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Phosphorus Uptake and Utilization Efficiency in Peanut[1]

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ABSTRACT

Cultivars of a crop can differ genetically with respect to their uptake, translocation, accumulation, and use of phosphorus. The objective of this paper was to evaluate genetic variation for P uptake and utilization among peanut (*Arachis hypogaea* L.) genotypes. Several traits contribute to the total P efficiency of the genotype, including root length, rate of P uptake per unit root length, leaf and pod characters such as P accumulation, and dry matter/yield produced per unit P absorbed [i.e., P efficiency ratio (PER)]. Peanut genotypes with increased P uptake and higher PER were identified. Some genotypes sustained higher PER at both low and high soil P availabilities.

Key Words: Genetic variation, *Arachis hypogaea*, plant nutrition.

Fertilizer application has generally resulted in increased yields, but investment in P fertilizer is difficult for resource-poor farmers. Therefore, most investigations recommend efficient use of P fertilizer to increase crop yields. Crop response to P fertilizer depends on genetic and physiological characteristics of the plant that help efficient P uptake and utilization, as well as soil and environmental conditions that affect P availability (2). Plant species differ in the magnitude of uptake, translocation, accumulation, and use of mineral elements (4,18). Genetic variation for P uptake and utilization has been reported for agriculturally useful crops (1,3,5,9,11,15), but it is seldomly utilized in the crop breeding and improvement programs. The knowledge on extent of genetic variation for P uptake and utilization efficiency within semi-arid crops is meager.

Peanut (*Arachis hypogaea* L.) is an important oil and protein source. Phosphorus is required for its growth and yield formation. Additionally, nitrogen fixation activity also needs P. Many of the peanut-growing regions in the tropics and semi-arid tropics have soils with low P availability, and yield loss due to P deficiency can be significant. Therefore, identification of genotypes efficient in P uptake and utilization is required. Occurrence of genetic variation for P uptake and utilization has not been reported previously for peanut. The objective of the experiments described in this paper were to identify genetic variation for P uptake and utilization traits among the peanut germplasm grown in the field, to analyze root growth and P uptake-related characteristics of peanut genotypes grown in pot culture, and to screen peanut genotypes for growth and P uptake at two different soil P fertility levels.

Materials and Methods

Two field trials and one greenhouse trial were conducted to detect genetic differences for P uptake and utilization in peanuts. Genotypes within different maturity groups, market types, and those having resistance to foliar diseases, insects and pests, and confectionery lines were used.

Field Trials. Twenty-five genotypes of peanut comprising early, medium, and late maturity groups were planted at the beginning of the rainy season (June to Oct. 1990) in a field with Alfisol soils (16.0 ppm Olsen's P, pH 7.5). The experimental area was divided into three blocks of 25 plots each. Each plot was 1.5 × 16 m and had four rows 30 cm apart and 15 m in length. Seeds were planted 10 cm apart within a row. Basal fertilizers at 375 kg ha^{-1} single superphosphate were applied before planting and 400 kg ha^{-1} gypsum at flowering. Furrow irrigation was provided five times during the season whenever natural precipitation was insufficient. Rainfall during the crop season was 450 mm and the average maximum and minimum temperatures were 30 and 22 C, respectively. Plants were sampled sequentially at 25, 39, 57, 67, 80, 96, 106, and 115 d after planting (DAP). At each sampling, plants in a 1.0-m area of

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each plot were harvested, pooled, then growth and yield parameters were measured and P contents of roots, stem, leaves, and seeds estimated by the vanadomolybdate yellow color method (13).

In another field trial, the performance of 40 peanut genotypes in low and high soil P conditions were compared in two different field locations. One was located at ICRISAT, India (17°32' N; 78°16' E), with high soil P (13 ppm Olsen's P, pH 6.5), and the other at Ananthapur, India (14°41' N and 73' E) with moderately low P (8.0 ppm Olsen's P, pH 7.2). The low P field received nitrogen at 40 kg N ha^{-1} as urea and no P application, while the high P field received 60 kg N ha^{-1} as urea and 40 kg P ha^{-1} as superphosphate. The 40 genotypes belonging to spanish, virginia, valencia and small-seeded virginia (runner) market types were planted on 75-cm ridges with 10 cm between plants. Plots were 5 m in length and contained four rows. Seeds were planted during the first week of June and harvested during the third week of Oct. 1987 at the ICRISAT Center. At Ananthapur, planting was done during the third week of July and harvested during the first week of Nov. A randomized block design with six replications was used. Irrigation was provided as required whenever natural precipitation was insufficient. Plants were harvested 60 DAP. Growth and yield parameters were measured and P contents in shoots estimated. ANOVA tests were used to analyze the data using a Genstat statistical package.

Greenhouse Trial. This experiment aimed at detailed analysis of growth and yield parameters with particular emphasis on roots and root-related characters that contribute to P uptake and utilization efficiency. It is difficult to estimate the contribution of roots to peanut P efficiency accurately in the field. Twenty-five genotypes including early (95-100 d), medium (110 d), and late (115-130 d) maturing accessions; foliar disease-resistant lines; and pest-resistant lines were planted in May 1991. Pots (30 cm diameter) filled with 15 kg Alfisol soil (3.0 ppm Olsen's P) were arranged in a randomized block design with three replicates (one plant per pot) on benches. Nitrogen as urea (0.6 g) and P as single superphosphate (2.0 g) were applied to all pots before planting. Hoaglands' micronutrient solution (50 mL per pot) was applied 15 DAP. Soil moisture was maintained at 60-70% of water-holding capacity on a weight basis. The mean temperature in the greenhouse was maintained at average minimum and maximum temperatures of 25 and 35 C, respectively. Plants were harvested sequentially at 22, 36, 53, 72, 96, 103, and 140 DAP. Root length was measured in a Comair root length scanner. Changes in the growth and yield parameters were recorded and P contents of the roots, shoots, stems and seeds were estimated by the vanadomolybdate yellow color method (13). Phosphorus efficiency ratio (PER) was calculated as 100 divided by percentage P on a dry weight basis (8). PER is the dry matter of pod or seed yield produced per unit of P absorbed.

Results

Genotypes of similar physiological maturity differed significantly in their PER in terms of total per plant, root, shoot, and seed (Table 1). Similarly, significant differences occurred among genotypes for total seed and shoot P contents and for seed P to shoot P ratio. Within the medium and late maturity groups, genotypes FDRS 10 and ICGV 86590 had similar pod dry weight, but seed P content was significantly different. Conversely, seed P contents were statistically similar for the genotypes ICGV 86590 and ICGV 86652, but pod dry weights were different. Some genotypes that translocated higher amounts of

Table 1. Genetic differences among peanut genotypes for characters contributing directly or indirectly to P uptake and utilization efficiency of peanuts grown in Alfisol, rainy season, 1990.[a]

Genotype[b]	Plant dry wt	Pod dry wt	P Shoot	P Seed	Total P uptake/ unit leaf area	P efficiency ratio[c] Plant	Shoot	Root	Seed	P seed: shoot ratio
	$g\ m^{-2}$	$g\ m^{-2}$	——mg m^{-2}——			mg m^{-2}				
Medium maturing lines										
FDRS 10	216.3	263.6	661	1560	59.7	192	322	416	106	2.4
ICGV 86020	288.8	232.5	723	1142	46.8	237	394	383	133	1.6
ICGV 86590	263.7	250.2	724	1172	54.6	219	359	368	125	1.5
FDRS 18	257.0	111.8	683	543	42.5	207	380	372	109	0.8
ICGV 86675	304.3	145.2	782	399	45.3	265	378	458	167	0.5
Early maturing lines										
ICGV 86652	257.5	201.2	542	1085	45.6	232	450	523	118	1.9
ICGV 87240	275.5	224.3	719	1179	52.0	224	366	475	127	1.6
JL 24	218.8	140.2	555	802	48.3	215	379	377	115	1.4
J 11	226.7	154.5	639	808	49.0	229	358	546	134	1.3
Mean	283.6	180.8	738	890	46.2	227	381	433	118	1.2
SE ±	22.79	20.60	76.3	103.4	4.08	12	27	31.5	6.7	0.13
CV (%)	14	20	18	20	15	9	12	13	9	18

[a]Crop grown in Alfisol, on broad beds, and irrigated as required. Data presented for samples drawn 96 DAP.

[b]Data shown only for representative genotypes of the 25 tested in the field and statistically analyzed.

[c]Phosphorus efficiency ratio is the dry matter of pod or seed yield produced per unit P absorbed.

P to the seeds also produced higher amounts of pod dry weights (e.g., ICGV 86020, ICGV 86590, ICGV 87240, and FDRS 10), indicating increased efficiency for P uptake and utilization for yield formation. In contrast, ICGV 86675 had higher PER, but very little P was translocated into the seeds. FDRS 10 had a low PER value, but large amounts of P were absorbed and translocated into the seeds. The greenhouse study indicated that peanut genotypes of the same physiological maturity group differed significantly in their root length and P uptake per unit root length (Table 2). Genetic variation occurred for P accumulation, PER in the shoot and pods, P uptake in relation to leaf area, and seed P to shoot P ratio (Tables 1 and 2). Some genotypes possess higher P uptake and translocation efficiency in their shoot and seed (Fig. 1). These are efficient dry matter and seed yield producers per unit P translocated.

Table 2. Genetic variation among peanut genotypes for root characteristics directly contributed to P uptake and utilization efficiency grown in the greenhouse during the rainy season, 1990.[a]

Maturity/ genotype	Total root length	Shoot P: root P ratio	Root P conc.	Total P uptake/root length	Total P uptake/root dry wt
	m plant^{-1}		% dry wt	µg m^{-1}	µg m^{-1}
Early maturing lines					
ICGMS 9	303	15.76	0.19	405	45
ICGMS 23	394	10.61	0.17	256	26
ICGMS 32	341	12.26	0.20	293	29
ICGMS 18	330	10.36	0.19	226	23
Medium and late maturing lines					
ICCV 86309	315	9.62	0.18	334	26
ICGV 86310	585	9.17	0.18	155	23
ICGV 86311	449	10.47	0.16	277	29
ICGV 86302	431	12.63	0.20	273	31
ICGV 86243	378	11.70	0.17	309	47
ICGV 86235	450	13.93	0.18	308	28
ICGV 86236	352	11.09	0.19	291	19
ICGV 86330	378	6.74	0.18	323	41
ICGV 86188	317	16.71	0.19	311	28
Foliar disease-resistant lines[b]					
ICGV 86020	390	11.67	0.18	313	26
ICGV 86590	362	7.19	0.19	422	23
ICGV 87240	431	10.78	0.16	318	28
ICGV 86675	812	6.17	0.16	300	28
Confectionery lines					
ICGV 88390	402	8.47	0.16	300	28
ICGV 88395	552	8.65	0.16	300	28
ICGV 88371	743	6.73	0.17	146	16
ICGV 88389	744	10.17	0.14	410	29
Insect- and pest-resistant lines[c]					
ICGV 87468	365	12.84	0.18	226	22
ICGV 86486	419	10.44	0.18	317	29
ICGV 86518	312	8.73	0.17	399	24
ICGV 86351	587	9.45	0.16	212	21
SE ±	83.1	2.059	0.014	62.4	7.2
CV (%)	33	34	14	36	44

[a]Plants grown for 72 d in pots (single plant per pot) containing 15 kg Alfisol.

[b]The foliar diseases include rust and early leaf spot.

[c]The insect- and pest-resistant lines include leaf miner and thrips.

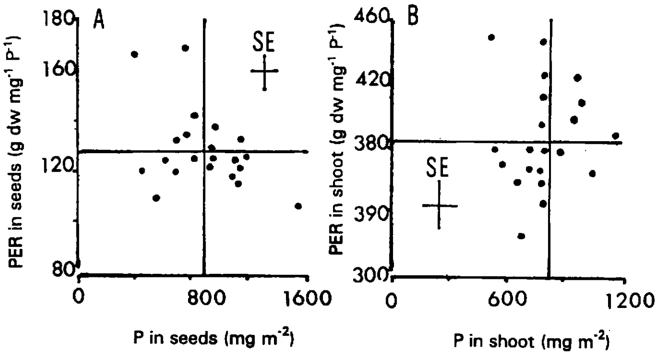


Fig. 1. Scatter diagram depicting phosphorus accumulation and P efficiency in seeds (A) and P accumulation and P efficiency ratio in shoot portions (B) of the peanut genotypes tested in Alfisol field, rainy season 1990 (perpendicular lines are drawn for experimental mean values derived for 25 genotypes).

Comparison of genotypes in low and high P conditions revealed that the PER is higher under low P conditions when compared with high soil P environments (Table 3). Mean total P uptake of genotypes was less in low P soils. Many genotypes, however, perform with higher P efficiency at both low and high soil P; nearly 50% of the genotypes are represented in the northeast quadrant in the graph (Fig. 2). Analysis of P content in various plant parts of each of the peanut genotypes revealed that P uptake increases are augmented by increased root length, root weight, and P uptake per unit root length (Fig. 3). Individual genotypes of similar maturity groups, however, differed in the pattern of root elongation and P absorbed per unit root length. The pattern of PER changed in relation to plant growth (Fig. 4), indicating that shoots initially accumulated higher tissue P. Demand for P is greater at the onset of flowering until pod filling. Absorption by roots also was greater during this phase. The patterns of PER differ between individual genotypes.

Discussion

Increased uptake of P from soil and increased yield and dry matter production per unit P absorbed (PER) are two important aspects of utilization efficiency (10,16). Some peanut genotypes have root characteristics that make them efficient in P uptake. Obviously, length of the roots, their spread in the soil, morphology, and rate of P uptake by roots together contribute to total P efficiency. Differences in root hair formation among peanut genotypes have been reported (7,12). Identification of gene mutations in roots that affect mineral uptake will further substantiate the genetic basis for P uptake and utilization in peanuts (6). Genetic differences in shoot and pod

Table 3. Phosphorus accumulation and phosphorus efficiency ratio of 40 different groundnut genotypes grown in low and high P-containing Alfisol during the rainy season, 1985.

Market type/ genotype	High fertility: Shoot dry matter	High fertility: Total P uptake	High fertility: P effic. ratio	Low fertility[a]: Shoot dry matter	Low fertility[a]: Total P uptake	Low fertility[a]: P effic. ratio
	g plant^{-1}	mg plant^{-1}		g plant^{-1}	mg plant^{-1}	
Spanish						
ICG 10505	11.23	28	400	6.44	16	442
ICG 5305	9.78	26	384	6.50	16	410
ICG 1521	9.80	26	344	5.20	12	429
ICG 1101	7.50	19	384	7.50	17	434
ICG 221	8.70	22	395	5.81	14	423
ICG 1506	8.80	22	406	5.17	11	476
ICG 1723	8.10	21	380	4.27	19	448
ICG 7827	5.61	14	395	6.27	14	434
ICG 10525	6.02	16	370	5.78	12	476
ICG 1164	5.72	15	380	5.43	11	469
Virginia						
ICG 4224	15.51	43	361	6.52	15	421
ICG 2671	14.90	43	344	6.08	15	411
ICG 3047	12.60	37	337	6.78	17	404
ICG 3833	12.66	36	348	7.08	17	404
ICG 4445	13.14	37	353	6.68	16	400
Robut 33-1	14.17	37	374	5.59	14	429
ICG 2490	9.82	27	366	8.08	21	389
ICG 3030	10.73	28	380	7.68	18	416
ICG 4507	11.81	32	366	5.46	13	411
ICG 3064	11.37	36	380	6.64	15	442
Valencia						
ICG 5139	12.63	33	384	7.47	18	423
ICG 7885	10.01	27	375	7.59	18	423
ICG 10509	11.92	29	411	5.74	13	442
ICG 1707	8.97	23	390	7.77	18	429
ICG 10974	9.44	25	370	6.29	15	421
ICG 1697	9.04	23	390	6.70	15	440
ICG 10470	8.85	23	390	5.78	18	448
ICG 1629	8.60	23	411	5.80	13	429
ICG 2738	5.60	13	395	5.22	12	434
ICG 1905	4.00	10	384	2.14	15	416
Runner						
ICG 5129	12.54	34	370	11.95	29	416
ICG 4159	15.00	42	357	7.17	17	321
ICG 156	13.12	35	374	8.06	20	404
ICG 4149	12.42	34	361	5.69	14	404
ICG 4344	11.15	32	349	6.47	16	400
ICG 5363	10.89	30	366	6.86	16	416
ICG 3948	9.54	27	348	7.70	18	416
ICG 2607	9.30	24	370	8.40	21	406
ICG 5622	9.72	27	357	5.95	15	421
ICG 5302	7.59	20	387	6.34	16	404
Mean	10.20	27	377	6.52	16	425
SE ±	0.618	2.9	14.5	0.618	1.5	18.0
CV (%)	18	18	7	18	16	7

[a]Low fertility soil contained 8 ppm Olsen's available P (pH 7.2) and was given 40 kg N ha^{-1} as urea, with no P application, while high fertility soil contained 13 ppm Olsen's P (pH 6.5) and was given 60 kg N ha^{-1} as urea and 40 kg P ha^{-1} as single superphosphate.

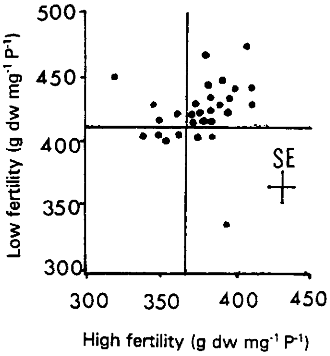
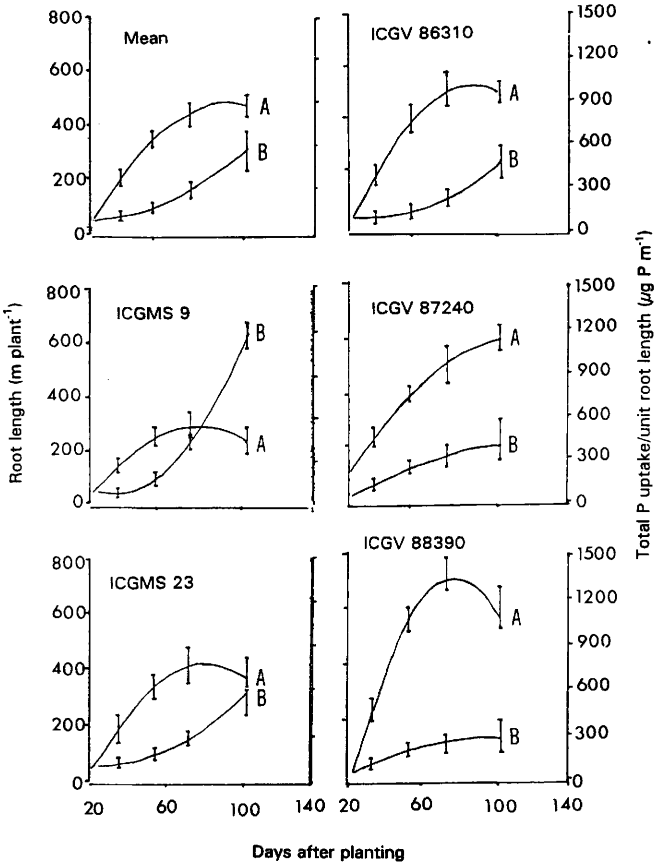
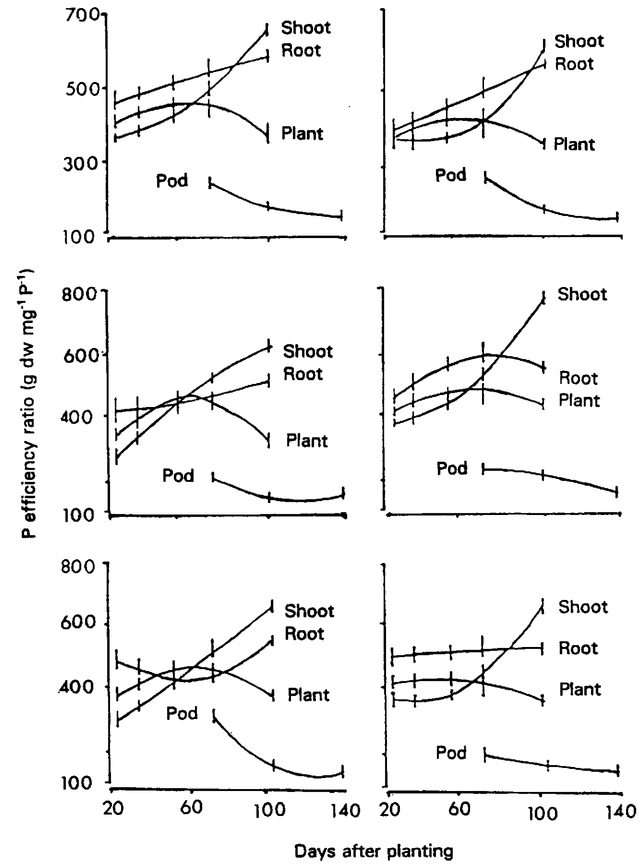


Fig. 2. Phosphorus efficiency ratio (g dw mg^{-1} P^{-1}) of 40 peanut genotypes belonging to different botanical and marketing types grown in two locations, one with higher P fertility (ICRISAT) and the other with lower fertility conditions (Ananthapur), rainy season 1985 (experimental mean shown by the perpendicular lines derived from 40 genotypes).



Mean
A: $y = -0.08X^2 + 15.5X - 24$
B: $y = 0.06X^2 - 1.75X + 88$
ICGMS 9
A: $y = -0.08X^2 + 12.7X - 1961$
B: $y = 0.22X^2 - 14.3X + 306$
ICGMS 23
A: $y = -0.10X^2 + 17.2X - 292$
B: $y = 0.08X^2 - 4.4X + 156$
ICGV 86310
A: $y = -0.11X^2 + 20.7X - 372$
B: $y = 0.74X^2 - 4.7X + 158$
ICGV 87240
A: $y = -0.06X^2 + 13.3X - 149$
B: $y = 0.02X^2 + 8.2X - 133$
ICGV 88390
A: $y = -0.2X^2 + 36.2X - 696$
B: $y = -0.03X^2 + 7.2X - 111$

Fig. 3. Patterns of root length (A) and total P uptake per unit root length (B) of peanut genotypes in an Alfisol soil, rainy season 1991 (mean is derived from 25 genotypes tested).



Mean
Root $y = 0.067 X^2 + 2.4 X + 400$
Shoot $y = 0.027 X^2 + 0.3 X + 342$
Plant $y = -0.05 X^2 + 5.8 X + 342$
Pod $y = 0.024 X - 6.4 X + 571$

ICGMS 9
Root $y = 0.007 X^2 + 0.3 X + 405$
Shoot $y = 0.031 X^2 + 8.42 X + 83$
Plant $y = 0.08 X^2 + 10.3 X + 103$
Pod $y = 0.042 X^2 + 9.8 X + 695$

ICGMS 18
Root $y = 0.059 X^2 - 6.6 X + 605$
Shoot $y = 0.005 X^2 + 3.9 X + 200$
Plant $y = 0.06 X^2 + 7.5 X + 200$
Pod $y = 0.066 X^2 - 16.5 X + 1158$

ICGV 86310
Root $y = 0.004 X^2 + 2.27 X + 366$
Shoot $y = 0.08 X^2 - 7.19 X + 549$
Plant $y = 0.04 X^2 + 5.9 X + 281$
Pod $y = 0.04 X^2 - 10.0 X + 813$

ICGV 86243
Root $y = -0.05 X^2 + 7.6 X + 294$
Shoot $y = 0.051 X^2 - 149 X + 380$
Plant $y = -0.04 X^2 + 5.72 X + 294$
Pod $y = -0.15 X^2 + 2.03 X + 168$

ICGV 86590
Root $y = 0.004 X^2 + 0.84 X + 474$
Shoot $y = 0.067 X^2 - 4.7 X + 440$
Plant $y = -0.024 X^2 + 2.4 X + 371$
Pod $y = 0.002 X^2 - 1.2 X + 275$

Fig. 4. Patterns of phosphorus efficiency ratio in overall plant, shoot, root, and seeds of peanut genotypes grown in an Alfisol soil (mean is derived from 25 genotypes tested).

characters that enhance P uptake efficiency of a genotype also have been identified, particularly differences in P accumulation and PER which are directly related to P utilization efficiency in peanuts. Physiological and genetic determinants of P efficiency, therefore, occur in roots, shoots, and pods.

To augment higher uptake, certain genotypes (e.g., ICGMS 9) depend more on increased root length and increased exploration of soil, while others (e.g., ICGMS 23) depend on greater P absorption rate and total P uptake per unit root length. Peanuts appear to translocate the most recently assimilated P into reproductive structures. This is substantiated by the significant increase in root length and P uptake per unit root length at the onset of the flowering until pod-filling stages. Similar observations have been made in other legumes (14,17). These data illustrate the need for selecting genotypes with higher P efficiency at the reproductive phase.

A peanut genotype is 'P efficient' when it absorbs higher amounts of P and produces higher seed yield per unit P in plant tissue. Genotypes which are efficient for seed yield per unit P absorbed, but lack the ability for higher P absorption from soil, could be improved by selecting higher P absorption traits in roots. Genotypes that possess the ability for higher P absorption from soil, but have inadequate P translocation to the seed (e.g., ICGV 86675), need to be improved by selection for higher seed to P to shoot P ratio. A genotype such as FDRS 10 needs to be improved by selection for higher PER because it absorbs and translocates higher amounts of P into seeds, but its ability to produce higher seed yield per unit P (i.e., PER) is low. A combination of good P uptake and translocation traits along with higher PER for yield formation can increase yield per unit P multiple folds. Gabelman and Gerloff (8) substantiated that P efficiency of a legume is a heritable character and can be enhanced by selection.

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