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Variation in phosphorus accumulation in groundnut cultivars as influenced by water salinity

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ABSTRACT
Soil salinity remains an obvious abiotic stress that changes the behavior of nutrient accumulation in crop plants. Phosphorus being a key element in determining crop growth and economic yield, its uptake in plant parts varies under saline condition. Hence an experiment was conducted to assess the changing phosphorus content in eight groundnut cultivars,were grown in a field trial having in-built soil salinity developed with 0.5, 2.0, 4.0 and 6.0 dS m^{-1} of saline irrigations (EC_{iw}). Root-P was observed to have an increasing trend of accumulation upto 6.0 EC_{iw} while leaf-P increased upto 4.0 EC_{iw} with a concomitant rise in soil P. The cultivars TG 37A and GG 7 accumulated more leaf-P and root-P. However, across the cultivars the P-uptake was reduced when the applied EC_{iw} was 6.0 dS m^{-1}. Further, these plant-P parameters correlated with the yield and yield attributes of groundnut crop.

Key words: Groundnut, Phosphorus, P-uptake, Salinity, Yield attributes.

INTRODUCTION

Phosphorus (P) is one of the major plant growth limiting nutrients despite being abundant in soils both in organic and inorganic forms. P deficiency arises in many soils as only 1–3% of the total soil phosphorus is available to the plants. This is due to the high reactivity of soluble P with calcium, iron and aluminium leading to its precipitation. The behaviour of P in soil follows the equilibrium reaction: Solution P $\leftrightarrow$ Labile P $\leftrightarrow$ Non-labile P. Availability of soil P is also important regarding its synergistic and antagonistic behaviour with several macro and micronutrients.

Groundnut (*Arachis hypogaea* L.) is an important leguminous oilseed crop, extensively grown in the semi-arid Saurashtra region of Gujarat. In these areas salinity is a common problem both in terms of saline soil and high level of total dissolved solids (TDS) in irrigation water along with calcareousness, characterized by free excess lime ($CaCO_3$ or $MgCO_3$). Both these factors often changes soil properties related with crops growth and yield either by modifying soil-water relations or soil fertility and availability of plant nutrients (FAO, 1973).

Phosphorus takes part in several anabolic and catabolic pathways, thus controls the energy metabolism of plant cells. In many cases, salinity resulted in a reduced P concentration in plant tissue with a notion that P-deficient plants are more sensitive to salinity (Sharpley *et al.*, 1992).P concentrations in the leaves of maize crop decreased markedly under the salt stress (Kaya *et al.*, 2013).However, others reported that salinity may increase the P requirement of certain plants like tomato (Awad *et al.*, 1990) and in shoots of bean plants (Tejera *et al.*, 2005) which infers that P accumulation in crop plants is variably influenced by salinity, partially depending on the plant and experimental conditions (Alam *et al.*, 1999).

With this background, it is undoubtedly significant to study the P accumulation pattern,especially under saline conditions in groundnut, as it is one of the important determinants of growth, yield and economic return. Hence, the present study is based on the hypotheses that the cultivars selected for the experiment will have a variation in P-uptake under different salinity levels and also P-partitioning in different plant parts may vary in harvested crops. The crop yield and other yield attributing characters if sustain any relationship with P uptake defines another objective of this study.

MATERIALS AND METHODS

Experimental details and soil: The field experiment was conducted at ICAR Directorate of Groundnut Research, Junagadh (Gujarat), India (21º31'N latitude and 70º36' E longitude and 60 m above mean sea level) during *kharif* (July

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– October), 2011 to evaluate the performance of different groundnut cultivars on a permanent site having different levels of soil salinity maintained over a period of more than ten years. The soil of the experimental site was medium black, clayey, shallow (15–20 cm depth), highly calcareous (21-22% $CaCO_3$), non-saline (EC 0.35 dS m^{-1}) and moderately alkaline (pH 7.7) and classified under Vertic Ustochrept.The experimental soil was low in available N and available P but high in available K with a low organic carbon (0.48%).

Four different levels of salinity treatment was allotted to main plots through irrigation water [0.5 (control), 2.0, 4.0 and 6.0 dS m^{-1}] and eight Spanish groundnut cultivars (TPG 41, GG 6, GG 8, SG99, GG 7, TG 37A, R 2001-3 and Girnar 3) allotted to sub plots in a split plot design with three replications in (4 × 5) m^2 plot. Each salinity treated plot was separated from other by putting a 250 µm polythene sheet up to 60 cm soil depth in different channels surrounding the various treated plots. Bunds of each plot were raised to the height of 30 cm and width of 30 cm with the objective to absorb maximum rainwater in the plot. The recommended doses of fertilizers were applied as 12.5 kg N (from urea) + 40 kg P_2O_5(from SSP) ha^{-1}. As the problem of salinity in the Saurashtra area prevails mostly due to sea water ingression, the artificial saline irrigation water was prepared using only sodium chloride (NaCl) salt. The salinity levels of 2.0,4.0 and 6.0 dS m^{-1} in irrigation water were maintained by adding 22.5 mM, 45.0 mM, and 67.5 mM NaCl solution, respectively. Saline irrigations were applied at weekly interval during entire crop growth period. Yield and yield contributing characters were recorded after harvesting as per standard practice.

Soil and plant analyses: After harvesting, soil samples were collected from 0-15 cm depth and analysis was carried out after drying, grinding and passing through 2 mm sieve. Soil pH and electrical conductivity (EC_e) was estimated by portable Hanna-make pH-EC meter in a soil-water suspension of 1:2.5 ratio and available P was colorimetrically measured (730 nm) by developing blue colour (Olsen *et al*., 1954). Soil organic C (SOC) and available K were analyzed by standard protocols of Walkley and Black (1934), and Jackson (1973), respectively.

Plant parts (leaves and root tissues) of the mature plants grown in soil at same level of salinity were sampled separately before harvesting and finely ground dried plant samples were used in triplicate for analysis. Concentrations of P in plant tissue was determined colorimetrically (420 nm) by developing yellow colour (Jackson, 1973) after triacid (HNO_3: H_2SO_4: $HClO_4$ in the ratio of 10:1:4) digestion. P uptake in plants was calculated by multiplying P concentration (%) of each plant part with their respective mean weight and finally expressed in g per plant.

Statistical analysis: All the data recorded were the mean values of three independent replications. The data was subjected to analysis of variance appropriate to the experimental design. Differences at $LSD_{P=0.05}$ were considered statistically significant (Gomez and Gomez, 1984). F-test and correlation among the parameters was analyzed by MS-Excel based programme DSAASTAT (Onfri, 2007).

RESULTS AND DISCUSSION

Effect of salinity on yield of cultivars: A significant decrease in pod yield (kg ha^{-1}) was observed with increasing salinity level. Severe reduction in pod yield was noticed from 2.0 EC_{iw} to 4.0 EC_{iw} (689 kg ha^{-1}) and 4.0 EC_{iw} to 6.0 EC_{iw} (142 kg ha^{-1}) showing the hindered effect of saline irrigation towards crop yield, as supported by previous studies (Meena *et al.*, 2012). Among various genotypes, highest pod yield was recorded in TPG 41 (1128 kg ha^{-1}), GG 8 (1034 kg ha^{-1}) and R2001-3 (1079 kg ha^{-1}), while SG 99 (847 kg ha^{-1}) recorded the lowest (Table 1).

Effect of salinity on soil properties: Soil pH and EC are most important soil physico-chemical properties, both in normal and saline soil. In this study a significant increase in pH was noticed from 0.5 to 4.0 EC_{iw} and 2.0 to 6.0 EC_{iw}, respectively. While soil salinity (EC_e) increases significantly from one salinity level to higher and highest EC_e 2.21 dS m^{-1} was noted at 6.0 EC_{iw} (Table 2).

Soil P (kg ha^{-1}) also increases significantly with increasing salinity similar to that of pH and EC_e with a highest soil P observed in 6.0 EC_{iw} (12.7 kg ha^{-1}). It may be due to long term salinity that dissolves non-exchangeable pool of Ca-bound phosphate in calcareous soil of the present study area by replacing Ca^{2+} with ample Na^+ ions, as the P concentration in soil solution is tightly controlled by sorption

Table 1: Yield potentials of groundnut cultivars by applying irrigation water of different salinity

Main plot Salinity level (dS m^{-1}) (T)	Pod yield (kg ha^{-1})	Sub plot Cultivars (V)	Pod yield (kg ha^{-1})
0.5	1584	TPG 41	1128
2.0	1467	GG 6	937
4.0	689	Girnar 3	881
6.0	142	GG 8	1034
		SG 99	847
SEm±	32	TG 37 A	994
LSD (P=0.05)	111	GG 7	864
CV (%)	16	R 2001-3	1079
T × V		SEm±	37
SEm±	2.2	LSD (P=0.05)	110
LSD (P=0.05)	219	CV (%)	14

Table 2: Changes in soil fertility parameters with irrigation water salinity after *kharif* season

ECiw (dS m^{-1})	Soil parameters				
	pH	EC_e (dS m^{-1})	OC (%)	P (kg ha^{-1})	K (kg ha^{-1})
0.5	7.45	0.47	1.10	10.4	253.9
2.0	7.78	1.03	1.03	9.8	247.2
4.0	8.23	1.48	0.98	10.9	237.1
6.0	8.42	2.21	0.94	12.7	266.9
SEm±	0.16	0.15	0.04	0.2	10.9
LSD(P=0.05)	0.56	0.53	NS	0.8	NS
CV (%)	3.52	20.56	6.55	3.7	7.5

Table 3: Descriptive statistics of plant-P parameters

	Leaf-P (%)	Root-P (%)	P-uptake (g $plant^{-1}$)	(Root: leaf) -P
Mean	0.215	0.123	0.023	0.592
Standard Error	0.006	0.004	0.001	0.019
Median	0.215	0.106	0.023	0.585
Standard Deviation	0.056	0.043	0.008	0.191
Sample Variance	0.003	0.002	0.0001	0.036
Range	0.219	0.186	0.039	0.803
Minimum	0.133	0.070	0.006	0.262
Maximum	0.352	0.256	0.046	1.065
Count	96	96	96	96

processes resulting low solubility of Ca-P minerals (Sharpley *et al.*, 1992). However, in general low availability of P in this soil is mainly due to the reaction of soluble P with free calcium ions, forming calcium phosphate of varying solubility (Freeman and Rowell, 1981) which leads to P fixation in soil. Changes in soil organic carbon and potassium remained non-significant with application of varied levels of saline water.

Influence of salinity on P-accumulation in plant tissues: A descriptive statistics of all plant-P parameters analyzed was represented in Table 3.

Leaf phosphorus: Among the eight cultivars grown, TPG 41, GG 6, TG 37A, GG 7 did not show any significant differences in leaf P concentration in lower salinity levels i.e. at 0.5 EC_{iw} and 2.0 EC_{iw}, however all the cultivars were observed to have higher leaf-P concentration at 4.0 EC_{iw} with a maximum content in TG 37A (0.342%) followed by SG 99 (0.299%), which subsequently declined at 6.0 EC_{iw} (Table 4). The cultivar TPG 41, GG 6, Girnar 3 and R 2001-3 showed similar levels of leaf-P content at both 4.0 EC_{iw} and 6.0 EC_{iw}. Among the tested cultivars, higher leaf-P concentration was observed at 4.0 EC_{iw}, while GG 8, TG 37A and GG 7 proved invariably better cultivar over four applied salinity levels. It is reported to be unlikely that Cl^- and $H_2PO_4^-$ ions are competitive in terms of plant uptake, in contrast to NO^{3-} uptake (Hu and Schmidhalter, 2005), so as reflected in our studies. However, presence of Cl^- and SO_4^{2-} ions created interference in P uptake in other crops like barley and sunflower (Alam *et al.*, 1999), similar to our findings at 6.0 EC_{iw}, possibly due to high ionic strength of soil solution at relatively higher levels of soil salinity (Awad *et al.*, 1990).

Root phosphorus: Unlike P accumulation in leaves, roots of groundnut cultivars were found to be more responsive in

Table 4: P concentration in leaves of eight groundnut cultivars grown under four levels of salinity

Salinity levels (T) ECiw (dS m^{-1})	P concentration (%) of cultivars grown (V)								Mean
	TPG 41	GG 6	Girnar 3	GG 8	SG 99	TG 37A	GG 7	R 2001-3	
0.5	0.151	0.151	0.182	0.178	0.143	0.147	0.184	0.160	0.162
2.0	0.153	0.156	0.209	0.225	0.188	0.147	0.171	0.141	0.174
4.0	0.275	0.262	0.224	0.273	0.299	0.342	0.238	0.241	0.269
6.0	0.290	0.254	0.225	0.236	0.222	0.262	0.311	0.226	0.253
Mean	0.217	0.206	0.210	0.228	0.213	0.225	0.226	0.192	
		LSD (P=0.05)		SEm±					
T		0.004		0.001					
V		0.008		0.003					
T ×V		0.015		0.005					

Table 5: P concentration in roots of eight groundnut cultivars grown under four levels of salinity

Salinity levels (T) ECiw(dS m^{-1})	P concentration (%) of cultivars grown (V)								
	TPG 41	GG 6	Girnar 3	GG 8	SG 99	TG 37A	GG 7	R 2001-3	Mean
0.5	0.093	0.085	0.074	0.094	0.096	0.087	0.100	0.086	0.089
2.0	0.130	0.120	0.086	0.083	0.088	0.099	0.135	0.149	0.111
4.0	0.077	0.188	0.104	0.094	0.125	0.135	0.108	0.082	0.114
6.0	0.124	0.190	0.167	0.162	0.147	0.251	0.195	0.182	0.177
Mean	0.106	0.146	0.108	0.108	0.114	0.143	0.135	0.125	
		LSD (P=0.05)		SEm±					
T		0.003		0.001					
V		0.004		0.001					
T ×V		0.007		0.003					

P accumulation and thus P-content significantly increased from 0.5 to 2.0 EC_{iw}, although showing a different trend for each cultivar concerned (Table 5). Except TPG 41, GG 7 and R 2001-3, other cultivars increased root-P content at 4.0 EC_{iw}, with an increasing trend upto 6.0 EC_{iw}. Among the cultivars GG 6 and TG 37A were found superior in terms root-P accumulation under saline condition. Ashraf (2004) and Zamani *et al.* (2012) also reported an increasing trend of phosphorus accumulation under different salinity levels in roots of colza and canola, respectively.

Total phosphorus uptake: Study on P-uptake revealed a different trend as compared to leaf-P and root-P (Table 6). For each cultivar, it showed a decreasing trend with increasing level of salinity although it did not show any significant variation from 0.5 EC_{iw} to 2.0 EC_{iw} and upto 4.0 EC_{iw}. But at 6.0 EC_{iw}, all cultivars (except SG 99) showed a marked decline in P uptake. This pattern also reflected on effect of saline irrigations across all the cultivars results in a significant drop at 6.0 EC_{iw} (0.015 g $plant^{-1}$); whereas the P-uptake of cultivars remained statistically at par over four salinity levels. Similar to our findings, some reported that plants under high salinity had the lowest P uptake due to impaired growth in terms of root and shoot dry weights (Brown *et al.*, 2006).

Root-P to leaf-P ratio: This was enumerated to assess the proportional distribution of concentration of P in groundnut roots over leaves under different levels of applied saline irrigation (Fig. 1). Ratio-P was observed higher for R 2001-3 (1.054) at 2.0 EC_{iw}, followed by TG 37A (0.958) at 6.0 EC_{iw} which infers that at lower salinity level R2001-3 accumulated P ions ($H_2PO_4^-$) in roots more efficiently. On the other hand, TG 37A seems to be salt-tolerant as it possesses the ratio-P value of 0.958 at highest salinity levels (6.0 EC_{iw}) indicating better translocation of P ions to the roots.

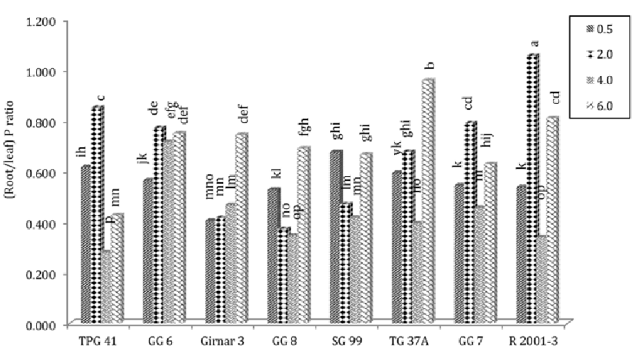

Fig 1: Changes in root-P to leaf-P ratio of eight groundnut cultivars grown under four levels of salinity. Different smaller case letters above the bars denote the values are significantly different at P=0.05 (L.S.D.$_{(0.05)}$ T×V = 0.065)

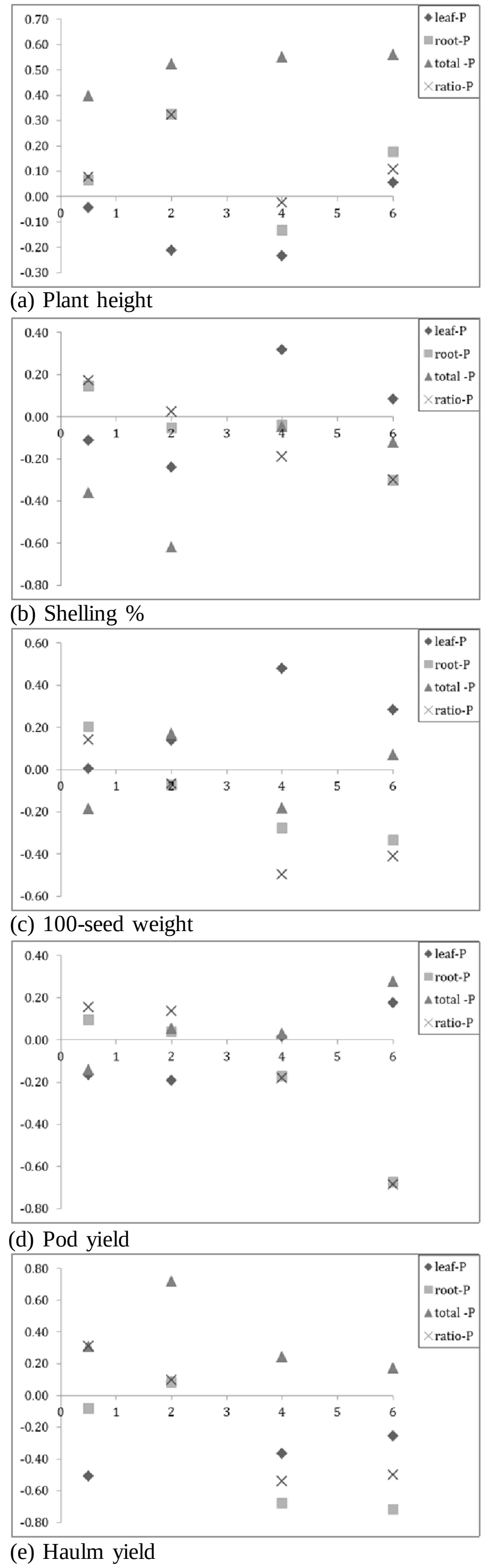

Fig 2: Scatter plot of correlation coefficients (r) (Y-axis) of yield and yield attributes with plant-P parameters cumulative of eight groundnut cultivars at four different levels of salinity (X-axis)

Table 6: Total-Puptake of eight groundnut cultivars grown under four levels of salinity

Salinity levels (T) ECiw(dS m^{-1})	P uptake (g $plant^{-1}$) of the cultivars grown(V)								
	TPG 41	GG 6	Girnar 3	GG 8	SG 99	TG 37A	GG 7	R 2001-3	Mean
0.5	0.026	0.030	0.030	0.021	0.024	0.030	0.020	0.022	0.025
2.0	0.029	0.026	0.031	0.027	0.022	0.021	0.022	0.039	0.027
4.0	0.022	0.019	0.023	0.029	0.025	0.028	0.034	0.025	0.026
6.0	0.017	0.011	0.014	0.012	0.016	0.019	0.019	0.012	0.015
Mean	0.024	0.022	0.024	0.022	0.022	0.024	0.024	0.024	
		LSD (P=0.05)		SEm±					
T		0.002		0.001					
V		NS		0.002					
T ×V		0.010		0.004					

Correlation between plant-P and yield parameters: The correlation study was aimed to determine the association of P content in leaf and root with the yield attributes and yield, which indicates the role of phosphorus nutrition in crop growth and yield. Each analyzed P parameters was subjected to correlation analysis with plant height, shelling out-turn, seed index, and pod and haulm yields individually at four salinity levels (0.5, 2.0, 4.0, 6.0 EC_{iw}) which revealed-

- Plant height had a significant positive correlation with root-P (r=0.32) only at 2.0 EC_{iw} while leaf-P did not have any correlation. But P-uptake correlated well with plant height throughout four EC_{iw}(Fig. 2a)
- Shelling out-turn (%) had positive correlation with leaf-P (r= 0.319*) at 4.0 EC_{iw} and negative correlation with P-uptake (r = -0.62*) at 2.0 EC_{iw} (Fig. 2b).
- Seed index (100-seed weight) was found to have negative correlations with root/leaf-P at both 4.0 and 6.0 EC_{iw} while positively correlated with leaf-P only at 4.0 EC_{iw} (r= 0.480*) (Fig. 2c).
- Pod yield was found to be influenced by root-P (r= -0.67), root/leaf-P (r= -0.69*) only at 6.0 EC_{iw} (Fig. 2d).
- Haulm yield was correlated with all the plant-P parameters which seemed to be more prominent in 4.0 and 6.0 EC_{iw}(Fig. 2e).

The aforesaid findings suggest that phosphorus is not as sensitive as other essential micro and macronutrient elements in saline condition hence its availability is conspicuous in both soil and salt-stressed plant parts of groundnut. The study implied that the distribution of phosphorus in leaves and roots and their ratio are found to be significantly different among the cultivars under varied levels of salinity, and the phosphorus uptake of groundnut cultivars affected at a salinity level of 6.0 EC_{iw}. Further, these P accumulation parameters correlated with the yield and yield attributes of groundnut crop and had a negative correlation with pod yield and haulm yield at 6.0 EC_{iw}. The study concludes that the phosphorus uptake of groundnut affected at a certain salinity level, although a higher consumption of phosphorus was observed under salinity as evidenced by increasing P content in leaves and roots.

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