Tropical Agricultural Research Vol. 12: 119-126 (2000)

Inter-cultivar Variations of Phosphorus-deficiency Stress Tolerance in Cotton

Z. Ahmad, M.A. Gill, R.H. Qureshi, M. Aslam, J. Iqbal and S. Nawaz

Department of Soil Science
University of Agriculture
Faisalabad-38040, Pakistan

ABSTRACT. *Identification of cotton cultivars that are efficient utilizers of native or added P can help in maintaining high productivity on soils of cotton growing tract of Punjab in Pakistan. These soils, being alkaline calcareous in nature, are frequently deficient in plant-available P. The objective of this experiment was to evaluate selected cotton cultivars for their performance in P-deficient conditions and response to added P. For this purpose, 6 cotton cultivars were grown in pots for 65 days after sowing, using a soil deficient in $NaHCO_3$-extractable P (4.10 mg kg^{-1}) with (+P = 56 mg P kg^{-1} soil) or without P addition (0P). Phosphorus deficiency reduced biomass production, P-concentration in roots and aboveground plant parts, and P-uptake by roots and shoots. However, parameters such as root:shoot ratio (RSR) and synthesis of biomass per unit of absorbed P (calculated on the basis of P-concentration in leaf blade : PUEL) remained unaffected due to P-deficiency. Reduction in shoot dry weight (SDW) as a result of P-deficiency i.e. P-stress factor (PSF) ranged from 40% (in 'NIAN–92') to 77% (in 'NIAB–78'), indicating variation in P-deficiency stress tolerance of these cultivars. Intra specific variations were statistically significant for most of the parameters studied while cultivar (C) × P-level (P) interactions were largely non-significant. Under condition of P-deficiency, the cultivars that produced higher root biomass were able to accumulate higher total plant P content ($r=0.933^{**}$), which in turn was related positively to production of SDW and total biomass ($r>0.88^{*}$) and negatively to PSF ($r=-0.893^{*}$). Wide differences of growth observed in this experiment, and better performance of cultivars such as 'FH–634', 'CIM–1100' and 'NIAB–92' under P-deficiency stress encourage screening of more germplasm, especially in the field, to identify P-efficient cotton cultivars.*

INTRODUCTION

Phosphorus deficiency is quite common in cotton grown on alkaline calcareous soils of the Punjab (Pakistan), for which several soil, plant and climatic factors are held responsible (Rashid and Rafique, 1997). Phosphorus deficiency may result in many plant physiological disorders and thus cause drastic yield losses. Several phoshatic fertilizers marketed throughout the world are applied to improve soil P supplies, but retention of added/applied fertilizer P in soil is well known for its notoriously low use efficiency (Tisdale *et al.*, 1984). Various soil and fertilizer management practices like band placement have been practiced for the last several years to improve P-use efficiency. A viable alternative to low P-use efficiency is to identify crop species or cultivars adaptable to low P conditions, especially in resource-poor situations such as Pakistan. Moreover, efficient P using crops may find significance in protecting environment by reducing pollution of surface and ground water resources.

Since Salinas and Sanchez (1976), several excellent reviews are available on soil-plant factors affecting varietal and species differences in tolerance to low P soil conditions (Blair, 1993; Foy, 1993; Ahmad *et al.*, 2000). Several mechanisms such as differential P absorption, translocation (Loneragan, 1978) or utilization in dry matter production per unit absorbed (Siddiqi and Glass, 1981; Egle *et al.*, 1999) have been found important for genetic differences in crop cultivars to tolerate low P. Such differences in P uptake, accumulation and utilization have been studied in many crop cultivars other than cotton.

Hydroponics is generally used for selecting crop cultivars suitable for low P root environment (Gahoonia and Nielson, 1996). But plant roots face different physical, chemical and biological environment at soil-root interface for P-acquisition. This poses problems in translating solution culture results to soil culture. In this experiment, selected cotton cultivars were evaluated in soil for their performance in P-deficient conditions and response to added P.

MATERIALS AND METHODS

A pot experiment was conducted at the University of Agriculture, Faisalabad, Pakistan, in a rain-protected net house during April-June 1998. The soil used was texturally sandy loam and categorized as P-deficient having $NaHCO_3$-extractable P 4.10 mg kg^{-1}, which was less than its critical limit (Page, 1982) of 8 $mg^{1}kg$ (Rashid and Rafique, 1997) for cotton. The soil had pH 8.2, EC 1.5 dS m^{-1}, organic matter 0.69%, and $CaCO_3$ 8.5%. The soil was air-dried and coarse-ground before filling in glazed china clay pots (27 cm deep and 20 cm diameter) at the rate of 10 kg pot^{-1}. To half the pots, P was applied at the rate of 56 mg P kg^{-1} soil as $NH_2H_2PO_4$ (+P) while no P was applied to the remaining half (0P). In addition, N was applied to all pots at the rate of 175 mg kg^{-1} (in +P pots by adding NH_4NO_3 in addition to N coming from $NH_4H_2PO_4$, while in 0P pots all N was applied as NH_4NO_3). Potassium (K) and Zn were also added to all pots at the rate of 75 and 5 mg kg^{-1} soil, respectively. All P, K, Zn and ½ N were applied in solution form using enough water to equilibrate with the entire soil for 3 days before sowing of cotton seeds. The remaining ½ of N was applied 35 days after sowing. Five acid-delinted seeds of each of the six cultivars used in this experiment (CIM–443, CIM–1100, NIAB–92, NIAB–78, FH–634 and S–12) were sown per pot.

The two factor factorial (two P-levels, six cultivars) experiment was laid out as a completely randomized design with three replicates. Canal water (EC=0.27 dS m^{-1}) was used for irrigation during the growth period according to plant growth requirements. Plants were harvested 65 days after sowing (pre flower initiation stage), washed instantly in distilled water and blotted dry using filter paper sheets. The shoots were then separated as leaf blade and stem+petiole. Plant roots were extracted from soils manually by gently washing away the soil. Leaf area was measured using a Leaf Area Meter. The harvested plants were dried in a forced air oven at 70°C for 48 h and weighed. Dry weights were then recorded using an analytical balance. Dried stem and leaf samples were ground to 40 mesh, while roots were cut into small pieces and mixed. Uniform portions of plant samples were then digested in diacid mixtures of nitric and perchloric acid (3:1) (Miller, 1998). Phosphorus in the digest was determined by vanadate-molybdate colourimetric method

(Kitson and Mellon, 1944). Phosphorus use efficiency was calculated as the reciprocal of P-concentration in plant tissue times SDW (Siddiqi and Glass, 1981).

Relative reduction in shoot dry weight due to P-deficiency or phosphorus stress factor (% PSF) of individual cultivars was calculated using the following expression.

$$PSF = \frac{SDW_{adequate\text{-}P} - SDW_{deficient\text{-}P}}{SDW_{adequate\text{-}P}} \times 100$$

Completely randomized factorial design was employed for analysis of variance (ANOVA). Mean comparisons were done using DMR test as suggested by Da Silva and Gabelman (1992). Correlation analysis among various parameters studied was performed using mean values. All statistical analyses were performed by using computer soft-ware 'MSTATC' (Russell and Eisensmith, 1983).

RESULTS AND DISCUSSION

Biomass production

Shoot dry weight

A difference of more than 3.5-fold in case of SDW (0.72–2.61 g $plant^{-1}$) and RDW (0.31-0.69 g $plant^{-1}$) of the cultivars when grown without applying P to soil indicated wide variation among these cultivars to exploit P-stressed conditions for production of biomass (Table 1). The magnitude of these differences was of lower order (< 2-fold) when these cultivars were grown in P-supplied pots. Comparison of cultivars relative to mineral nutrition has been judged mostly on the basis of biomass production (Saric, 1981). Da Silva and Gabelman (1992) reported that tolerance to low P stress based on evaluation of SDW can be regarded as the product of the plant mechanisms involving acquisition, translocation and utilization of P in maize inbreds grown in the sand-alumina culture medium.

Variation in P-deficiency stress tolerance of these cultivars was obvious from their PSF values (Fig. 1) ranging from 40% (NIAB–92) to 77% (NIAB–78). The cultivars showing lower relative reduction in SDW production due to P-deficiency (PSF) are considered better adaptable to P-deficient conditions (Ahmad *et al.*, 1998). The cultivars were generally responsive to P-addition (Fig. 2) and could be categorized as inefficient-responsive (NIAB–78) to efficient-responsive (FH–634) (Blair, 1993). 'NIAB–92' can be characterized as efficient-non-responsive with respect to SDW production, while there were no cultivars that could be characterized as non-efficient-non-responsive in this study. Although, overall P×C interaction was statistically non-significant, some individual interactions were considerable. The cultivar 'CIM–443' exhibited crossover interactions with 'NIAB–92' and 'CIM–1100' (Fig. 2). Such crossover interactions due to their non-additive and non-separable nature are considered important in crop cultivar development (Kang, 1998).

Table 1. **Growth parameters of cotton cultivars at 0P and +P.**

Parameter	P-level	CIM-443	CIM-1100	NIAB-92	NIAB-78	FH-634	S-12	Mean
Shoot[1] dry weight	0P	1.86 ab	2.38 a	2.35 a	0.72 c	2.61 a	1.36 bc	1.88 B
(g plant^{-1})	+P	4.98 a	4.79 ab	3.90 bc	3.15 c	4.92 a	3.54 c	4.21 A
Root dry weight	0P	0.47 b	1.13 ab	1.60 a	0.43 b	1.77 a	0.71 b	1.02 B
(g plant^{-1})	+P	2.46 ab	1.96 bc	1.78 bc	1.81 bc	2.94 a	1.48 c	2.07 A
Whole plant dry weight	0P	2.69 abc	3.52 ab	3.95 a	1.16 c	4.38 a	2.07 bc	2.96 B
(g plant^{-1})	+P	7.44 a	6.75 ab	5.68 bc	4.96 c	7.86 a	5.02 c	6.29 A
Root:shoot ratio	0P	0.31 b	0.48 ab	0.68 a	0.62 a	0.69 a	0.52 ab	0.55
	+P	0.49	0.41	0.45	0.57	0.59	0.42	0.49
Leaf area	0P	225 a	214 a	207 a	71 b	226 a	106 b	175 B
(cm^2 3 plant^{-1})	+P	404 ab	446 a	335 bc	253 d	407 ab	280 cd	354 A
P-concentration, Leaf	0P	1.76	1.70	1.42	1.82	1.34	1.54	1.60 B
blade (mg g^{-1})	+P	3.20 a	2.62 ab	3.19 a	2.30 b	3.17 a	3.16 a	2.94 A
P-concentration,	0P	1.26	1.43	1.53	1.10	1.05	0.94	1.22 B
Stem+petiole (mg g^{-1})	+P	1.82 abc	1.67 bc	2.51 ab	2.04 abc	1.47 c	2.59 a	2.02 A
P-concentration, Root	0P	2.50	2.22	2.07	1.48	2.24	2.10	2.10
(mg g^{-1})	+P	2.56	2.44	2.79	2.76	2.53	3.01	2.68
Shoot-P uptake	0P	2.82	3.41	3.49	1.19	3.19	1.86	2.65 B
(mg plant^{-1})	+P	12.99 a	10.71 a	11.74 a	6.99 b	12.09 a	10.57 a	10.85 A
Root-P uptake	0P	1.28 bc	2.29 abc	3.32 ab	0.63 c	3.98 a	1.44 bc	2.16 B
(mg plant^{-1})	+P	6.17 ab	4.68 b	4.96 b	4.97 b	7.51 a	4.41 b	5.45 A
Total-P uptake	0P	4.09 abc	5.69 ab	6.81 ab	1.78 c	7.16 a	3.30 bc	4.81 B
(mg plant^{-1})	+P	19.16 a	15.39 bc	16.69 ab	11.96 c	19.60 a	14.98 bc	16.30 A
PUEL[2]	0P	1.18 ab	1.73 ab	1.69 ab	0.42 b	1.98 a	1.04 ab	1.34
	+P	1.56 ab	1.92 a	1.25 b	1.39 ab	1.57 ab	1.14 b	1.47
PUES[3]	0P	1.61 ab	1.82 ab	1.53 ab	0.71 b	2.71 a	1.46 ab	1.64 B
	+P	2.86 a	3.08 a	1.62 b	1.57 b	3.43 a	1.41 b	2.33 B

[1] Leaf blade + (stem+petiole)
[2] P-utilization efficiency (g^2 SDW mg^{-1} P in leaf blade)
[3] P-utilization efficiency (g^2 SDW mg^{-1} P in stem+petiole)
Means with different letter(s) differ significantly according to Duncan's Multiple Range Test (P=0.05)

Root dry weight and root:shoot ratio

In this experiment, although mean RDW of the cultivars grown in +P pots was significantly ($P<0.01$) higher compared to 0P (Table 1), mean RSR of both treatments was not statistically different. However, lack of negative correlation between RSR and SDW of the cultivars ($r<0.129^{NS}$) in any of the two P levels negate the possibility of preferential translocation of phostosynthates from shoots to roots. Nevertheless, RDW of the cultivars grown under P-deficiency was positively correlated to their total P-content ($r=0.933^{**}$), which in turn was related positively to SDW ($r=0.880^{*}$) and TBM ($r=0.987^{**}$), and negatively to PSF ($r=-0.893^{*}$).

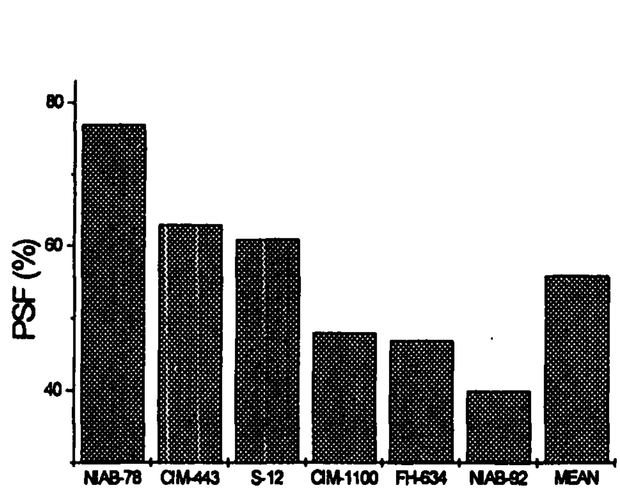

Fig. 1. Relative reduction in SDW of the cultivars (% PSF) due to P-deficiency.

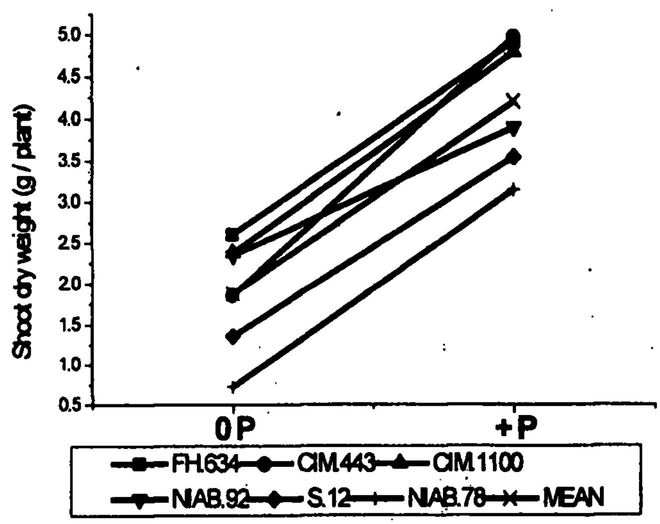

Fig. 2. Shoot dry weight of cotton cultivars at deficient (0P) and adequate (+P) P supply.

It signified the importance of RDW on P-deficiency stress tolerance of these cultivars, without imposing any drainful effects on the aboveground plant parts. Diversion of growth from shoot to root (higher RSR) is considered as a possible mechanism for plant adaptability under nutrient stress conditions through efficient exploitation of growth medium (Marschner, 1986; Fohse *et al.*, 1991). Some workers have suggested that increase in RSR of the plants under conditions of nutrient stress is at the cost of SDW (Cakmak *et al.*, 1994; Caradus *et al.*, 1995). This is generally attributed to higher export of photosynthates from shoots to roots (Cakmak *et al.*, 1994), mainly due to repressed sink activity in shoots *i.e.*, reduced leaf expansion and shoot growth rate (Radin and Eidenbock, 1984).

Leaf area per plant

Leaf area per plant of all the cultivars was lower in 0P pots in comparison to P-treated pots (Table 1). The magnitude of reduction, however, was variable among cultivars ranging from 38% in case of 'NIAB–92' to 72% in case of 'NIAB–78' with a mean value of 51% (data not given). Repressing effect of P-deficiency on plant growth is considered to be a result of decrease in photosynthetic (leaf) surface area (Clarkson *et al.*, 1983; Chaudhry, 1998). Radin and Eidenbock (1986) reported that sub-optimal application levels of P strongly inhibited leaf expansion in young cotton plants through significantly decreasing hydraulic conductance and the negative effect of P-deficiency was primarily on cell expansion. It can be conceived from data presented in Table 1 that the cultivars that realized greater decrease in leaf area plant^{-1} due to P-deficiency (such as CIM–1100, NIAB–78 and S–12) depicted greater sensitivity to P-deficient conditions in terms of PSF. On the other hand, minimum relative reduction in leaf area plant^{-1} was observed in 'NIAB–92'; the cultivar that realized minimum value of PSF or better ability to tolerate P-deficiency stress.

Phosphorus acquisition and utilization

Phosphorus concentration and uptake

Mean P concentration of leaf blade, stem+petiole as well as root of the cultivars increased substantially with P application in soil (Table 1). Highly significant effects of cultivar as well as P-level were realized in case of P uptake by various plant tissues as well as the whole plant (Table 1). Phosphorus deficiency caused invariable decrease of P uptake in all plant parts of the cultivars. The magnitude of decrease, however, was relatively lower in case of root compared to aboveground parts. Cultivar 'NIAB–78' remained consistently inefficient with respect to P uptake by various plant parts while no cultivar was consistently efficient in this respect. The impact of P-uptake on dry weight production was more pronounced in 0P pots as realized by the presence of stronger positive correlations between P-uptake by various tissues and corresponding dry weights ($r > 0.86^*$), compared to +P pots where these correlations were statistically non-significant.

Phosphorus use efficiency

The synthesis of biomass unit^{-1} of absorbed P (PUE) under P-deficient conditions is a useful criterion for assessing the tolerance of cultivars to P-deficiency stress (Ahmad *et al.*, 1998; Egle *et al.*, 1999). Statistically significant differences ($P<0.05$) of both PUES and PUEL under both conditions of P supply indicated variability among these cultivars to utilize absorbed P for biomass synthesis. The effect of P level, however, was non-significant in case of PUEL.

A highly significant negative correlation existed between PSF and PUEL of the cultivars (r=-0.94**) observed in 0P pots implying that the cultivars which were inefficient utilizers of the absorbed P under P-deficiency stress were more sensitive to such conditions. Thus the parameter seems to be a useful index of P-deficiency stress tolerance of cotton cultivars. The cultivars such as 'FH-634', 'CIM-1100' and 'NIAB-92', which produced higher biomass under P-deficiency stress due to their higher PUE may prove useful where economic constraints restrict fertilizer application.

CONCLUSIONS

Cotton cultivars differed in their growth response to added P, and their ability to tolerate P-deficiency stress was variable. Higher RDW production under P-deficient conditions resulted in increased P-uptake by the cultivars, the efficient utilization of which helped them in sustaining better growth under such conditions. The cultivars such as 'FH-634', 'CIM-1100' and 'NIAB-92', which could produce higher biomass under P-deficient conditions because of their higher PUE, may prove useful where economic constraints restrict fertilizer use.

REFERENCES

Ahmad, Z., Gill, M.A., Shah, A.M., Mehmood, T., Hamud-ur-Rehman and Yaseen, M. (1998). Differential growth behavior of cotton varieties at adequate and deficient levels of nitrogen and phosphorus. Pak. J. Biol. Sci. 1: 342-345.

Ahmad, Z., Aslam, M., Gill, M.A., Yaseen, M. and Hamud-ur-Rehman (2000). Intra-specific variations of phosphorus utilization efficiency. Pak. J. Biol. Sci. 3: 537-541.

Blair, G. (1993). Nutrient efficiency - what do we really mean? pp. 205-213. *In*: Randall *et al.* (Eds). Genetic Aspects of Plant Mineral Nutrition, Kluwer Acad. Publ., Netherlands.

Cakmak, I., Hengeler, C. and Marshner, H. (1994). Partitioning of shoot and root dry matter and carbohydrates in bean plants suffering from phosphorus, potassium and magnesium deficiency. J. Exp. Bot. 45: 1245-1250.

Caradus, J., Makey, A.D. and Bosch, J.V.D. (1995). Relationship between root and shoot characteristics of white clover cultivars differing in response to phosphorus. J. Plant Nutr. 18: 2701-2722.

Chaudhry, M.I. (1998). Response of mashbean (*Vigna aconitifolia*) and soybean (*Glycin max* L.) to phosphorus nutrition. Doctoral thesis, Graduate School of Biosphere Sciences, Hiroshima University, Japan.

Clarkson, D.T., Kerridge, P.C., Sherriff, D.W. and Fisher, M.J. (1983). Effects of phosphorus deficiency on photosynthesis and stomatal function in the tropical legume, Siratro. Annual Report, ARC Letcombe Lab., 1983. pp. 65-66.

Da Silva, A.E. and Gabelman, W.A. (1992). Screening maize inbred lines for tolerance to low-P stress conditions. Plant Soil. 146: 181-187.

Egle, K., Manske, G., Römer, W. and Vlek, P.L.J. (1999). Improved phosphorus efficiency of three new wheat genotypes from CIMMYT in comparison with an older Maxican variety. J. Plant Nutr. Soil Sci. 162: 353-358.

Fohse, D., Claassen, N. and Jungk, A. (1991). Phosphorus efficiency of plants. II. Significance of root radius, root hairs and cation-anion balance for phosphorus influx in seven plant species. Plant Soil. 132: 261-270.

Foy, C.D. (1993). Role of soil scientists in genetic improvement of plants for problem soils. pp. 185-206. *In*: Adaptation of plants to soil stresses. INTSORMIL Pub. No. 94-2, University of Nebraska, Lincoln, USA.

Gahoonia, T.S. and Nielsen, N.E. (1996). Variation in acquisition of soil phosphorus among wheat and barley genotypes. Plant Soil. 178: 223-230.

Kang, M.S. (1998). Using genotype-by-environment interaction for crop cultivar development. Adv. Agron. 62: 199-251.

Kitson, R.E. and Mellon, M.G. (1944). Colourimetric determination of phosphorus as molybdovanado phosphoric acid. Industr. Engng. Chem. Analys. 16: 379-383.

Marschner, H. (1986). Mineral nutrition of higher plants. Academic Press, London.

Miller, R.O. (1998). Nitric-perchloric wet digestion in an open vessel. pp. 57-62. *In*: Kalra, Y.P. (Ed). Handbook of Reference Methods for Plant Analysis, Soil and Plant Analysis Council, Inc. CRC Press, Washington D.C., USA.

Page, A.L. (*Editor*) (1982). Methods of soil analysis, Part 2, Chemical and microbiological properties. Amer. Soc. Agron., Inc. Publisher Madison. Pp. 422.

Radin, J.W. and Eidenbock, M.P. (1984). Hydraulic conductance as a factor limiting leaf expansion of phosphorus-deficient cotton plants. Plant Physiol. 75: 372-377.

Radin, J.W. and Eidenbock, M.P. (1986). Carbon accumulation during photosynthesis in leaves of nitrogen- and phosphorus-stressed cotton. Plant Physiol. 82: 869-871.

Rashid, A. and Rafiq, E. (1997). Nutrient indexing and micronutrient nutrition of cotton, and genetic variability in rapeseed-mustard and rice to boron deficiency. Annual Report, 1997, Land Resources Research Institute, National Agricultural Research Center, Islamabad.

Russell, D.F. and Eisensmith, S.P. (1983). MSTAT-C. Crop Soil Sci. Dept., Michigan State Univ., USA.

Salinas, J.G. and Sanchez; P.A. (1976). Soil-plant relationships affecting varietal and species differences in tolerance to low available phosphorus. Cien. Cult. 28: 156-168.

Saric, M.R. (1981). Genetic specificity in relation to plant mineral nutrition. J. Plant Nutr. 3: 743-766.

Siddiqi, M.Y. and Glass, A.D.M. (1981). Utilization index: A modified approach to the estimation and comparison of nutrient utilization efficiency in plants. J. Plant Nutr. 4; 289-302.

Tisdale, S., Nelson, W.L. and Beaton, J.D. (1984). Soil Fertility and Fertilizers. 4th Ed., McMillan Co., NY, USA.