International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2019; 7(5): 1668-1673

Received: 01-07-2019
Accepted: 04-08-2019

S Meena
Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

K Radhika
Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

P Malarvizhi
Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

Correspondence
S Meena
Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

Phosphorus dynamics and phosphorus efficiency indices of maize and cotton in a phosphorus deficient soil

S Meena, K Radhika and P Malarvizhi

Abstract
A pot culture experiment was conducted with maize and cotton to study phosphorus (P) dynamics in soil and phosphorus efficiency indices in a P deficient soil (7.2 kg ha^{-1}) with four levels of phosphorus (0, 3.75, 7.50 and 15.0 mg P kg^{-1} soil). The experiment was conducted for duration of 60 days. Phosphorus - 32 was used for studying the variation in isotopically exchangeable phosphorus in soil and specific radioactivity in plant. Phosphorus stress increased the root – shoot ratio in both cotton and maize and cotton recorded the higher root – shoot ratio.
Rhizosphere pH after 60 days of growth was slightly acidic irrespective of the crop and available P status of maize in rhizosphere soil was higher compared to cotton. Enhanced activity of acid phosphatase was observed in cotton. At all levels of P application maize recorded significantly lesser values of Fe-P and Ca-P and higher values of saloid - P when compared to cotton. Phosphorus translocation efficiency was also higher with maize than cotton under P deficient condition (P_0). Under P deficiency condition maize recorded lower Phosphorus Stress Factor (PSF) values (42.56% at P_0, 22.56% at $P_{3.75}$ and 2.47% at $P_{7.5}$) when compared to cotton. Maize recorded the Phosphorus Acquisition Efficiency (PAE) of 59 per cent while in the case of cotton it was 48 per cent. Maize having depicting high PAE, PE and low PSF values is better choice for P deficient condition.

Keywords: Cotton, efficiency, maize, phosphorus

Introduction
Crop yield on 40 per cent of the arable land in the world is affected by P unavailability (Vance, 2003) [23]. Even though total phosphorus content of the soil is in higher amounts, phosphorus availability to plants is a problem because of the phosphate binding capacity of several types of soils (Syers *et al*., 2008) [20]. Although P ions can reach larger concentrations in highly fertilized soils, in many soils indeed, their concentration in the soil solution is in the micro molar range, ranging between 0.1 and 10 μM. These are rather low compared with the adequate P concentrations for optimal plant growth (external P requirement) which can reach values of several μM or tens of μM for the most demanding crop species such as bean, cotton, pea, potato, onion, spinach or tomato.
Anticipated phosphate crisis for agriculture coupled with farmer's 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 the efficient utilization of P and its availability. Under such conditions, the integration of crop species and crop cultivars that can make most efficient use of the P supplied by the soil and maintenance of fertilizer applications represents a key element of the sustainable cropping system.
Crops differ in their capacity in acquisition and utilization of phosphorus. Some species develop more extensive root systems and root hairs allowing the plants to explore a larger volume of soil (Gahoonia and Nielsen 1998; Lynch and Brown 2001) [7, 13] while others alter the chemistry or biochemistry of the rhizosphere allowing the uptake of P from insoluble P forms (Braum and Helmke 1995; Gilbert *et al*., 1999; Watt and Evans 2003) [8, 25], increased production of phosphatases (Bariola *et al*., 1994) [2] and enhanced rate of P uptake (Schachtman *et al*., 1998) [19]. Understanding the changes in P dynamics in soil and variation in plant P uptake under P deficient condition can help in selecting P efficient crops for P deficient soils.

With this background, this work is was undertaken to understand the phosphorus dynamics and phosphorus efficiency indices as influenced by cotton and maize in a phosphorus deficient soil.

Materials and Methods

Pot culture experiment with maize (CO 6) and cotton (MCU 13) as the test crops and with four levels of phosphorus (0, 3.75, 7.50 and 15 mg P kg^{-1} soil) was conducted in a P deficient soil (7.2 kg ha^{-1}). Carrier free ^{32}P was obtained as orthophosphoric acid in dilute hydrochloric acid medium from the Board of Radiation and Isotope Technology, Mumbai. The physical half-life ($T_{½}$) of ^{32}P is 14.3 days. It decays into ^{32}S by emitting negatrons ($β^-$) of E_{max} 1.71 MeV. Solution of carrier free ^{32} P orthophosphate was added and the soil was labeled at 3200 kBq pot^{-1}. After the addition of phosphorus as SSP as per the treatments, the soil was homogenized. Other cultural practices were followed as per the Crop Production Guide. The experiment was carried out for duration of 60 days.

At harvest, the soil adhering to the roots of the plants were wiped out, pooled and stored for analysis and this represented the rhizosphere soil and the soil which was out of contact with the roots was sampled as non rhizosphere (bulk) soil. Uprooted plants at harvest were cleaned with water followed by diluted HCl and deionized water and then separated into shoot and root. The shoot and root samples were kept in paper covers, shade dried and later oven dried (60ºC) for 72 hours. Shoot and root DMP were determined and expressed in g pl^{-1}. The oven dried plants were finely milled for further analysis.

The rhizosphere and non rhizosphere soil samples collected were subjected to analysis of pH (Jackson, 1973) [10], available phosphorus (Olsen *et al.*, 1954) [17], inorganic P fractions (saloid - P, Al - P, Fe - P, Ca - P) (Chang and Jackson, 1957) [4] and phosphataes activity (Tabatabai and Bremner, 1969) [21].

In the plant samples (shoot and root), P content was estimated by vandomolybdate phosphoric acid yellow colour method (Piper, 1966) [18] and radioactive phosphorus was measured in a Liquid Scintillation counter (PerkinElmer - Tricarb 2810 TR) ((L' Annuziata and Legg, 1984) [11]. All radioactive measurements were counted for radioactive decay. Based on the analytical values, the following parameters were derived.

1. Isotopically Exchangeable Phosphorus (IEP)

IEP = 1/ms $\{(A_t P_p - Ps)/Ap\}$

Where,

m_s = Mass of soil in the pot (g); At = Total activity added (Bq)

Ap = Radioactivity in the plant (Bq)

Pp = Mass of P in the plant (µg)

Ps = Mass of P in the seed (µg)

IEP = Measure of the amount of soil P that is potentially available to the plant

Root: Shoot ratio = Root dry matter / Shoot dry matter

$$\text{Phosphorus translocation efficiency} = \frac{\text{Shoot P uptake (mg pl}^{-1})}{\text{Total P uptake (mg pl}^{-1})} \times 100$$

Phosphorus stress factor (PSF) = [Yield at adequate P – deficient P / Yield at adequate P] x 100

Where,

Yield at adequate P (P_{40})

Yield at deficient P (P_{20} or P_0)

Phosphorus Efficiency (PE) = [yield (-P) / yield (+ P)] X 100

$$\text{Phosphorus acquisition efficiency} = \frac{\text{Total P uptake in P}_0\text{ (mg pl}^{-1})}{\text{Total P in P}_{40}\text{ (mg pl}^{-1})} \times 100$$

Results

Dry Matter Yield

Phosphorus (P) levels, crop and their interaction exerted a significant effect on shoot dry matter. Biomass production was higher for maize than cotton and P application had a significant positive effect on increasing the dry matter of both root and shoot. In maize shoot dry matter varied between 6.29 g pl^{-1} (P_0) to 10.95 g pl^{-1} (P_{15}). The variation in shoot dry matter for cotton was between 2.38 g pl^{-1} (P_0) to 6.63 g pl^{-1} (P_{15}). In response to P application (15 mg kg^{-1}), shoot dry weight increased by 64.10 per cent in cotton, 42.6 per cent in maize (Table 1).

Increase in P application also resulted in increasing root dry matter in both the crops $P_{7.5}$ and P_{15} resulted in on par root yield. Root – shoot ratio varied from 0.281 - 0.744 for cotton and from 0.363 -0.463 for maize. Cotton root growth was vigorous and had greater root – shoot ratio compared with maize at P_0 and $P_{3.75}$ (Table 1).

Table 1: Shoot and Root Dry Matter (60 DAS) of cotton and maize as influenced by P levels under P deficient condition

Crop	P supply (mg P kg $^{-1}$soil)	Shoot dry matter (g pl^{-1})		Root dry matter (g pl^{-1})		Root /Shoot Ratio
Cotton	0	2.38 (64.1)		1.77		0.744
	3.75	4.23 (36.2)		1.72		0.407
	7.50	6.29 (5.1)		1.82		0.289
	15.00	6.63		1.86		0.281
	Mean	4.88		1.79		0.430
Maize	0	6.29 (42.6)		2.91		0.463
	3.75	8.48 (22.6)		3.16		0.373
	7.50	10.68 (2.5)		3.94		0.369
	15.00	10.95		3.98		0.363
	Mean	9.10		3.50		
		SEd	CD	SEd	CD	
	Crop (C)	0.32	0.64	0.02	0.04	
	P level (P)	0.45	0.94	0.03	0.06	
	C x P	0.60	0.13	0.04	0.08	

Fig in brackets indicates per cent decrease over 15mg P kg $^{-1}$ soil

Table 2: Soil pH, available phosphorus and phosphatase activity in rhizosphere and non rhizosphere of cotton and maize as influenced by P levels under P deficient condition

Crop	P supply (mg P kg $^{-1}$soil)	pH		Available P (kg ha^{-1})		Acid phosphatase activity (µg of ρNP g $^{-1}$ hr $^{-1}$)	
		R	NR	R	NR	R	NR
Cotton	0	7.45	7.82	7.69	6.69	125.07	111.42
	3.75	7.55	7.79	9.49	9.20	116.09	109.11
	7.50	7.63	7.84	11.51	10.92	109.06	95.94
	15.00	7.57	7.80	12.58	11.59	101.88	89.77
	Mean	7.55	7.81	10.31	9.60	113.02	101.56
Maize	0	7.38	7.74	8.04	7.14	91.10	83.37
	3.75	7.44	7.78	9.66	8.91	89.57	80.30
	7.50	7.38	7.77	13.35	11.28	79.43.	72.32
	15.00	7.44	7.77	14.02	12.15	82.66	70.01
	Mean	7.43	7.76	11.26	9.87	85.69	76.62
		SEd	CD	SEd	CD	SEd	CD
Crop (C)		0.018	0.036	0.30	0.60	0.72	1.45
P level (P)		0.025	0.050	0.42	0.84	1.02	2.04
Rhizosphere (R)		0.018	0.036	0.30	0.60	0.72	1.45
C x P		0.034	NS	0.60	1.20	1.45	2.89
C x R		0.025	0.050	0.42	0.84	1.02	2.04
P x R		0.034	NS	0.60	1.20	1.44	2.89
C x P xR		0.050	0.101	0.84	1.69	2.05	4.09

R: Rhizospere soil NR: Non rhizosphere soil

In both cotton and maize, acidification in the rhizophere soil was higher when compared to non rhizosphere soil (Table 2). Acidification was significantly higher for maize than for cotton. Increasing levels of P application increased the soil pH in both the crops. Mean Soil pH averaged over treatments was 7.55 for cotton and 7.43 for maize. Soil pH ranged from 7.45 - 7.57 in rhizophere soil and 7.82 -7.80 in non rhizosphere soil for cotton. In maize, the respective values were 7.38-7.74 and 7.74 - 7.77.

In both the crops studied, rhizosphere soil recorded significantly higher available P compared to non rhizosphere soil. The rhizosphere of maize recorded significantly higher available P compared to cotton however the available P in the non rhizosphere soil of both the crops were on par (Table 2).

The maximum secretion of acid phosphatase due to P deficiency was observed for cotton in rhizosphere (125.07 µg of ρNP g $^{-1}$ hr $^{-1}$) and bulk soil (111.42 µg of ρNP g $^{-1}$ hr $^{-1}$) and the respective values in maize were 91.10 and 83.37 µg of ρNP g $^{-1}$ hr $^{-1}$. Under P deficiency (P_0) the activity of acid phosphatase in rhizosphere soil was 12 per cent higher in cotton and 9 per cent higher in maize than the bulk soil (Table 2).

Inorganic Phosphorus Fractions

Among the inorganic fractions, Al-P, Fe-P and Ca-P are the three major fractions recorded. Phosphorus application resulted in increasing the various inorganic P fractions in both rhizosphere and non - rhizosphere soil. The saloid - P content recorded in rhizosphere soil was 13.32 ppm for cotton and 24.16 ppm for maize. In non - rhizosphere soil the saloid – P content was 11.64 for cotton and 20.86 ppm for maize. In both the crops Al- P, Fe-P and Ca-P was higher in the non rhizosphere soil when compared to the rhizosphere soil. In control and 3.75 mg P kg^{-1}, maize was able to utilize Fe-P and Ca - P but not Al-P where in a decrease in Fe-P and Ca-P was noticed when compared to cotton.

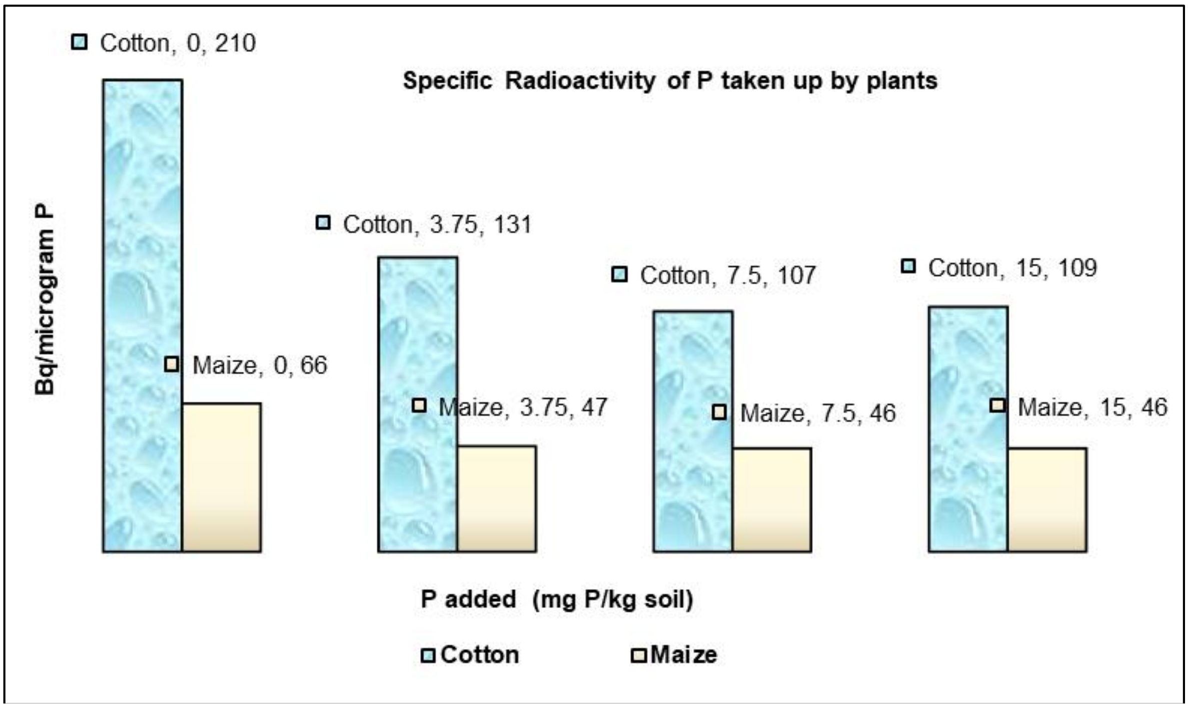
Table 3: Changes in P fractions (ppm) in rhizosphere and non rhizosphere of cotton and maize as influenced by P levels under P deficient condition

Crop	P supply (mg P kg $^{-1}$soil)	Saloid-P		Al-P		Fe-P		Ca-P	
		R	NR	R	NR	R	NR	R	NR
Cotton	0	11.19	9.06	29.88	31.25	31.25	41.88	78.75	93.75
	3.75	12.19	10.63	46.25	53.13	41.25	46.88	120.31	128.75
	7.50	13.50	11.25	51.25	57.81	58.13	63.13	145.47	166.25
	15.00	16.38	15.63	57.50	57.81	64.50	66.88	168.44	192.50
	Mean	13.32	11.64	46.22	50.00	48.78	54.69	128.24	148.31
Maize	0	23.13	17.81	28.63	32.63	12.88	22.50	73.44	88.13
	3.75	21.63	20.00	44.50	52.75	24.00	37.88	117.03	133.95
	7.50	25.00	22.50	49.38	54.98	50.68	44.38	146.75	165.63
	15.00	26.88	23.13	53.13	53.38	56.25	56.25	147.50	185.94
	Mean	24.16	20.86	43.91	48.44	35.95	40.25	121.18	143.41
	Initial	7.32		30.14		28.92		72.46	
Source		SEd	CD	SEd	CD	SEd	CD	SEd	CD
Crop (C)		0.192	0.384	0.502	1.004	0.686	1.372	1.428	2.852
P level (P)		0.272	0.544	0.710	1.419	0.971	1.940	2.019	4.034
Rhizosphere (R)		0.192	0.384	0.502	1.004	0.686	1.372	1.428	2.852
C *P		0.385	0.770	1.004	2.007	1.374	2.744	2.856	5.706
C * R		0.272	0.544	0.710	1.419	0.971	1.940	2.019	4.034

Table 4: Specific Radioactivity of P taken up by plants and the Isotopically Exchangeable Phosphorus in soil of cotton and maize as influenced by P levels under P deficient condition

P supply (mg P kg $^{-1}$soil)	Specific Radioactivity (Bq µg^{-1} P)		Isotopically Exchangeable Phosphorus (IEP) (Bq µg^{-1} P)	
	Cotton	Maize	Cotton	Maize
0	210	66	12.31	39.07
3.75	131	47	19.80	54.16
7.50	107	46	23.75	53.89
15.00	109	46	24.18	56.17
Mean	139	51	20.01	50.82

Specific radioactivity ranged from 109 (P_{15}) – 210 (P_0) for cotton and from 46 (P_{15}) to 66 for maize (P_0). At all levels of P application maize recorded significantly lower specific radioactivity (51 Bq µg P^{-1} for maize and 139 Bq µg P^{-1} for cotton). Isotopically Exchangeable Phosphorus (IEP) increased with increasing levels of P application. The calculated mean values of IEP for maize was significantly larger (50.82 Bq µg^{-1} P) than for cotton (20.01 Bq µg^{-1} P) (Table 4 and Fig).



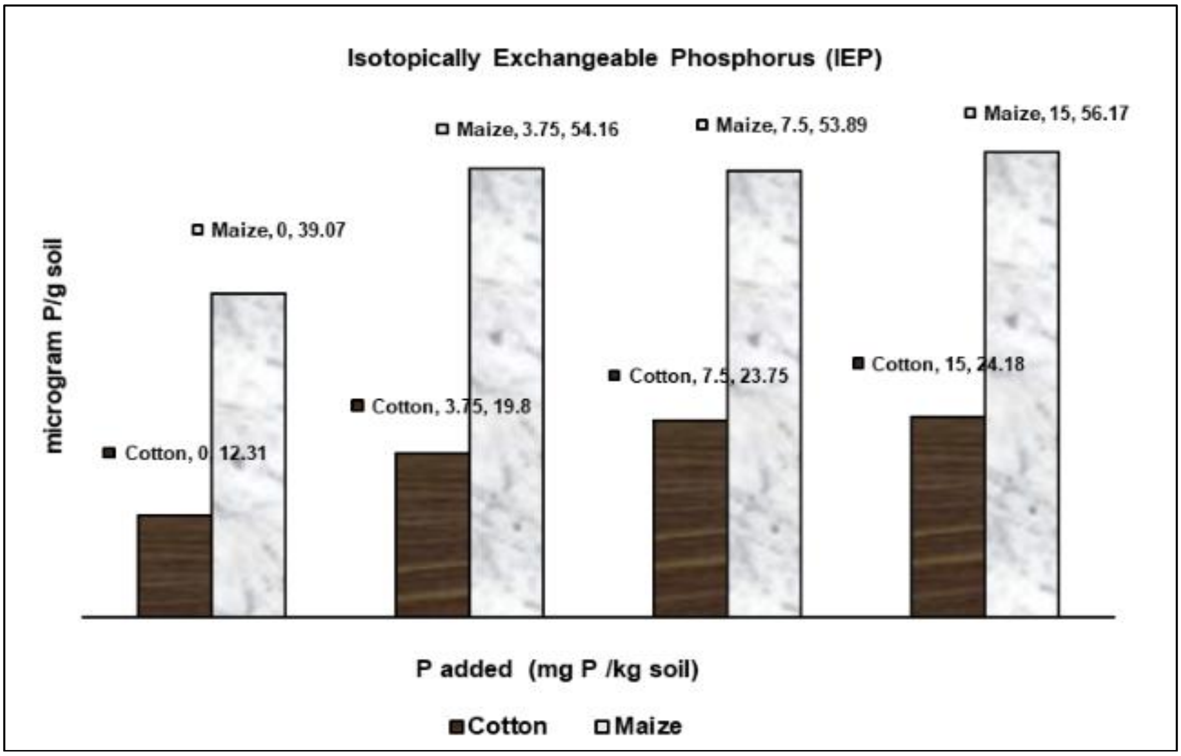


Fig 1: Specific Radioactivity of P taken up by plants and the Isotopically Exchangeable Phosphorus in soil

Table 5: Total P uptake and P translocation efficiency of cotton and maize as influenced by P levels under P deficient condition

P supply (mg P kg $^{-1}$ soil)	Total P uptake (mg pl $^{-1}$)			P translocation efficiency (%)		
	Cotton	Maize	Mean	Cotton	Maize	Mean
0	4.79	13.56	9.18	60.54	77.43	72.98
3.75	7.16	21.95	14.56	83.24	85.01	84.55
7.50	10.65	22.97	16.81	87.98	85.55	86.32
15.00	10.22	22.85	16.54	88.85	86.74	87.36
Mean	8.21	20.34		83.19	84.37	
Source	SEd	CD				
Crop (C)	0.284	0.578				
P level (P)	0.346	0.706				
C *P	0.487	0.992				

Phosphorus uptake and P Translocation Efficiency

The amount of P uptake in the shoot of both the crops depended on the rate of P accumulation. An increase in shoot P concentration was observed with increase in levels of P applied (Table 5). A significant positive relationship existed between the shoot biomass and P uptake. In cotton, a decrease in root P uptake was recorded with increasing levels of P application. Total P uptake increased with increasing levels of P application and it ranged from 4.79 (P_0) to 10.65 ($P_{7.5}$) mg p1 $^{-1}$ for cotton and 13.56(P_0) to 22.97 ($P_{7.5}$) mg p1 $^{-1}$ for maize.

Efficient translocation of absorbed P within plants from roots may increase the growth of plants per unit of P absorbed. Under P_0, maize recorded higher P translocation efficiency (77.43%) when compared to cotton (60.54%) (Table 5).

Table 6: Phosphorus Stress Factor, P Efficiency Ratio, P Efficiency (Relative shoot growth), P Acquisition Efficiency in cotton and maize as influenced by P levels under P deficient condition

P supply (mg P kg $^{-1}$soil)	P Stress factor		P Efficiency (Relative shoot growth)		P Acquisition Efficiency (%)	
	Cotton	Maize	Cotton	Maize	Cotton	Maize
0	64.10	42.56	34.81	57.60	48.0	59.0
3.75	36.20	22.56	61.95	77.64	-	-
7.50	5.12	2.47	92.19	97.55	-	-
15.00	-	-	-	-	-	-
Mean	35.14	22.53	47.24	58.20	-	-

Phosphorus stress factor decreased with increasing levels of P and it ranged from 5.12 – 64.10 for cotton and 2.47 ($P_{7.5}$) – 42.56 (P_0) for maize. P Efficiency Ratio (g DM mg $^{-1}$ P) was highest at P_0 in both the crops. In cotton, the value recorded at P_0 was 0.821 g DM mg $^{-1}$ P and in maize PER at P_0 was 0.599 g DM mg $^{-1}$ P. The mean value averaged over treatments was 0.733 for cotton and 0.537 for maize (Table 6).

Phosphorus efficiency (relative shoot growth) for maize was higher (58.20%) when compared to cotton (47.24%). Phosphorus acquisition efficiency recorded was 48 per cent for cotton and 59 per cent for maize (Table 6).

Discussion

A considerable decrease in plant dry matter in cotton under P deficiency was associated with an increase in root dry matter suggesting increased investment in root system for nutrient uptake. In both the test crops, cotton and maize P deficiency decreased total plant dry matter and increased the root - shoot ratio. Higher root – shoot ratio in P stressed plants as compared to P sufficient plants might be due to severely reduced leaf growth under P stress which leads to diminished leaf demand for assimilates consequently causing translocation of photosynthates to the root for better root growth (Cadmak *et al.*, 1994; Fujita *et al.*, 2004) [3, 6]. The response was higher in cotton when compared to maize.

Increasing levels of P application increased the soil pH in both the crops. The decrease in pH under P deficiency may be attributed to the release of H^+ ions and organic acids under P starvation. Acidification of the rhizosphere by maize under P deficient condition has also been reported by Liu *et al*. (2003). The production of acid phosphatases in response to P deficiency is a universal phenomenon in higher plants. Crop species might alter the potential phosphatase activity in the rhizosphere, as the degree of phosphatase activity has been shown to vary among crop species and with severity of P starvation (Tadano *et al*., 1993; Nath and Samanta, 2012) [22, 16]. Higher phosphatase activity associated with cotton than maize may indicate their differing potentials for obtaining P from organic pools. Inal *et al*. (2007) [9] also observed higher acid phosphatase activity in soil under peanut than maize.

Sparingly soluble P sources such as Ca phosphates, Al and Fe phosphates are not equally available to plants, and plant species differ in their ability to utilize these different P sources. Significant differences noticed in various inorganic fractions in rhizosphere soil indicated that rhizosphere chemistry might have contributed to the solubilisation of the sparingly soluble source. At all levels of P application maize recorded significantly lesser values of Fe-P and Ca-P and higher values of saloid – P suggesting the superiority of maize to access sparingly soluble P from soils compared to cotton. Higher acidification of rhizosphere by maize might have increased the solubility of Ca- P and Fe- P when compared to cotton.

Different values of IEP for maize and cotton indicate that chemically different pools of soil P were utilized and maize was able to asses a larger pool than cotton. Lower specific radioactivity indicates that maize is using otherwise unavailable P sources. If cotton and maize use the same pool of available P, then the specific radioactivity (Bq µg $^{-1}$P) of the P taken by both the crops will be the same. Since maize utilizes a pool of soil P that is unavailable to cotton it records a low specific radioactivity which indicates that maize was able to utilize unavailable P sources than cotton. The efficiency of maize with regard to P utilization was supported by the fact that L value of maize was nearly two times higher than that of cotton. The efficiency of maize to take up P from sparingly soluble inorganic P sources as indicated by low specific radioactivity in a medium P soil was reported earlier by Adu – Gyamfi *et al*. (2009) [1].

Root acts as a good sink for P under P deficient conditions (Mengel and Kirkby, 2001) [15]. The increase in P uptake with the higher application of P could have been resulted from enhanced supply of P to the plants.

Translocation Efficiency

Crops with low ability to translocate a nutrient are less tolerant to the deficiency of that nutrient because they are less efficient to absorb that nutrient from the growth medium and partly they have lower ability to translocate that nutrient from root to shoots. In the present study, under P stress (P_0) maize exhibited a higher translocation efficiency than cotton. The P retention in root decreased with increasing P supply. Wang *et al.* (2013) [24] reported that under P deficient cotton retained 35 per cent of total P in roots compared with only 14 per cent in P sufficient cotton. This may result from preferential retention of P from the soil in the roots or mobilization and transport of P and sucrose (Marschner, 1995) [14] from shoots to roots and especially to root meristem in response to continuing P stress.

Phosphorus efficiency indices

Phosphorus stress factor

Crops showing relatively lower values of PSF are considered suitable for growing under P limiting conditions. Maize has recorded lower PSF values compared to cotton.

Phosphorus acquisition efficiency (PAE) relates to the different extents to which plants are able to mobilize phosphorus from poorly soluble sources or to take up the soluble phosphorus available in the soil solution. Maize having greater capacity for rhizosphere acidification and solublisation of sparingly soluble Fe-P and Ca-P fractions might have resulted in higher PAE.

Conclusion

Cotton and maize responded to P application in a P deficient soil. Enhanced activity of acid phosphatase by cotton roots when compared to maize conferred a potential advantage for cotton to acquire P from organic pools. The depletion of inorganic P fractions (Fe-P and Ca-P) by cotton was smallest. At all levels of P application maize recorded significantly lesser values of Fe-P and Ca-P and higher values of Saloid – P when compared to cotton. The higher efficiency of maize over cotton in inorganic P fraction acquisition might be related to root morphological traits e.g. root hair development. At all levels of P application maize recorded significantly lower specific radioactivity and higher IEP. Different values of IEP for maize and cotton indicate that chemically different pools of soil P were utilized and maize was able to asses a larger pool than cotton.

Phosphorus translocation efficiency was also higher with maize than cotton under P deficient condition (P_0). Under P deficiency condition maize recorded lower PSF values (42.56% at P_0, 22.56% at $P_{3.75}$ and 2.47% at $P_{7.5}$) when compared to cotton. Maize recorded the PAE of 59 per cent while in the case of cotton it was 48 per cent.

Maize having depicting high PUE, PE and low PSF values is better choice for P deficient condition. A higher PAE efficiency of maize can be related to the ability of maize to take up P from insoluble inorganic P forms.

Acknowledgements

This research work was supported by Science and Engineering Research Board (SERB) under the Extra Mural R& D Project on Crop and Genotypic Variation – A Tool to Enhance Phosphorus Use Efficiency for Sustainable Cropping in Low Phosphorus Soil.

References

1. Adu-Gyamfi JJ, Aigner M, Gludovacz D. Variations in phosphorus acquisition from sparingly soluble forms by maize and soybean in low-and medium-P soils using P-32. Proc. XVI Int. Plant Nutr. Colloquium, UC Davis, USA, 2009. http://repositories.cdlib.org/ipnc/xvi/13172009.
2. Bariola PA, Howard CJ, Taylor CB, Verburg MT, Jaglan VD, Green PJ. The Arabidopsis ribonuclease gene RNS1 is tightly controlled in response to phosphate limitation. The Plant Journal. 1994; 6(5):673-685.
3. Cadmak I, Hengeler C, Marchner H. Partitioning shoot and root dry matter and carbohydrates in beans plants suffering from phosphorus, potassium and magnesium deficiency. Journal of Experimental Botany. 1994; 45:1245-1250.
4. Chang SC, Jackson ML. Fractionation of soil phosphorus. Soil Science. 1957; 84**:**133-144.
5. Duff SMG, Sarath G, Plaxton WC. The role of acid phosphatases in plant phosphorus metabolism, Physiology Plant. 1994; 90:791-800.
6. Fujita K, Kai Y, Abu-Gyamti MJJ, Mahapatra PK. Genotypic variability of pigeon pea in distribution of photosynthetic cerber at low phosphorus level. Plant Science. 2004; 166:641-649.
7. Gahoonia TS, Nielsen NE. Direct evidence on participation of root hairs in phosphorus (^{32}P) uptake from soil. Plant and Soil. 1998; 98:147-152.
8. Gilbert GA, Knight JD, Vance CP, Allan DL. Acid phosphatase activity in phosphorus deficient white lupine roots. Plant, Cell and Environment. 1999; 22:801-810.
9. Inal A, Gunes A, Zhang F, Cakmak I. Peanut/maize intercropping induced changes in rhizosphere and nutrient concentrations in shoots. Plant physiology and biochemistry. 2007; 45(5):350-356.
10. Jackson ML. Soil Chemical Analysis. Prentice Hall, New Delhi. 1973.
11. L'Annunziata MF, Legg JO. Isotopes and radiation in agricultural sciences. Soil-plant-water relationships. 1984;1.
12. Liu Y, Mi G, Chen F, Zhang J, Zhang F. Rhizosphere effect and root growth of two maize (*Zea mays* L.) genotypes with contrasting P efficiency at low P availability. Plant Science. 2004; 167:217-223.
13. Lynch JP, Brown KM. Topsoil foraging-an architectural adaptation of plants to low phosphorus availability. Plant and Soil. 2001; 237:225-237.
14. Marschner H. Mineral nutrition of higher plants, 2nd edition, Academic Press, Boston, MA, USA, 1995.
15. Mengel K, Kirkby EA. Principle of plant nutrition. Kluver Academic Publication. London, 2001.
16. Nath R, Samanta R. Soil pH, microbial population, nitrate reductase and alkaline phosphatase activities of different environment of Dibrugarh district, Assam. Advances in Applied Science Research. 2012; 3(3):1772-1775.
17. Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of available phosphorus in soil by extracting with sodium bicarbonate, 1954.
18. Piper CS. Soil and Plant Analysis. Hans publisher, Bombay, 1966.
19. Schachtman DP, Reid RJ, Ayling SM. Phosphorus uptake by plants, from soil to cell. Plant Physiology. 1998; 16:447-453.
20. Syers JK, Johnston AE, Curtin D. Efficiency of soil and fertilizer phosphorus use. Fertilizer and Plant Nutrition Bulletin, FAO, Rome, Italy. 2008, 18.
21. Tabatabai MA, Bremner JM. Use of p-nitrophenyl phosphate for assay of soil phosphatase activity. Soil biology and biochemistry. 1969; 1(4):301-307.
22. Tadano T, Ozawa K, Sakai H, Osaki M, Matsui H. Secretion of Acid phosphatase by the roots of crop plants under phosphorus-deficient conditions and some properties of the secreted by lupine roots. Plant and Soil. 1993; 155:95-98.
23. Vance CP, Uhde C, Stone, Allan DL. Phosphorus acquisition and use, critical adaptations by plants securing a nonrenewable resource. New Phytologist. 2003; 57:423-447.
24. Wang J, Sun J, Mian J, Gud J, Shi Z, He M *et al*. Wheat phosphate starvations regular Ta-PHRI is in phosphate signaling and increases grain yield in wheat. Annals of Botany. 2013; 111(6):631139-1153.
25. Watt M, Evans JR. Phosphorus acquisition from soil by white lupine (*Lupinus albus* L.) and Soybean (*Glycine max* L.) species with contrasting root development. Plant and soil. 2003; 248:271-283.