Phosphorus Response in Bt Cotton: A Comparative Study in Karnataka and Odisha

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A comparative study on the contribution of P to Bt cotton yield showed a high P response to seed cotton yield in Odisha over Karnataka by an extent of 920 kg/ha.

The study suggested a judicious P management strategy while growing Bt cotton in medium black to deep black soils of Karnataka, whereas adequate P application based on P response from ample NPK was recommended in the red and lateritic soils of Odisha.

Bt-cotton was the first GM technology to be introduced into India. The area under cotton has increased to 12.2 million (M) ha in 2011, an increase of about 4.5 M ha since the introduction of Bt-cotton in 2002. India is second only to China in global cotton production, which was increased significantly from 15.2 M bales during 2002 to 35.3 M bales during 2011. During this period, the productivity of lint in India has increased from 302 to 492 kg/ha (CICR, 2011). However, India is currently witnessing yield stagnation at 510 ± 27 kg/ha lint over the past 7 years from 2005 to 2011. Some of the reasons for yield stagnation in Bt cotton are: current hybrids not suitable for rainfed growing situations, prevalence of severe moisture stress during the critical period of peak boll formation stage, especially in regions with shallow and marginal soils, and imbalanced use of nutrients (Kranthi, 2012).

With the development of Bt technology, the transgenic traits increased crop yields due to reduced insect pest damage, which in turn resulted in more removal of nutrients into seed cotton from the soil system. The expression of the Bt protein in cotton was found to be reduced by nutrient deficiency in the crop, owing to restricted growth and poor crop health (Rochester, 2006). Nutrient management in cotton is a complex phenomenon due to its long duration (180 to 200 days for most of the Bt hybrids), and indeterminate growth habit, where simultaneous production of vegetative and reproductive structures during the active growth phase takes place (Ravikiran et al. 2012). Thus, a sound nutrient management strategy would be required that minimizes deficiencies and optimize nutrition for better crop yields.

Phosphorus is an important nutrient in cotton production. It is essential for vigorous root and shoot growth, promotes early boll development, hastens maturity, helps to overcome the effects of compaction, increases water use efficiency, and is necessary for energy storage and transfer in plants (Snyder and Stewart, 2003). The total P uptake in cotton is completed by the time the crop reaches the 50% open boll stage. Adequate P nutrition has to be supplied to build and maintain adequate soil P levels to ensure proper seed and lint development. Deshpande et al (2014) reported that the P availability in soil increased with advancement in crop age in Bt cotton compared to non-Bt cotton, indicating that the residual effect of P was more pronounced in soils grown with Bt cotton hybrids than the non-Bt cotton hybrids. Since India is leading in Bt cotton acreage, at an adoption rate of 92%, a study was proposed in the major Bt cotton growing areas of the country to understand the extent of P response in different cotton growing ecologies with the objective of understanding the contribution of P to maximize the yields of Bt cotton. This paper discusses the results of P response observed in the states of Karnataka and Odisha.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Ca – calcium; Mg = magnesium; B = boron; Cl- = chloride; Fe = iron; Zn = zinc; GM = genetically modified; DAS = days after seeding; One Bale = 170 kg.

P Omission Plot Studies in Karnataka

Three sets of experiments from Karnataka, conducted during the kharif season of 2012, were considered in this study. This included a replicated on-station experiment at the agricultural research station, Dharwad farm, one non-replicated on-station experiment at the main agricultural research station of the University of Agricultural Sciences, Dharwad, and 22 on-farm non-replicated experiments. The on-farm trials were distributed in the major cotton-growing districts of Dharwad, Gadag, Bijapur, Haveri, Belgaum, and Bagalkot, with varying soil types ranging from medium black to deep black soils of the order Vertisols. The details of soil properties at all the experimental sites are given in **Table 1**, which revealed that soil reaction was slightly alkaline in nature, the EC measured in 1:2.5 soil:water suspension was non-saline (≤ 0.4 dS/m), available N, P_2O_5 and K_2O contents were low (< 280 kg/ha), medium (22.5 to 55 kg/ha) and high (> 335 kg/ha), respectively (**Table 1**). Before the start of the experiment, the targeted seed

Table 1. Available nutrient status of the experimental locations.

Soil property	On-farm locations Range	Mean	S.D.	On-station locations ARS, Dharwad	MARS, Dharwad
pH	7.6-8.9	8.2	0.38	7.8	7.4
EC, dS/m	0.18-0.38	0.24	0.05	0.34	0.4
Available N, kg/ha	168-290	240	43.03	163.1	208
Available P_2O_5, kg/ha	35-85	44.3	11.4	52.2	35
Available K_2O, kg/ha	365-811	552.4	109.3	362.2	350
Available S, kg/ha	-	-	-	18.5	25
Available Ca, me/100g	-	-	-	40.0	4
Available Mg, me/100g	-	-	-	13.7	36
Available Zn, mg/kg	0.43-0.82	0.64	0.13	0.85	1
Available Fe, mg/kg	0.42-0.81	0.62	0.10	0.90	3

cotton yield was set at 3 t/ha considering the available information on attainable yields, nutrient uptake and soil test values from the experimental sites. At the on-station site, the experiment at ARS Dharwad farm was set up in a randomized block design with 4 treatments and 5 replications, whereas, at on-station site in MARS Dharwad and at the on-farm sites, 4 treatments were compared at each site, considering each location as an individual replication. The treatments consisted of ample NPK (180, 70 and 80 kg/ha N, P_2O_5 and K_2O) and three nutrient omission plots for N, P and K based on the ample NPK treatment where all limiting nutrients were applied in ample quantity except the omitted nutrient. Deficient micro and secondary nutrients were applied to all four treatment plots wherever necessary based on soil test results. Each treatment was laid out in a minimum plot size of one guntha (10 m x 10 m) covering an area of 4 gunthas at each location. Chiranjeevi and RCH-2 were the Bt cotton hybrids used at ARS and MARS farms, whereas, 7 different Bt cotton hybrids (Kanaka, Mallika, Shalimar, Brent Bt, RCH-2, Chiranjeevi, and JK Durga) were used at the on-farm sites. Urea, single superphosphate, KCl, and sulfates of Zn, Fe, Mg were the sources of nutrients used in the experiments and all nutrients were applied at sowing with the exception of N and K, which were applied in three splits (i.e., 25% basally, 50% at 30 DAS, and 25% at 60 DAS). Uniform cultural practices and plant protection measures were adopted in all treatments. The observations on growth and yield parameters were recorded at all the locations and the average of all on-farm sites were reported in addition to reporting the results of on-station sites separately.

Inferior growth of Bt cotton in red and lateritic soils of Odisha under P omission plot compared to better growth in K omission plot.

On-farm Trials with P Omission at Kalahandi, Odisha

Nine non-replicated on-farm trials were conducted during 2012 in Tol Brahamani, Chinpadar, and Ghantmal villages in Kalahandi district of Odisha state. The soils from the farmer fields were analyzed for physical and chemical properties before imposing the treatments. All soils were acidic (pH range 5.4 to 5.5) with low organic carbon (range 3.8 to 4.1 g/kg), low available N (127 kg/ha), medium available P_2O_5 (48 kg/ha, Bray-1 method), medium available K_2O (202 kg/ha), low S (8.1 kg/ha), and low in available B and Zn.

Five treatments were compared, which consisted of ample NPK (180 kg N, 85 kg P_2O_5, 115 kg K_2O, 55 kg S, 10 kg B through Borax, and 25 kg Zn through $ZnSO_4$), three nutrient omission plots for N, P and K, as described in the previous section, and farmer fertilizer practice (FFP). The average use of fertilizer by farmers of the locality was 160 kg/ha N, 100 kg/ha P_2O_5 and 60 kg/ha K_2O, while there was no application of any secondary and micronutrients by farmers. The compound fertilizer (20-20-0-13), along with Urea, SSP, MOP, Borax, and $ZnSO_4$ were the sources of nutrients used in the experiments and the application schedule was similar to that of Karnataka state. For this paper, the recorded observations on the growth and yield parameters were presented only for the Ample NPK and P Omission treatments and compared with FFP treatment.

Results

Seed Cotton Yield and P Response

The average Bt seed cotton yield in Karnataka due to ample NPK was 2,447 kg/ha (**Table 3**), with highest yield recorded at on-farm locations (3,600 kg/ha) followed by the on-station locations, 1,957 kg/ha at MARS Dharwad and 1,783 kg/ha at ARS, Dharwad farm. Earlier experiments conducted at on-station sites in Karnataka recorded similar yields of 1,706 kg/ha (Ravikiran et al., 2012) and 1,925 kg/ha (Hosamani et al., 2013) at agricultural college farm of Raichur with the application of nutrients at 125% of RDF (187.5, 93.5 and 93.5 kg/ha N, P_2O_5 and K_2O, respectively).

The higher yield at on-farm locations was in the ample NPK treatment, which had a significant effect on different growth parameters such as plant height, number of monopodials and sympodials, average boll weight and average seed cotton yield per plant (**Table 2**). Whereas, such effect of ample NPK treat-

Table 2. Growth and yield parameters of Bt cotton as influenced by P omission.

Treatments	Plant height, cm	No. of monopodia per plant	No. of sympodia per plant	No. of bolls per plant	Average boll weight, g	Seed cotton yield, g/plant
On-farm locations (n = 22), Karnataka						
Ample NPK	134.6	2.10	23.1	44.7	5.16	36.0*
N omission	104.1	1.89	19.3	29.1	4.30	20.3*
P omission	125.8	1.95	21.9	41.1	5.15	31.2*
K omission	125.7	2.01	21.8	40.5	5.12	29.7*
C.D. at 5%	7.1	0.11	0.65	1.88	0.15	0.66
On-station location, ARS Dharwad Farm						
Ample NPK	79.5	1.60	18.84	29.50	5.00	111.6
N omission	65.9	1.08	14.76	18.24	4.41	74.2
P omission	75.8	1.54	17.44	26.16	4.95	104.0
K omission	74.8	1.20	17.72	25.40	4.92	88.5
C.D. at 5%	8.5	NS	2.68	3.60	0.36	23.9
On-station location, MARS Dharwad						
Ample NPK	125.7	3.2	27.2	36.7	5.48	168.3
N omission	91.6	2.2	12.5	17.5	4.52	111.5
P omission	108.3	2.4	21.7	28.5	5.32	157.5
K omission	112.4	2.8	23.5	25.4	5.24	140.4
On-farm locations (n = 9), Odisha						
Ample NPK	157.1	-	-	20.65	13.7	31.74**
N omission	123.4	-	-	9.77	11.1	18.11**
P omission	128.6	-	-	16.94	11.8	18.67**
K omission	140.1	-	-	13.0	12.4	22.91**
FFP***	115.0	-	-	14.41	11.7	19.93**
C.D. at 5%	36.8			2.8	0.6	8.6

*At on-farm locations, seed cotton yield is reported as kg/guntha (100 m^2). **Data represents no. of squares per plant. ***Farmer Fertilizer Practice.

Table 3. Seed cotton yield and yield loss as influenced by omission of P.

	On-farm locations (Karnataka)		ARS, Hebbali farm		MARS, Dharwad		On-farm locations (Odisha)	
Treatment	Yield, kg/ha	Yield loss, %	Yield, kg/ha	Yield loss, %	Yield, kg/ha	Yield loss, %	Yield, kg/ha	Yield loss, %
Ample NPK	3,600	-	1,783	-	1,957	-	2,760	-
N omission	2,033	43.5	871	51.1	1,224	37.5	1,160	58.0
P omission	3,119	13.4	1,594	10.6	1,724	11.9	1,340	51.4
K omission	2,965	17.6	1,466	17.8	1,657	15.3	1,870	32.2
FFP*	-	-	-	-	-	-	1,180	57.2
C.D. at 5%	66.1	-	194	-	-	-	348	-

*Farmer Fertilizer Practice.

ment was non-significant with different growth parameters of Bt cotton at on-station locations, respectively (**Table 2**). The average yield due to P omission (2,146 kg/ha) also followed a similar trend, with highest yield recorded at on-farm locations (3,119 kg/ha) followed by the other two on-station sites (**Table 3**). The yield loss due to P omission at on-farm sites (13.4%) was statistically significant, whereas, the yield loss of 11% due to P omission at the on-station location was statistically non-significant.

In Odisha, nutrient application based on ample NPK treatment resulted in a significantly higher seed cotton yield (2,760 kg/ha), followed by P omission (1,340 kg/ha) and FFP (1,180 kg/ha). Omission of P led to a significant yield difference of 1,420 kg/ha as compared to the ample NPK treatment and resulted in a yield loss of 51.4%. The corresponding mean reduction in seed cotton yield in FFP over ample NPK was 1,580 kg/ha, which resulted in a yield loss of 57.2%. The higher yield in ample NPK over P omission and FFP is due to significant differences in growth parameters (**Table 2**), which revealed more number of bolls and more number of squares per plant in addition to recording a high average boll weight in ample NPK treatment.

The seed cotton yield response to application of P (**Figure 1**) across all the on-farm and on-station locations in Karnataka varied from 189 to 820 kg/ha with an average of 459 kg/ha. In an earlier study, Biradar et al. (2011) reported a low P response of 374 kg/ha in cotton grown at Dharwad and 293 kg/ha at Siruguppa and indicated a yield loss of 11 and 12% respectively due to omission of P. The low P response in Karnataka is ascribed to the soil type of the experimental sites with medium black to deep black soils having medium available P_2O_5 (average of 43.8 kg/ha across all the locations in the study as given in **Table 1**). The average post harvest available P_2O_5 in the P omission plot at on-farm locations was 30 kg/ha against an initial soil available P_2O_5 of 44 kg/ha, whereas, at an on-station site at Dharwad farm, the corresponding soil available P_2O_5 after harvest of cotton crop in P omission treatment was 36.9 kg/ha against an initial soil P_2O_5 level of 52.2 kg/ha (**Table 1**), respectively, indicating a retention of medium level of soil P even after harvest of Bt cotton. The increased P availability with advancement in crop age was also ascribed to increased root activity in the soil. Plant roots excrete organic acids and chelating organic compounds in rhizosphere, which form multiple complex compounds with

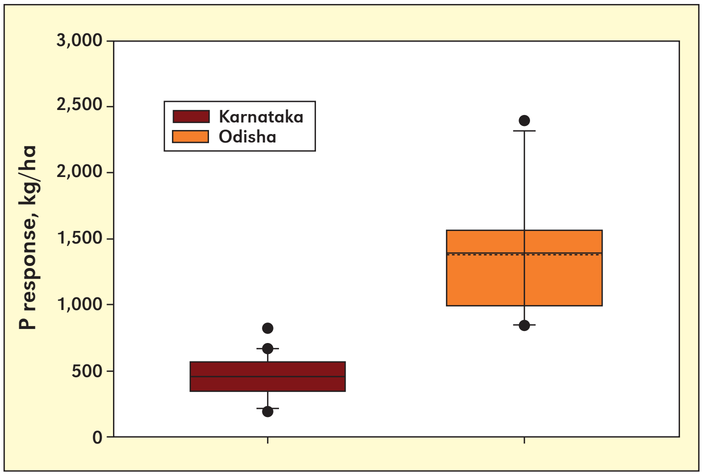

Figure 1. Range of seed cotton yield response to P application. Boxes represent data within the first and third quartiles (interquartile range). The thin line denotes the second quartile or media, and the dotted line denotes the mean. Lines extending beyond the interquartile range denote the 10th to 90th percentile of the data. Statistical outliers are plotted as individual points outside these lines.

Ca, Mg and/or Fe and thereby increased P availability in soil (Tinker, 1980).

The seed cotton yield response to P application across nine on-farm locations in Odisha varied from 840 to 2,390 kg/ha, with an average of 1,420 kg/ha. The high P response in Odisha (**Figure 1**) was due to the red and lateritic soil type of the experimental sites with acidic soil pH (ranged from 5.4 to 5.5 across nine on-farm sites) and low available soil P_2O_5 (average of 27.4 kg/ha, Bray-1 method). Misra et al. (1989) reported a high P-fixing capacity (80 to 91%) in the soils of Odisha, which tends to reduce the efficiency of the added P fertilizer (Dev and Rattan, 1998). The study indicated a low response of Bt cotton to application of P in Karnataka, which is 32% of the P response in Odisha (**Figure 1**). The difference of P uptake between ample NPK treatment and P omission treatments in Karnataka and Odisha was 4.3 and 9.5 kg/ha (**Table 5**), indicating that the lower P response in Karnataka over Odisha is also due to low P uptake in Karnataka than in Odisha. Deshpande et al. (2014) reported a high available soil P residue after the harvest of Bt cotton due to low absorption of soil P by Bt cotton hybrids in Vertisols of Maharashtra.

Effect of P omission on the economics of Bt cotton at on-farm locations in Karnataka (**Table 4**) revealed that the gross returns, net returns and benefit:cost ratio significantly decreased due to P omission over ample NPK by Rs.19,273, Rs.13,772 and 0.26, respectively. The overall reduction in net returns due to P omission over ample NPK was 19%, indicating the importance of P application in the Bt cotton-growing soils of Karnataka.

The results of this study based on P response and economics due to P application indicated a judicious P management strategy in Karnataka where Bt cotton is grown under medium black to deep black soils. However in Odisha, considering the critical role played by P in maintaining the productivity of Bt cotton in red and lateritic soils, adequate P application rates based on the results of P response from ample NPK may be promoted to improve P use efficiency of soils by reducing P-fixing capacity of soils. BC-SA

Table 4. Effect of P omission on economics of Bt cotton at on-farm locations in Karnataka.

Treatment	Gross returns, Rs./ha	Net returns, Rs./ha	% Reduction in net return	B:C ratio
Ample NPK	144,036	74,036	-	2.05
N omission	81,309	21,309	71.2	1.17
P omission	124,763	60,264	18.6	1.79
K omission	118,636	54,336	26.6	1.70
C.D. at 5%	2,645	2,645	-	0.04

Table 5. Nutrient uptake of Bt cotton as influenced by P omission.

Treatment	N uptake, kg/ha	P uptake, kg/ha	K uptake, kg/ha
On-station location, ARS Dharwad farm, Karnataka			
Ample NPK	46.0	7.8	61.0
N omission	13.5	3.5	25.5
P omission	35.5	3.5	48.6
K omission	33.5	4.2	26.9
On-farm locations (n = 9), Odisha			
Ample NPK	115.4	17.1	106.8
N omission	46.3	7.5	53.6
P omission	47.2	7.6	59.5
K omission	75.1	11.8	79.3
FFP*	52.6	10.4	56.7
C.D. at 5%	20.0	2.01	15.1

*Farmer Fertilizer Practice.

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