EFFECT OF P-STRESS ON GROWTH, PHOSPHORUS UPTAKE AND UTILIZATION EFFICIENCY OF DIFFERENT COTTON CULTIVARS

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Phosphorus (P) availability is severely low in alkaline calcareous soils. Crop cultivars adopt morphological and physiological adaptation to maintain their normal growth under P stress conditions. Twelve cotton cultivars were grown in solution culture with two P levels (10 µM & 100 µM). Effect of P-levels and cultivars was observed on leaf area, shoot dry matter (SDM), root dry matter (RDM), root-shoot ratio, P concentration, P-uptake and P-utilization efficiency. Phosphorus stress reduced the leaf area significantly among all the cotton cultivars and 52 % reduction in the leaf area was observed. Shoot dry matter and root dry matter was significantly affected by P-levels and 32 % reduction in the SDM and 2-fold increase in the RDM was observed due to P-stress. There was highly significant positive correlation (r= 0.91 & r=0.75) between leaf area, SDM and RDM. Leaf-weight ratio of the P-stressed plants decrease by 5 % compared with adequate P-level. Phosphorus stress decreased P-concentration in both shoot and root highly significantly (70% and 61% respectively). Highly significant positive correlation (r=0.85) was found between SDM and shoot P-concentration. P-stress caused 7 % more assimilate partitioning to the roots as compare to the P-adequate level. Phosphorus stress reduced the P-uptake significantly and reduction was 81% and 53% in shoot and root respectively. Phosphorus stress caused preferential distribution of dry matter and P-concentration to roots as compared to the shoot indicated by highly positive correlation between RDM and root P-concentration.

Key words: *P-stress, cotton cultivars, leaf area, root shoot ratio.*

INTRODUCTION

Phosphorus (P) availability is severely low in alkaline-calcareous soils. Alkaline-calcareous soils with highly reactive $CaCO_3$ and highly Ca-saturated clay has low solution P as P can easily precipitate or adsorb under such conditions (Tisdale et al., 2002). Heavy fertilization is a traditional approach to increase the crop production by maintaining high solution P (Tisdale et al., 2002). However, transformation of added P to the plant unavailable forms (Buckman, 1990) has restricted the effectiveness of the heavy fertilization. Furthermore good quality phosphate ore are being depleted owing to heavy fertilization and would last for about 200 years (Bohn et al., 2004). Anticipate phosphate crisis in the 21st century for agriculture (Abelson, 1999) coupled with farmers' inability to purchase expensive phosphatic fertilizers and transformation of the added P to plant unavailable forms has threatened agricultural productivity and demands the effective strategy to deal with this problem. Different crop cultivars differ widely in their ability to uptake and utilize mineral elements especially P (Clark and Duncan, 1991). Selection and breeding of crops for P-use efficiency that can reduce P-fertilization and sustain high yield in P-deficient soils is good strategy. Phosphorus plays very important physiological role in plant growth and P-deficiency stress trigger many morphological, biochemical and molecular changes/adaptations in plants (Raghothama, 1999). Crop cultivars maintain their growth under P-stress conditions by exploring more soil for P, increasing root hair and root length thereby increasing root-shoot ratio (Gahoonia and Neilson, 2004). Phosphorus stress reduces the leaf area and no more required assimilates for leaf area expansion, are directed towards roots (Wissuwa et al., 2005), ultimately increasing root surface area to absorb more P from P-deficient medium (Valizadeh et al., 2003). Phosphorus also plays important role for cotton growth. It is essential for vigorous root and shoot growth. Phosphorus stress results in dwarfed plants, delayed maturity, and reduced yield (Synder and Stewart, 2003). We grow twelve cotton cultivars in solution culture to evaluate the effect of P-stress on the cotton growth parameters, differential growth response of cotton cultivars, P-uptake, P-concentration and P-utilization efficiency.

MATERIAL AND METHODS

Seeds of 12 cotton cultivars were collected from Ayub Agriculture Research Institute and NIAB, Faisalabad and germinated in pre-washed silica sand in polythene lined iron trays. Nursery was irrigated with distilled water. Two weeks old uniform sized seedlings were transplanted in foam plugged holes of thermopal sheets floating on continuously aerated Johnson solution (Johnson et al., 1957) in polythene lined (200 L capacity) iron tubs. Two phosphorus levels were maintained i.e. 200 µM (adequate) 20 µM (deficient) in the iron tubs. The pH of the solution was maintained at 5.5 $\pm$ 0.5 throughout growth period. Experiment was laid out in completely randomized design with eight repeats of each cultivar and each repeat consists of one plant. Three weeks old plants were harvested, washed with distilled water, blotted dry with tissue paper and cut into roots and shoots. Leaf area was measured with leaf area meter (MK 2) immediately after harvesting. Washed samples were dried at 70 °C in oven and weighed for root and shoot dry matter. Shoots and roots were ground to 40 mesh with mechanical grinder. 0.25 g of ground samples of roots and shoots were digested with diacid mixture (Nitric acid: Per Chloric acid). Phosphorus was determined by using vanadate-Molybdate yellow color method (Chapman and Pratti, 1961) using spectrophotometer. Data was subjected to statistical analysis with MSTATC.

RESULTS AND DISCUSSION

Phosphorus (P) stress affects the leaf area (LA) significantly (P< 0.05) and reduced the leaf area by 52 % compared with P-adequate level. Cotton cultivar GP-188 exhibited maximum reduction (65%) in the leaf area, followed by NIAB-92 (60 %) due to P-stress (Table 1.) Phosphorus stress reduces the leaf area by limiting the cell division at meritematic apex of the shoot (Chiera et al., 2002; Radin and Eidenbock, 1984). Cotton cultivar GP-188 exhibited maximum reduction (4-fold) in root-shoot ratio at adequate P compared with P-deficient indicating that under P-stress assimilates are directed towards the roots thereby restricting the leaf expansion (Wissuwa et al., 2005) and increasing root surface area for more P-absorption under P-stress conditions (Valizadeh et al., 2003).

Cultivars CIM-1100 and NIAB-92 had maximum leaf area (169 $cm^2 plant^{-1}$) and (93 $cm^2 plant^{-1}$) respectively but CIM-1100 had have lower root-shoot ratio compared to GP-188 (98 $cm^2 plant^{-1}$). It indicates that CIM-1100 was less affected due to P-stress and there is low partitioning of assimilates to the root.

Phosphorus (P) deficiency affects significantly (P<0.05) reduced the shoot dry matter (SDM) and 32 % reduction in SDM was observed due to P-stress. Cultivar CIM-1100 produced maximum SDM (1.37 g $plant^{-1}$) at deficient P-level while minimum SDM (0.77 g $plant^{-1}$) was produced by GP-188. Cultivars differences for SDM indicated that SDM can be used as reliable parameter for screening efficient cultivars (Liao et al., 2004). Cotton cultivars differed significantly (P<0.05) for root dry matter (RDM). Cultivar CIM-1100 produced the maximum RDM (0.33 g $plant^{-1}$) followed by CIM-240 (0.29 g $plant^{-1}$) while minimum RDM (0.13 g $plant^{-1}$) was produced by GP-77 at deficient P-level. Cultivar GP-188 exhibited maximum increase in RDM (40%) followed by NIAB-92 (38%) due to P-stress. However, GP-188 exhibited maximum reduction in leaf area (65%) indicating that this cultivar partitioned more assimilates into root by restricting leaf expansion (Wissuva et al., 2005). Phosphorus stress significantly (P<0.05) reduced the RDM (16%) compared with adequate P-level (Fig. 1 & 2).

Table 1. Growth parameters of different cotton cultivars grown at deficient and adequate P-levels

Genotypes	Leaf Area ($cm^2 Plant^{-1}$)		Root-shoot Ratio		Leaf-Weight Ratio	
	Deficient	Adequate	Deficient	Adequate	Deficient	Adequate
GP-7	125 bcd	289 ab	0.22 b-f	0.12 bc	0.48 bcd	0.50 abc
GP-77	110 cde	228 cde	0.15 efg	0.10 bc	0.55 a	0.55 a
GP-90	110 cde	215 de	0.19 defg	0.14 ab	0.52 ab	0.48 bc
GP-188	98 de	282 ab	0.29 abc	0.07 c	0.45 d	0.54 ab
GP-218	148 ab	191 e	0.12 g	0.18 a	0.51 abc	0.47 c
GP-220	135 bc	197 e	0.15 fg	0.18 a	0.50 bcd	0.49 abc
NIAB-78	103 de	202 e	0.21 c-g	0.14 ab	0.50 bcd	0.55 a
NIAB-92	93 e	231 cde	0.34 a	0.11 bc	0.45 d	0.55 a
NIAN-313	112 cde	266 bc	0.23 b-f	0.11 bc	0.48 bcd	0.54 ab
CIM-240	109 cde	251 bcd	0.31 ab	0.12 bc	0.46 cd	0.51 abc
CIM-1100	169 a	319 a	0.24 bcde	0.14 ab	0.51 abc	0.50 abc
SLS-1	108 cde	269 bc	0.27 abcd	0.14 ab	0.46 cd	0.51 abc
Mean	118 B	245 A	0.23 A	0.13 B	0.49 B	0.51 A

Values differed significantly (<0.05) unless followed by same letter

Fig. 1: Percent (%) distribution of dry matter between root and shoot as affected by P-deficiency stress

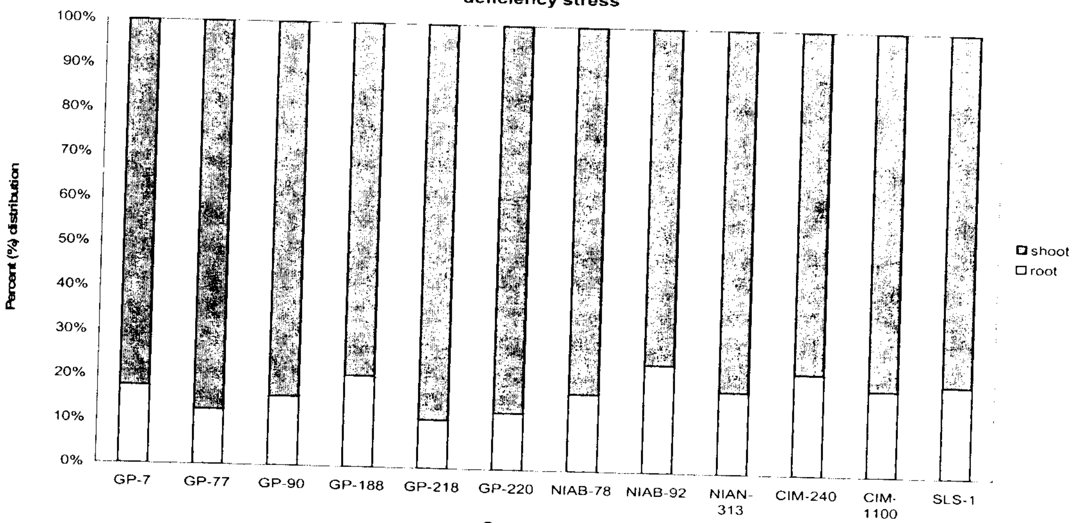
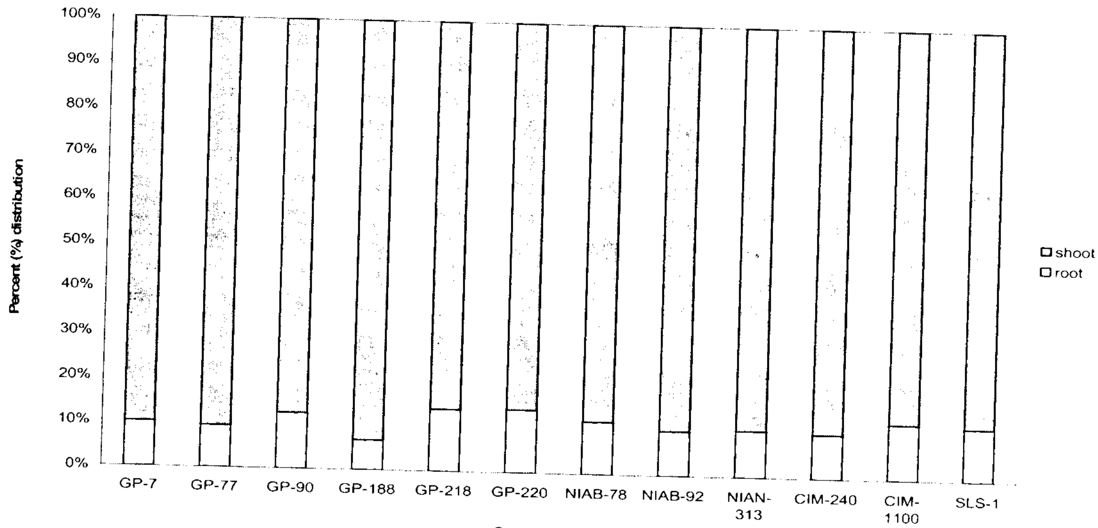


Fig. 2: Percent (%) distribution of dry matter between shoot and root as affected by adequate P level



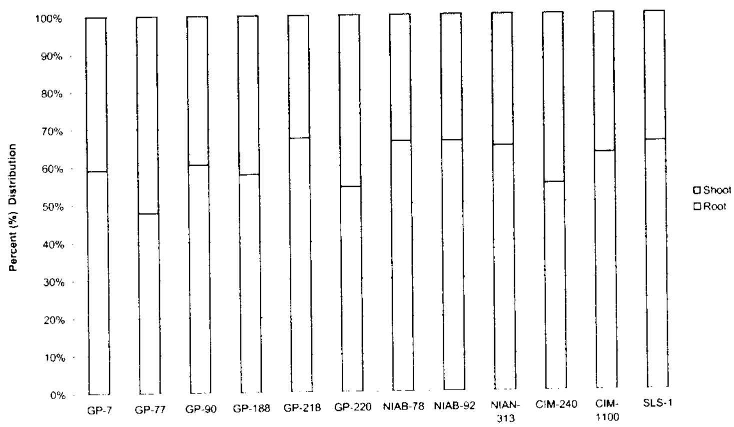
Cotton cultivars differed in distribution of dry matter between root and shoot. Most of the cultivars distributed more assimilates towards the roots (Vance et al., 2003) thereby increasing absorptive surface area of roots. Cultivars GP-218 and GP-220 were most affected due to P-stress as these cultivars exhibited maximum reduction in RDM and reduction in RDM indicates poor tolerance of the cultivars to P-stress. (Wissuva et al., 2005). Leaf area was highly significantly correlated with SDM and RDM (r =0.91 & 0.75 respectively) (Table. 4)

Leaf–weight ratio gives the distribution of plant's total dry matter distribution between photosynthetic system and total plant biomass. Cotton cultivars differed in leaf weight ratio due to P-levels. Phosphorus stress decreased the leaf-weight ratio by 5%. Cultivar NIAB-92 was most affected (18% reduction) while the cultivar GP-7 remained the least affected in terms of leaf-weight ratio. Phosphorus stress significantly affected the dry matter distribution between shoot and root. Phosphorus stress caused 7% more assimilated towards the roots as compare to the adequate P-level and roots are strong sinks of assimilates under P-stress and thus increase the root-shoot ratio (Mollier and Pellerin, 1999). Differences for distribution of dry matter between shoot and root were more pronounced under P-stress conditions as compared to adequate P-level indicating that cultivars adopt physiological and morphological adaptations for more P acquisition under P-stress conditions (Raghothama, 1999). NIAB-92 distributed 25% assimilates to the roots, 15 % more as compare to the adequate P-level while CIM-1100 had only 7% more assimilate distributed the roots as compare to P-adequate level and it had maximum SDM indicating its ability to grow efficiently under P-stress without decreasing shoot growth.

Phosphorus uptake, concentration and utilization efficiency

Phosphorus levels significantly ($P<0.05$) affected the P-concentration, P-uptake and P-utilization efficiency among all the cultivars. Phosphorus stress reduced the P-concentration in shoot by 70% and in roots by 61 %. Mollier and Pellerin (1999) observed the similar results in maize. Cotton cultivars differed significantly in distribution of P between root and shoot. Phosphorus stress cause the preferential distribution of P to the roots (61%) compared with adequate P-level (55%) and roots act as good sink for P under P-deficient conditions (Mengel and Kirkby, 2001). Cultivar CIM-1100 accumulated maximum shoot P-concentration (2.07 mgg^{-1}) while GP-218 had the minimum shoot P-concentration (0.81 $mg\ g^{-1}$) (Table 2).

Fig. 3P-Distribution between Root and Shoot



Effect of P-levels on the distribution of P to the roots

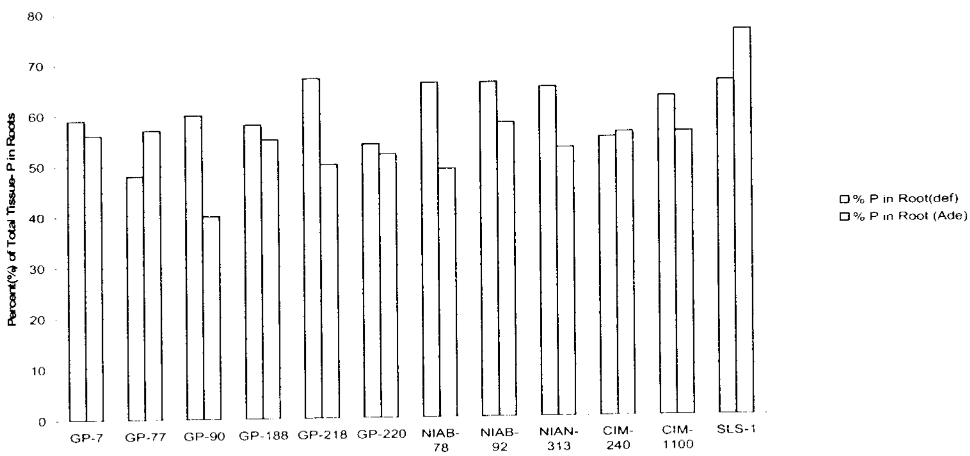


Table 2. Shoot and root P concentration and shoot P uptake of different cotton cultivars grown with deficient and adequate P-levels

Genotypes	Shoot P Concentration (mgg^{-1})		Root P Concentration (mgg^{-1})		Shoot P Uptake (mgg^{-1})	
	Deficient	Adequate	Deficient	Adequate	Deficient	Adequate
GP-7	1.04 b	4.23 bcd	1.50 ghi	5.28 bc	1.09 c	7.51 b
GP-77	1.18 b	3.08 e	1.08 i	4.08 ef	1.05 c	3.83 d
GP-90	1.06 b	3.37 e	1.62 ghi	2.25 gh	1.02 c	3.67 d
GP-188	1.03 b	4.57 abc	1.41 ghi	5.53 b	0.79 c	7.70 b
GP-218	0.81 b	4.27 bcd	1.67 ghi	4.33 def	1.05 c	5.54 cd
GP-220	1.12 b	4.20 bcd	1.33 hi	4.48 cde	1.20 c	5.43 cd
NIAB-78	1.08 b	4.08 cd	2.13 gh	3.97 ef	0.96 c	4.91 d
NIAB-92	1.10 b	3.56 de	2.17 gh	4.95 bcd	0.89 c	5.25 cd
NIAN-313	1.08 b	4.93 ab	2.00 gh	5.62 b	1.11 c	7.07 bc
CIM-240	1.86 a	4.48 ab	2.26 g	5.66 b	1.77 b	9.00 ab
CIM-1100	2.07 a	5.22 a	3.51 f	6.58 a	2.81 a	10.44 a
SLS-1	0.91 b	4.76 abc	1.75 ghi	5.45 b	0.85 c	7.54 b
Mean	1.19 B	4.26 A	1.87 B	4.85 A	1.22 B	6.45 A

Values differed significantly (<0.05) unless followed by same letter

Table 3. Root phosphorus uptake, root and shoot P-use efficiency of different cotton cultivars grown at adequate and deficient P-level

Genotypes	Root P uptake (mg $plant^{-1}$)		Phosphorus use efficiency (g^2mg^{-1})	
	Deficient	Adequate	Deficient	Adequate
GP-7	0.34 fghi	1.08 bc	1.23 b	0.43 ab
GP-77	0.14 i	0.51 efgh	0.82 bcd	0.42 ab
GP-90	0.30 ghi	0.34 fghi	1.01 bcd	0.32 bc
GP-188	0.28 ghi	0.68 def	0.77 bcd	0.38 abc
GP-218	0.26 ghi	0.83 bcde	1.65 a	0.27 c
GP-220	0.20 hi	0.95 bcd	1.10 bc	0.31 c
NIAB-78	0.39 fghi	0.66 def	1.09 bc	0.30 c
NIAB-92	0.57 efg	0.81 cde	0.75 bcd	0.44 a
NIAN-313	0.45 fghi	0.94 bcd	0.96 bcd	0.31 bc
CIM-240	0.59 efg	1.14 bc	0.59 d	0.38 abc
CIM-1100	1.15 b	1.85 a	0.68 cd	0.38 abc
SLS-1	0.45 fghi	1.13 cb	1.15 bc	0.34 abc
Mean	0.43 B	0.91 A	0.98 A	0.36 B

Values differed significantly (<0.05) unless followed by same letter

Phosphorus stress significantly affected the root P concentration and reduced the root P-concentration by 61 % compared with P-adequate level. Cultivars differed significantly for root P-concentration and maximum root P concentration (3.51 mg g^{-1}) was found in CIM-1100 and minimum root P-concentration (1.08 mg g^{-1}) was found in GP-77 at deficient P-level. There was highly positive correlations exist between roots P-concentration and shoot P-concentration indicating that roots transfer P to the shoot. GP-218 transferred maximum P to the shoot as it had high transfer rate (Tu et al., 2002). Phosphorus levels significantly affected the P-uptake among all the cultivars and reduction due to P-stress was 81% in shoot and 53% in root (Fig. 3). Cultivar CIM-1100 uptake maximum P (2.81 mg $plant^{-1}$) while GP-188 uptake minimum P (0.79 mg $plant^{-1}$). Minimum reduction in shoot P-uptake was observed in GP-90 followed by CIM-1100 (73%). Shoot P-uptake was significantly correlated with SDM (r =0.94). Root P-uptake was less affected due to P-stress as compare to the shoot P-uptake. This may be attributed to the more root growth under P-stress (Mollier and Pellerin, 1999) and more distribution of P to the roots under P-stress as root are good sink for P under P-stress

Table 4. Correlation matrix

	Leaf Area	SDM	RDM	RSR	P concentration (shoot)	P concentration (root)	P uptake (shoot)	P uptake (root)
Leaf area								
SDM	0.91							
RDM	0.75	0.87						
RSR	0.15	0.29	0.62					
P concentration (shoot)	0.74	0.85	0.84	0.42				
P con. (root)	0.78	0.85	0.86	0.52	0.88			
P uptake (shoot)	0.86	0.94	0.89	0.45	0.95	0.92		
P uptake (root)	0.82	0.90	0.96	0.47	0.86	0.92	0.91	
P Utilization efficiency	0.21	-0.19	-0.33	-0.54	-0.42	-0.45	-0.42	-0.38

SDM = Shoot Dry Matter RDM = Root Dry Matter RSR = Root Shoot Ratio

(Mengel and Kirkby, 2001). Phosphorus use efficiency (PUE) was significantly ($P<0.05$) affected by P-levels and increased the PUE 3-fold as compared to the adequate P-level.

Cultivar GP-218 exhibited the maximum PUE while the CIM-240 had the minimum PUE (0.59 g mg^{-1} P). Cultivar GP-218 also exhibited the maximum reduction (6-fold) in PUE due to adequate P and thus may be considered as most sensitive cultivar.

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