Indian Journal of Agronomy **57** (3): 235–240 (September 2012)

Research Paper

Effect of phosphorus sources and levels on Bt-cotton (*Gossypium hirsutum*) based intercropping systems

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Received : November 2011; Revised accepted : July 2012

ABSTRACT

A field experiment was conducted during *kharif* of 2007 and 2008 at New Delhi to assess the performance of intercropped Bt cotton as influenced by P nutrition. The experiment was laid out in split plot design. Five cropping systems *viz.,* sole cotton (*Gossypium hirsutum* L.); sole groundnut (*Arachis hypogaea* L.); sole soybean [*Glycine max* (L.) Merr.]; cotton + groundnut; and cotton + soybean were taken in the main plots and two combination of P sources and biofertilizers viz., single superphosphate and rock phosphate + phosphate solubilising bacteria (PSB) + *vesicular-arbuscular mycorrhiza* (AM) and two P levels viz., 17.5 and 35 kg/ha including control in the sub- plots. Cotton + groundnut cropping system gave the highest cotton equivalent yield (CEY) of 2.4 t/ha, followed by cotton + soybean system (2.2 t/ha) and sole cotton (2.1 t/ha). Application of 35 kg P/ha recorded on an average 14.2 % higher CEY over 17.5 kg P/ha. Cotton + groundnut system recorded an additional mean net returns of ₹6,512 compared to sole cotton (₹39,382/ha). Application of 35 kg P/ha increased the mean net income to the tune of ₹5,604/ha over 17.5 kg P/ha with a mean B:C ratio of 1.8. Quality traits of cotton remained unaffected by cotton intercropping.

Key words : Bio-fertilizers, Bt-cotton, Groundnut, Intercropping, Phosphorus sources, Rock phosphate, Soybean

Cotton the king of fibre crops, plays an important role in the national economy. In India, cotton occupies 11.1 million ha with a production of 31.2 million bales. Cotton is usually grown at a wider inter row spacing and the growth is quite slow upto 60-75 days and this offers a good scope for intercropping with a short duration crop. Intercropping of legumes in cotton has no adverse effect on cotton performance, but an additional yield of legume makes the system more remunerative. It has been projected that country should produce 35 million tonnes of oilseeds and 30.3 million tonnes of pulses by 2020 AD to meet nutritional requirement of 1,400 million populations. As land area is shrinking, vertical expansion provides an opportunity to meet the demands of oil and protein. Intercropping of pulses and oilseeds with cotton provides an opportunity to address this issue.

The most important constraint in productivity of cotton-legume intercropping systems is poor nutrient management. With legume as intercrop, there is a good scope to cut down nitrogen application from external sources, but P is an important and limiting nutrient for both legumes and oilseeds. As the cost of superphosphate, the widely used phosphatic fertilizer is on the increase, it is essential to go for cheaper sources of phosphorus. In this context, rock phosphate appears to be a better and cheaper alternative. The use efficiency of applied phosphorus is only 15-20% and the remaining P gets fixed in the soil. Phosphorus solubilising bacteria (PSB) *viz.,* microphos (*Pseudomonas striata*) and fungi i.e., *vesicular-arbuscular mycorrhiza* (AM) solubilise native soil phosphorus through secretion of various organic acids (formic acid, butyric acid, propinic acid and lactic acid). These acids bring down the soil pH resulting in the dissolution of less soluble forms of phosphates and this increases efficiency of applied and native phosphorus (Behera *et al*., 2007). P requirement is relatively higher in legumes as compared to non-legumes. Therefore, the total requirement of P in cotton + legume intercropping is usually higher than sole cotton. The present investigation was, therefore, undertaken to study the effect of P nutrition in cotton based intercropping system.

MATERIALS AND METHODS

A field experiment was carried out during *kharif* season of 2007 and 2008 at the research farm of the Indian Agri-

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cultural Research Institute, New Delhi. The experiment was conducted in a split plot design with three replications. Five cropping systems viz., sole cotton; sole groundnut; sole soybean; cotton + groundnut and cotton + soybean were taken in the main plots with combinations of two phosphorus sources *viz.,* single superphosphate and rock phosphate + phosphate solubilising bacteria (PSB) + *vesicular-arbuscular mycorrhiza* (AM) and two P levels *viz.,* 17.5 and 35 kg/ha including control were in the subplots. The soil of the experimental site was sandy loam (66.8% sand, 14.3% silt and 18.9% clay) having pH 7.8, low in organic C content (0.46%), and low in $KMnO_4$-oxidizable available N (227 kg/ha) and medium in Olsen's available P (12.8 kg/ha) and NH_4OAc-extracable K (270 kg/ha). Cotton 'MRC-6301' Bt was sown by dibbling at120 cm × 60 cm spacing on 29 May in 2007 and on 7 June in 2008. Three rows of groundnut and soybean were sown in additive series between two rows of cotton at 37.5 spacing on 16 July in 2007 and 8 July in 2008. The total rainfall received during the cropping period was 489.0 mm in 2007 and 631.5 mm in 2008. In cotton 150 kg N/ha was applied in split doses. Half of the nitrogen was applied at seeding and remaining N in two equal doses side dressed at flowering and boll formation stages. P was applied at seeding time as per the treatments only. No additional dose of nutrient was applied to intercrops. Seeds were inoculated with specific and efficient strains of phosphate solubilising bacteria *viz.,* microphos (*Pseudomonas striata*), and after sowing, *Glomus mosseae* (AM) culture applied to the open furrow @ 15 kg/ha using field soil to bulk the carrier over seed before sowing in rock phosphate treated plots only. Groundnut 'Punjab groundnut 1' and soybean 'PS 9072' were sown at 30 cm inter-row spacing using a seed rate of 100 kg/ha. Both crops were harvested in the last week of October. Cotton was harvested in two pickings upto last week of November. Fibre properties were measured by air flow method (Ahlawat *et al*., 2005).

RESULTS AND DISCUSSION

Growth parameters

Cotton intercropped with either groundnut or soybean produced taller plants as compared to sole cotton (Table 1). Sole cotton had highest LAI and dry matter accumulation over the cotton+groundnut and cotton+soybean intercropping system. This might be due to competitive environment between main and intercrop for moisture, solar radiation and nutrients. P application through SSP resulted in significantly taller plants, higher LAI and dry matter accumulation over P through RP + PSB + AM. This was due to instant and easy availability of P in soil through SSP as compared to RP + PSB + AM. The later source is solubilised slowly over a longer period.

Table 1. Effect of cropping system, P sources and levels on growth, yield components and yield of cotton (Mean data of 2007 and 2008)

Treatment	Plant height at maturity (cm)	LAI	Dry matter at maturity (g/plant)	Open bolls/ plant	Boll weight (g/boll)	Seed cotton yield (t/ha)	Stalk yield (t/ha)	Seed index	Ginning (%)
Cropping system									
Sole cotton	131.5	3.0	547.9	45.0	4.0	2.1	5.0	8.5	28.4
Cotton+groundnut	142.9	2.8	523.6	43.4	3.8	2.1	4.6	8.2	30.1
Cotton+soybean	144.6	2.7	509.5	43.1	3.6	2.0	4.7	8.3	30.4
SEm±	2.6	0.1	5.3	0.6	0.1	0.1	0.1	0.2	1.3
CD (P=0.05)	10.3	0.2	20.8	1.9	NS	NS	0.4	NS	NS
P sources									
SSP	151.4	3.0	567.6	47.8	4.2	2.2	5.2	8.8	32.7
RP + PSB + AM	137.0	2.8	524.3	42.7	3.7	2.0	4.7	8.4	29.5
SEm±	2.2	0.1	8.1	0.8	0.1	0.04	0.1	0.2	1.2
CD (P=0.05)	6.6	0.2	23.6	2.2	0.2	0.1	0.3	NS	2.8
P levels									
17.5	139.3	2.8	513.2	43.3	3.6	2.0	4.6	8.5	28.5
35	149.1	3.0	578.6	47.1	4.3	2.3	5.4	8.7	33.8
SEm±	2.2	0.1	8.1	0.8	0.1	0.04	0.1	0.2	1.2
CD (P=0.05)	6.6	0.2	23.6	2.2	0.2	0.1	0.3	NS	2.8
Control vs treated									
Control	121.6	2.5	451.3	38.2	3.1	1.8	4.0	7.3	28.0
Treated	144.2	2.9	545.9	45.2	4.0	2.1	5.0	8.6	33.2
SEm±	3.6	0.1	12.8	1.2	0.1	0.1	0.2	0.5	1.2
CD (P=0.05)	7.3	0.2	26.3	2.5	0.2	0.1	0.3	1.5	2.8

Application of 35 kg P/ha recorded taller plants with higher LAI and dry matter accumulation over 17.5 kg P/ha. Higher doses of P lead to increased photosynthesis, energy transfer reactions and symbiotic biological N_2 fixation, which ultimately results in better growth (Blaise *et al.,* 2005).

Yield attributes and seed cotton yield

Cropping system significantly influenced the yield attributes of cotton (Table 1). Cotton+ soybean had the highest number of open bolls/plant (4.8%) and higher boll weight (11.8%) over sole cotton. Intercropping did not significantly influence seed cotton yield. Thus initial competition provided by groundnut and soybean as observed in some growth parameters did not last long (Table 1). Application of P through SSP gave higher number of bolls/plant, boll weight, seed cotton yield and stalk yield over P applied through RP + PSB + AM.

Application of 35 kg P/ha had higher number of open bolls/plant, boll weight, seed cotton yield and stalk yield of cotton as compared to 17.5 kg P/ha. Improvement in yield parameters with better P management was due to diversion of more plant metabolites towards developing buds, flowers and bolls. Increase in seed cotton and stalk yield due to application of P was largely a function of improved growth, translocation of more photosynthates towards sink and consequent development of yield attributes.

Intercrop

The performance of intercrops was drastically altered in intercropping with cotton as compared to sole stand (Table 2). Intercropped groundnut/soybean, on an average, produced 6.5 % less pods/plant as compared to its sole. However, the extent of reduction in kernels/pods and 1000 kernel weight in intercropping was of lesser magnitude when compared to its sole stand and it was same for soybean also. The cumulative effect of reduction in pods/pant, kernels/pod and 1,000-kernel weight in intercropped groundnut led to lower productivity (1.2 t/ha in sole groundnut and 0.4 t/ha intercropped groundnut, respectively). The poor performance of groundnut and soybean in intercropping was mainly attributed to lower plant population (45% base population in intercropping as compared to sole groundnut/soybean). Further, the shading effect of cotton foliage (90 days after sowing onwards) and competition for resources, particularly water and nutrients also contributed to lower values of yield attributes and yield (1.1 t/ha in sole soybean and 0.5 t/ha in intercropped soybean, respectively). Among the three rows of intercropped ground-

Table 2. Growth, yield components and yield of intercrop as influenced by cropping system, P sources and levels (Mean data of 2007 and 2008)

Treatment	Pods/plant	Kernels/ pod	Pod yield (t/ha)	Haulm yield (t/ha)	Pods/plant	Grain/ pod	Grain yield (t/ha)	Stover yield (t/ha)
Cropping system								
Sole groundnut	91.7	1.9	1.2	3.8	-	-	-	-
Sole soybean	-	-	-	-	49.1	2.4	1.1	3.5
Cotton+groundnut	84.0	1.8	0.4	-	-	-	-	-
Cotton+soybean	-	-	-	1.4	46.8	2.3	0.5	1.3
SEm±	2.7	0.1	0.02	0.04	0.7	0.05	0.02	0.04
CD (P=0.05)	NS	NS	0.1	0.2	2.05	NS	0.1	0.2
P sources								
SSP	99.1	2.0	0.9	2.8	54.6	2.6	0.9	2.6
RP + PSB + AM	85.4	1.8	0.8	2.6	46.6	2.3	0.8	2.4
SEm±	2.3	0.1	0.02	0.1	1.2	0.1	0.04	0.1
CD (P=0.05)	6.8	0.2	0.1	0.2	3.7	0.2	0.1	0.2
P levels								
17.5	88.1	1.8	0.8	2.5	47.5	2.3	0.8	2.3
35	96.8	1.9	0.9	2.8	53.7	2.6	0.9	2.7
SEm±	2.3	0.1	0.02	0.1	1.2	0.1	0.04	0.1
CD (P=0.05)	6.8	NS	0.1	0.2	3.7	0.2	0.1	0.2
Control vs treated								
Control	69.3	1.7	0.6	2.2	37.3	2.0	0.6	2.0
Treated	92.5	1.9	0.8	2.7	50.6	2.5	0.8	2.5
SEm±	3.6	0.1	0.03	0.1	1.9	0.1	0.1	0.9
CD (P=0.05)	7.6	0.2	0.01	0.2	4.1	0.2	0.1	0.2

nut/soybean, the contribution of centre row to the yield was the maximum. These results are in the line of Waterworth (1994). P through SSP showed superior performance of intercropped groundnut/soybean in terms of pods/plant and yield over RP + PSB + AM. Application of 35 kg P/ha had highest pods/plant, pod and haulm yield in groundnut. Plant height, dry matter accumulation, grains/pod, grain and stover yield in soybean was found maximum with 35 kg P/ha over 17.5 kg P/ha. The higher P uptake in sole groundnut/soybean could be ascribed to the fact that it received recommended dose of fertilizers (N and P), while intercropped groundnut/soybean survived on nutrients applied to base crop of cotton. Hence, intercropped groundnut faced competition for nutrients from cotton compared to sole groundnut/soybean. P uptake was lower in intercropping because of less pods and biomass yield of groundnut and soybean.

Fibre quality parameters

Cotton grown sole or intercropped with soybean or groundnut did not differ significantly in respect to fibre quality, seed index and ginning percentage (Table 1). Fibre quality is largely a genetic character in cotton and does not change easily by cultivation practices (Blaise *et al*., 2005).

Application of phosphorus in different cropping systems through SSP did not affect most of the quality attributes of cotton. However, application of phosphorus to different cropping systems through SSP significantly increased the ginning percentage of cotton over phosphorus supplied through RP + PSB + AM. Application of 35 kg P/ha to different cropping systems recorded significant increase in ginning percentage over 17.5 kg P/ha in both the years. Similar results were reported by Singh *et al.* (2006).

Nutrient content and uptake

P uptake was significantly influenced by cropping system. Sole cotton had highest P uptake over intercropped cotton (Table 3). Cotton + groundnut remained being at par with cotton + soybean in terms of P uptake. Among the P rates, P uptake was higher with 35 kg P/ha as compared to 35 kg P/ha. P application through SSP had higher P uptake over RP+PSB+AM. Higher uptake with SSP might be due to ready availability of P as compared to RP+PSB+AM, where P availability was gradual.

Post-harvest fertility status

Sole soybean and sole groundnut left higher soil N, P and OC as compared to sole cotton. Among the intercropping systems cotton + soybean maintained higher fertility status as compared to cotton + groundnut (Table 3). SSP had the highest available soil N but P and OC remained

Table 3. Effect of cropping system, P sources and levels on P uptake and available soil OC, N and P status (Mean data of 2007 and 2008)

Treatment	P uptake by cotton	P uptake by groundnut	P uptake by soybean	P uptake by cotton+ groundnut	P uptake by cotton+ soybean	Available nutrient and OC after harvest of crops		
						N(kg/ha)	P(kg/ha)	OC (%)
Cropping system								
Sole cotton	13.3	-	-	13.3	13.3	220.7	11.6	0.4
Sole groundnut	-	9.5	-	9.5	-	266.2	13.2	0.4
Sole soybean	-	-	13.4	-	13.4	270.7	13.4	0.4
Cotton+groundnut	12.2	3.4	-	15.6	-	239.5	10.9	0.5
Cotton+soybean	11.8	-	4.9	-	16.7	243.7	11.2	0.5
SEm±	0.4	0.2	0.5	0.6	0.6	5.1	0.4	0.02
CD (P=0.05)	1.2	0.5	1.5	1.6	1.7	16.7	1.1	0.1
P sources								
SSP	14.6	8.1	11.2	22.6	25.9	260.1	13.0	0.5
RP + PSB + AM	12.1	6.2	8.9	18.2	21.1	252.8	12.7	0.5
SEm±	0.3	0.1	0.3	0.5	0.6	5.0	0.2	0.01
CD (P=0.05)	0.9	0.4	0.9	1.4	1.6	NS	NS	NS
P levels								
17.5	11.6	6.1	8.5	17.7	20.1	245.0	11.4	0.5
35	15.2	7.9	11.4	23.1	26.6	267.8	14.2	0.5
SEm±	0.3	0.1	0.3	0.5	0.6	5.0	0.2	0.01
CD (P=0.05)	0.9	0.4	0.9	1.4	1.6	14.4	0.7	NS
Control vs treated								
Control	8.7	4.0	5.8	12.7	14.5	215.1	9.0	0.3
Treated	13.4	7.0	10.0	20.5	23.4	256.4	12.8	0.5
SEm±	0.5	0.2	0.4	0.5	0.6	5.6	0.3	0.01
CD (P=0.05)	1.4	0.6	1.1	1.4	1.7	16.1	0.8	0.04

Table 4. Effect of cropping systems, P sources and P levels on CEY and economics of cotton

Treatment	Cotton equivalent yield (t/ha)	Cost of cultivation (×10³ ₹/ha)	Net returns (×10³ ₹/ha)	B:C ratio
Cropping system				
Sole cotton	2.1	17.9	39.4	2.2
Cotton+groundnut	2.4	18.8	45.9	2.4
Cotton+soybean	2.2	18.7	42.6	2.3
SEm±	0.03	-	-	-
CD (P=0.05)	0.1	-	-	-
P sources				
SSP	1.8	17.4	32.4	1.7
RP + PSB + AM	1.6	16.4	28.4	1.6
SEm±	0.03	-	-	-
CD (P=0.05)	0.1	-	-	-
P levels				
17.5	1.6	16.6	27.6	1.5
35.0	1.8	17.2	33.2	1.8
SEm±	0.03	-	-	-
CD (P=0.05)	0.1	-	-	-
Control vs treated				
Control	1.4	15.9	21.9	1.3
Treated	1.7	16.9	30.4	1.7
SEm±	0.04	-	-	-
CD (P=0.05)	0.1	-	-	-

being at par over RP + PSB + AM. Control plots had the lowest available soil N, P and OC. Organic carbon was not influenced by P levels. By application of 35 kg P/ha soil N and P post status remained higher as compared to 17.5 kg P/ha. Cropping system significantly affected available P of soil after harvest of cotton, groundnut and soybean over initial soil status. Increase in available P, N and OC might be due to the N_2 fixation, litter fall and secretion of acids by soybean which solubilises initial pool of P in the soil. It could also be attributed to application of *vesicular arbuscular mycohrize* and P solubilising bacteria which secretes acids viz., globulin, propinic acid and lactic acid. Secretion of acids by bacteria had a synergistic effect on AM through which multiplication of fungal hyphae occurred and at last increased population of soil microbes releases fixed P into available form (Elwan *et al*., 2002).

System productivity

Cotton + groundnut system recorded significantly higher cotton equivalent yield (11.3%) over cotton + soybean and followed by sole cotton (Table 4). Similarly, cotton yield in intercropping as that of sole cotton coupled with additional yield of intercropped groundnut (0.9 t/ha CEY) and soybean (0.6 t/ha CEY) resulted in superior performance of cotton intercropping system. Higher CEY was found when P applied through SSP than RP+PSB+AM. Application of 35 kg P/ha gave higher CEY over 17.5 kg P/ha. This was due to efficient utilization of P resources and less competition between component crops.

Economics

Cotton + groundnut system on an average fetched ₹10,401 more net returns and thus has 0.20 more B:C ratio than sole cotton (Table 4). Among the intercropping system cotton + groundnut had ₹1,378 advantage over cotton + soybean system. The higher seed cotton equivalent yield (groundnut 0.3 tonnes/ha and soybean 0.1 tonnes/ha) coupled with corresponding stover yield with minimal increase in cost of cultivation has resulted in higher net returns and B:C ratio in intercropping system over sole cotton. RP + PSB + AM was cheaper as compared to SSP. But net returns and B:C ratio was lower in RP + PSB + AM over SSP. This was due to SSP application leads to higher yield increase resulted into more economic gains. 35 kg P/ha had higher net returns and B:C ratio as compared to 17.5 kg P/ha. This might be due to increased proportion of net returns in relation to cost of cultivation.

Based on these findings it can be concluded that intercropping of cotton with groundnut and 35 kg P/ha through SSP is sustainable.

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