotton yield (kg ha^{-1}) as influenced by foliar application of KNO_3 at different concentration.

Treatments	North zone	Central zone	South zone	Mean
Control	1,537	1,443	1,466	1,482
Two sprays of 2% KNO_3	1,684	1,652	1,644	1,660
Three sprays of 2% KNO_3	1,791	1,725	1,672	1,729
Four sprays of 2% KNO_3	1,878	1,834	1,758	1,823
Two sprays of 3% KNO_3	1,872	1,790	1,675	1,779
Three sprays of 3% KNO_3	1,776	1,878	1,758	1,804
Four sprays of 3% KNO_3	1,742	1,860	1,712	1,771
Muriate of potash (MOP) in four splits	1,833	1,736	1,685	1,751
Full dose of MOP at sowing	1,844	2,586	1,536	1,989
CD (P = 0.05)	250	270	229	

Table 11. Seed cotton yield (kg ha^{-1}) as influenced by drip fertigation of different levels of nutrients

AICRP centre	100% RDN	75% RDN	50% RDN	*CD (P = 0.05)*
Rahuri	2,220	2,141	2,005	149
Lam	4,089	3,952	2,971	206
Dharwad	2,845	2,486	2,253	138
Indore	1,492	1,451	1,383	93
Banswara	2,893	2,701	2,100	138
Faridkot	2,308	2,208	1,958	218

Source: AICRPC (2014)

nutrient losses associated with conventional application. In addition to that, fertilizer savings through fertigation could also be possible. Moreover, as drip irrigation wets only a portion of the soil volume around each plant and thus, conventional methods of fertilizer application are ineffective in this case. The limited root zone and the reduced amount of mineralization are the main reasons for the decreased nutrient availability to the plants with normal method of fertilizer application under drip irrigation. Application of nutrients through drip fertigation improved seed cotton yield by 43% compared to the conventional surface irrigation with soil application of fertilizers (Surendran, 2014).

Drip fertigation studies conducted under AICRP showed that the application of 100% recommended dose of N produced significantly higher seed cotton yields of 2220, 4089, 2845, 1492, 2893 and 2308 kg ha^{-1} at Rahuri, Lam, Dharwad, Indore, Banswara and Faridkot centres, respectively (**Table 11**), which were significantly superior to 50% RDN at all the centres but were on par with 75% of RDN at all places except Dharwad. The results indicate that drip fertigation could save 25% on N and K application in cotton. Amongst different centres, Lam farm observed the highest seed cotton yield (4089 kg ha^{-1}) under drip fertigation. Drip fertigation was better in terms of productivity and offered an economic advantage over the conventional method. Drip fertigation increased the seed cotton yield by 41%. Return was more than the variable cost and benefit-cost ratio was higher and better than the conventional method. Partial budget analysis showed that drip fertigation is economically feasible and profitable over the conventional method (Rosario et al., 2001). Fertigation studies in Bt cotton indicated that the application of RDF (NPK) and 125% RDF through drip were at par and were superior to 75% RDF (Venugopalan et al., 2009). Application of 100% of recommended NPK (120:60: 60 kg ha^{-1}, N and K in four equal splits) with foliar spraying of 0.15% B as solubor (twice) during flowering to boll development stages was *on par* with application of 75% of recommended NPK with foliar spraying of 0.15% B as solubor (Nalayini et al., 2012).

Conclusions

Research and development programmes have been in place in developing high yielding varieties and hybrids of cotton which are being evaluated and released through the single window system of AICRP on Cotton. Equally, numerous innovative and novel agro-techniques including nutrient management have been developed and evaluated for their potential in having the cotton yield enhancement. It is pertinent to focus on implementation of strategic amalgamation of improved cultivars along with ideal nutritional management practices developed for different agro-ecological conditions of the zone in which cotton is cultivated. Amongst the major cotton growing countries, India's cotton productivity is abysmally low despite the availability of strong research establishment/back up both at the central and state levels. It is possible to enhance productivity and further reduce the cost of cultivation by making the judicious use of fertilizers based on the crop requirement and minimize the leakage of applied fertilizer to the environment through adoption of efficient fertilizer application methods, integrated nutrient management and integrated pest management strategies developed by ICAR-CICR and validated by the AICRP on Cotton.

Acknowledgements

Authors acknowledge the Indian Council of Agricultural Research, New Delhi for generously funding AICRP on Cotton since its inception in 1967 which led to the conducting of systematic studies on nutrient management in cotton. The scientific and technical support extended by ICAR- Central Institute for Cotton Research (Nagpur) and ICAR-Central Institute for Cotton Technology (Mumbai) is also acknowledged. Authors also extend thanks to all the scientists from AICRP centres who participated in validation of the technologies.

References

AICCIP. 2003. *Annual Report. 2002-03*. All India Coordinated Cotton Improvement Project, Coimbatore, Tamil Nadu.

AICCIP. 2007. *Annual Report. 2006-07*. All India Coordinated Cotton Improvement Project, Coimbatore, Tamil Nadu.

AICCIP. 2008. *Annual Report. 2007-08*. All India Coordinated Cotton Improvement Project, Coimbatore, Tamil Nadu.

AICCIP. 2009. *Annual Report. 2008-09*. All India Coordinated Cotton Improvement Project, Coimbatore, Tamil Nadu.

AICRPC. 2014. *Annual Report. 2013-14.* ICAR - All India Coordinated Research Project on Cotton, Coimbatore, Tamil Nadu.

AICRPC. 2017. *Annual Report 2016-17*. ICAR - All India Coordinated Research Project on Cotton, Coimbatore, Tamil Nadu.

AICRPC. 2018. *Annual Report. 2017-18.* ICAR - All India Coordinated Research Project on Cotton, Coimbatore, Tamil Nadu.

Anonymous. 2019. *Crop Nutrition. Role of Phosphorus in Cotton Production.* https://www.yara.us/crop-nutrition/cotton/role-of-phosphorus-in-cotton-production.

Brar, J.S., Sidhu, B.S., Sekhon, K.S. and Buttar, G.S. 2008. Response of Bt cotton (*Gossypium hirsutum* L.) to plant geometry and nutrient combinations in sandy loam soil. *Journal of Cotton Research and Development* **22(1)**, 59-61.

Chandrashekara, C.P. and Halemani, H.L. 2004. Response of irrigated cotton to split application of nitrogen, phosphorus and potassium at GLBC area. *International Symposium on Strat. Sustained Cotton Production – A Global Vision, Crop Production*. Held on November 23-25, pp. 154. University of Agricultural Sciences. Dharwad.

Deepa, G. and Aladakatti, Y.R. 2016. Effect of nutrient levels and split application of nitrogen and potassium on yield, economics and fibre quality parameters of interspecific bt cotton. *Journal of Farm Sciences* **29**, 203-207.

DeRosa, M.C., Monreal, C., Schnitzer, M., Walsh, R. and Sultan, Y. 2010. Nanotechnology in fertilizers. *Nature Nanotechnology* **5**, 91.

Ebelhar. M.W. and Ware, J.O. 1998. Summary of cotton yield response to foliar applications of potassium nitrate and urea. *Proceedings of 1998 Beltwide Cotton Production Research Conference*, pp. 683-687. National Cotton Council of America, Memphis, 1998.

Errington, M., Campbell, L.C., Rochester, I. and Tan, D.K.Y. 2007. Efficacy of foliar fertilization in cotton. *WCRC-4*, 2007.

FAO. 1998. *Guide to Efficient Plant Nutrient Management*. Land and Water Development Division, FAO, Rome.

Hallikeri, B.A. and Gershenzon, J. 2006. Biology and biochemistry of glucosinolates. *Annual Review of Plant Biology* **57**, 303-333.

Howard, D.D., Gwathmey, C.O. and Sams, C.E. 1998. Foliar feeding of cotton: evaluating potassium source; potassium solution buffering and boron. *Agronomy Journal* **90**, 740-746.

IBEF. 2017. Indian Brand for Equity Foundation Exports: Cotton-Industry India. www.ibef.org

Indoria, K., Sharma, K.L., Sammi Reddy, K., Srinivasarao, Ch., Srinivas, K., Balloli. S.S., Osman, M., Pratibha, G. and Raju, N.S. 2018. Alternative sources of soil organic amendments for sustaining soil health and crop productivity in India – impacts, potential availability, constraints and future strategies. *Current Science* **115**, 2052-2062.

John, D. 2007. Nitrogen efficiency and management, nutrient management. *Technical Note* **No. 6**, September 2007.

Kranthi, K.R. 2013. How India can double the national average cotton yield. *Cotton Statistics & Newsletter* **24**, 1-3.

Kulvir Singh, Buttar, G.S., Sudeep Singh, Sarlach, R.S., Brar, A.S. and Rathore, P. 2015. Productivity enhancement in Bt cotton (*Gossypium hirsutum*) through foliar feeding of nutrients in north-western India. *International Journal of Agricultural and Statistical Sciences* **11**, 419-424.

Kumar, V. and Gupta, V.K. 1989. Response of cotton to zinc application and its residual effect to succeeding wheat crop. *Agricultural Science Digest (Karnal)* **9(3)**, 130-132.

Mahmood-ul-Hassan, Muhammad, T., Nasrullah, M., Iqbal, M., Nasir, A. and Inamul-Haq. 2003. Cotton response to split application of nitrogen fertilizer. *Asian Journal of Plant Sciences* **2**, 457-460.

Manjunatha, S.B., Biradar, D.P. and Aladakatti, Y.R. 2016. Nanotechnology and its applications in agriculture – a review. *Journal of Farm Sciences* **29**, 1-13.

Muthukrishnan, P., Thavaprakaash. N. and Srinivasan, K. 2017. Effect of organic nutrient management practices in comparison with conventional method on performance of cotton in Tamil Nadu. *Madras Agricultural Journal* **104**, 15-22.

Nalayini, P.S., Paul Raj and Sankaranarayanan, K. 2012. Drip fertigation of major, secondary and micronutrients for enhancing the productivity of extra-long staple *Bt* cotton. *Journal of Cotton Research and Development* **26**, 186-189.

Oosterhuis, D.M. and Jernstedt, J. 1999. Morphology and anatomy of the cotton plant. In *Cotton: Origin, History, Technology and Production* (W. Smith and J.S. Cothren, Eds), pp.175-206. John Wiley & Sons, New York.

Oosterhuis, D.M. and Weir, B.L. 2010. Foliar fertilization of cotton. In *Physiology of Cotton* (J.M. Stewart, D.M. Oosterhuis, J.J. Heitholt and J.R. Mauney, Eds.), pp. 272-288. Springer, Dordrecht.

Patil, V.C., Halemani, H.L., Girijesh, G.K., Chandrashekhar, C.P., Kalibhavi, C.M., Hallikeri, S.S. and Yenagi, B.S. 2004. Scheduling of drip irrigation for hybrid cotton (*Gossypium hirsutum* L.) in northern dry zone of Karnataka. *International Symposium on. Strat. Sustainedheld on Cotton Production. – A Global Vision, Crop Production* held on November 23-25, 2004, pp. 207-212. University of Agricultural Sciences, Dharwad.

Pilbeam, C. 1998. The recovery of N fertilizer by cereal crops in different geographical locations. In *Proceedings of the 11th World Fertilizer Congress* (A. Vermoesen, Ed.), pp. 472-479. International Centre of Fertilizers, Ghent.

Rashid, A. and Ryan, J. 2004. Micronutrient constraints to crop production in soils with Mediterranean type characteristics: a review. *Journal of Plant Nutrition* **27**, 959-975.

Rosario, G.A, Cruz, R.S., Ganotisi, N.D. and Pearanda, H.D. 2001. Drip fertigation for cotton production. University Library, University of the Philippines accessed at http://www.uplb.edu.ph.

Sabesh, M., Prakash, A.H. and Bhaskaran, G. 2014a. Shift in Indian cotton scenario due to shift in cotton technology.*Cotton Research Journal* **6(1)**, 75-82.

Sabesh, M., Ramesh, M., Prakash, A.H. and Bhaskaran, G. 2014b. Is there any shift in cropping pattern in Maharashtra due to introduction of Bt Cotton? *Cotton Research Journal* **6**, 63-70.

Sankaranarayanan, K., Praharaj, C.S., Nalayini, P., Bandyopadhyay, K.K. and Gopalakrishnan, N. 2010a.Climate change and its impact on cotton (*Gossypium* sp.). *Indian Journal of Agricultural Sciences* **80**, 561–575.

Sankaranarayanan, K., Praharaj, C.S., Nalayini, P., Bandyopadhyay, K.K. and Gopalakrishnan, N. 2010b. Effect of magnesium, zinc, iron and boron application on yield and quality of cotton (*Gossypium hirsutum*). *Indian Journal of Agricultural Sciences* **80**, 699–703.

Sankaranarayanan, K., Praharaj, C.S., Nalayini, P., Bandyopadhyay, K.K. and Gopalakrishnan, N. 2010c. Low cost drip as a precision irrigation tool in Bt cotton (*Gossypium hirsutum*) cultivation. *Indian Journal of Agronomy* **55**, 312-318.

Sharma, V.P. 2014. The role of fertilizer in transforming of agriculture in Asia - a case study of Indian fertiliser sector. **IFPRI Policy Note 08**, November 2014.

Singh, S.K. 2009. Management of micronutrients for increasing crop productivity. *Indian Journal of Agricultural Chemistry* **42**, 17-41.

Suppan, S. 2017. *Applying nanotechnology to fertilizer: rationales, research, risks and regulatory challenges*. The Institute for Agriculture and Trade Policy works locally and globally, Brazil.

Surendran. 2014. Drip fertigation effects on yield, nutrient uptake and soil fertility of Bt Cotton in semi-arid tract. *International Journal of Plant Production* **8**, 375-390.

Swagata. 2018. *Principles and Methods of Fertilizer Application*. Accessed at http://www.soilmanagementindia.com/fertilizers/principles-and-methods-of-fertilizer-application/3752.

Venugopalan, M.V., Sankaranarayanan, K., Blaise, D., Nalayini, P., Prahraj, C.S. and Gangaiah, B. 2009. Bt cotton (*Gossypium* sp.) in India and its agronomic requirements - a review. *Indian Journal of Agronomy* **54**, 343-360.

Yang, G., Tang, H., Tong, J., Nie, Y. and Zhanga, X. 2012. Effect of fertilization frequency on cotton yield and biomass accumulation. *Field Crop Research* **125**, 161-166.■