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Genetic Variability in Root and Shoot Growth Characteristics of Peanut[1,2]

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ABSTRACT

The shape and extent of root systems influence the rate and pattern of nutrient and water uptake from the soil. In dicotyledons such as peanut (*Arachis hypogaea* L.), the primary root and its laterals constitute the main root system. Rooting trait differences in some crops have been associated with drought tolerance. Our objective in this study was to determine if variation in root length and number occurs among peanut genotypes. In one test, shoot and root growth of 23 genotypes (12 spanish and 11 virginia types) were compared in the greenhouse at 55 days after planting using clear acrylic tubes 7.5 cm in diameter and 2.2 m in length. Shoot dry weight, leaf area, tap root length, and root number at 1 m depth ranged for spanish-type entries from 1.23 to 2.65 g, 214 to 409 cm^2, 95.0 to 186.8 cm, and 1.0 to 3.1, respectively. Similarly, ranges for virginia-type entries were 1.35 to 3.23 g, 135 to 460 cm^2, 122.4 to 192.6 cm, and 1.0 to 7.1. Correlations between shoot and root parameters indicated strong positive association between aerial and subterranean growth. However, the relationship of leaf area to root length was stronger for virginia- than for spanish-type entries. Root length and numbers were highly correlated for spanish, but not for virginia entries. In other tests that included two each of virginia-, spanish-, and valencia-type entries, similar results were found for plants at 34 and 47 days after planting. Significant differences in both root (length and numbers) and shoot growth (dry weight and leaf area) were found among the genotypes tested. Inherent differences in root growth rate were evident at early stages of seedling growth. The results from this sample of peanut germplasm indicate that there is considerable diversity in root growth and there is high shoot/root growth association.

Key Words: Root growth, Shoot growth, Virginia-, Spanish-, Valencia-types, groundnut, *Arachis hypogaea* L., Growth correlations.

In the interdependence between plant shoots and roots, the roots greatly determine the availability of mineral nutrients and water from soil. Although, extensive work by plant breeders has been directed toward modification of the aerial portion of crop plants to enhance yield, quality, and pest resistance, extremely little effort has been expended to modify root systems. The shape and extent of root systems are known to influence the rate and pattern of nutrient and water uptake from the soil (17, 21, 27). Rooting characteristics differ greatly among plant species (20, 25), and variation within species has been documented for some crops, particularly among monocotyledonous plants. Spencer (22) found that inbred lines of corn (*Zea mays* L.) differed in number and dry weight of seminal roots. Hybrids from the lines had more total root length and more root dry weight than the parents. There also were differences in dry weight and length of the crown roots. In 1981, Jenison et al. (11) reported differences in root dry weight and root spread among corn inbreds.

Hurd (8) found differences in rooting patterns between wheat species (*Triticum aestivum* L. and *T. durum* L.) and among wheat cultivars (9, 10). The rooting patterns were related to differences in ability to escape drought. Cultivars differed in root lengths, dry weight of roots at different soil depths, and extent of rooting in the seedling stage. Extensive wheat root systems were also associated with higher yields (10).

Reports vary as to the interrelationship between shoot and root growth of wheat. In a study of high yielding wheat cultivars, there were differences in depth and lateral spread of roots between two dwarf cultivars; and tall cultivars had a more extensive lateral spreading root system than the dwarfs (24). However, Lupton et al. (15) found that intercultivar differences in the root systems of semidwarf and tall wheat cultivars were generally small, but when differences occurred the roots of semidwarf cultivars were more extensive than those of taller wheats. Under field conditions in those experiments where root systems of semidwarf wheat genotypes were more extensive than those of taller genotypes, there was also more phosphate uptake by the semidwarfs (15). Yet, among selected spring-wheat cultivars of diverse origin with considerable variability in growth of shoot and root, there was a close interdependence between these organs. Tall and short cultivars tended to have deep and shallow root systems, respectively (16).

Barley (*Hordeum vulgare* L.) cultivars differed in dry weight, number, and length of roots (7). Root volumes and weights differed among *Avena* spp., and these were highly correlated with shoot and panicle weight (4). Rice (*Oryza sativa* L.) cultivars have extensive diversity in rooting depth and density. Upland cultivars, which are more drought tolerant, have a deeper and more prolific rooting habit than lowland cultivars (23).

Comparison between an early and a late-maturing sorghum (*Sorghum bicolor* L. Moench) cultivar showed that an early-maturing genotype developed crown roots earlier and had more rapid initial root growth rates than a late genotype, but the latter had greater root volume than the former (2). Leaf area development corresponded with root growth so that the ratio of leaf area to root length was similar for both cultivars, and a balance between shoot and root growth was maintained regardless of maturity (12). Also, studies with sorghum hybrids and their parents indicated that plants having a larger leaf area were more likely to have a larger root volume and total length of adventitious roots (3). Among ten sorghum cultivars selected for their relative drought tolerance, Nour and Weibel (18) found differences in root wet weight, length, and volume. The more drought tolerant lines had higher root/shoot ratios. Genetic variability among sorghum

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genotypes exists for both shoot and root traits. Greater drought tolerance was associated with greater root weights, more deeply penetrating root systems, and higher root/shoot ratios (12, 18).

Little research has been done to determine shoot-root traits and their interrelationships for dicotyledonous plants. Among soybean (*Glycine max* L. Merr) cultivars, Taylor et al. (26) found differences in taproot growth rate and root length. Significant linear correlation was found between shoot weight and taproot length. Studies with cotton (*Gossypium* sp.) indicated that genetic variability exists in taproot growth and number of strong, downward-growing lateral roots. Shoot growth was correlated with root growth (number of laterals and length) under dryland, but not irrigated conditions (19). Peanut (*Arachis hypogaea* L. cv. Florunner) roots penetrated to a depth of at least 150 cm in a sandy soil, and the most extensive rooting occurred in the top 30 cm (20). Bhan (1) found differences in rooting depth among and within spanish- and virginia-type peanuts. Differences in number of primary and secondary roots and in root weight also were found. Number of primary roots at 25 cm depth, number of secondary roots at both 25 and 50 cm depth, and total dry weight of roots were significantly correlated with shoot weight.

Relatively little has been done to examine peanut germplasm for variability in rooting habit. Our objective in this study was to evaluate peanut germplasm for diversity in rooting traits. These studies determined taproot length and number of major downward-growing lateral roots, and their relationship with shoot growth parameters.

Materials and Methods

Plant Material. The peanut (*Arachis hypogaea* L.) genotypes used in these studies are listed in Tables 1, 2, and 3. Since little is known about the rooting traits of peanuts, the genotypes were chosen based on diverse shoot morphology (spanish, virginia, and valencia botanical types), cultivars presently of commercial importance (Tamnut 74, Pronto, Florunner, Florigiant), cultivars previously of commercial importance (Argentine, Spancross, Comet, Starr, Dixie Runner, Early Runner), breeding lines that may be of future commercial value (EC-5, EM-9, UF77318), other genotypes of diverse shoot morphology (Hughes Narrow, PI 405915, PI 404021), and 120 recent plant introductions (designated by PI and US numbers) of mostly uncharacterized germplasm. In this way, rooting relationships with botanical type, changes in rooting habit with progress in the release of new cultivars, and possibilities for introduction of new germplasm into the breeding program could be explored.

Experimental Procedure. Tests conducted at two institutions are included in this report. One test with 23 genotypes (12 spanish and 11 virginia, Table 1) and three additional tests with a total of 120 plant introductions were performed at Temple, Texas. Those entries with shoot and root traits superior to the standard genotype, Starr, are listed in the Results and Discussion. Seeds were soaked in 0.03% Ban Rot solution for 20 h at 22 C and then transferred to 30/20 C alternating temperatures for an additional 22 h for pregermination. Seedlings selected for uniformity of growth were planted in clear, acrylic tubes (7.5 X 220 cm) following the method of Taylor et al. (26). Although the seed sources varied, the selection of uniform seedlings for transplant to the acrylic tubes is assumed to have reduced possible seed source effects. The tubes contained the nonrestricting medium Peatlite (Grace Horticultural Products). Before planting the medium was thoroughly settled by soaking from the top with a trickle irrigation system. Plants were watered every other day with this system, and 400 ml of Hoagland solution was applied weekly to each tube. Root growth was measured weekly. Temperatures in the glasshouse were set for 32/24 C day/night regimes, but short term variations ranged to 37/15 C.

Table 1. Shoot and root growth characteristics of selected peanut genotypes grown for 55 days in acrylic tubes in a glasshouse at Temple, TX, during October and November, 1979.

Genotypes	Shoot			Root	
	Height	Dry wt.	Leaf area	Length	Number at 1 m
	cm	g	cm^2	cm	no.
Spanish-types					
Hughes Narrow	15.9a[1/]	1.75d-e	214b	145.6b-c	1.8a-b
Argentine	15.9a	1.85b-e	266b	149.1b-c	2.0a-b
PI 360862	15.2a	1.81c-e	255b	149.3b-c	2.4a-b
Spancross	15.0a	2.65a	409a	186.8a	2.8a-b
EC-5	13.9a	2.32a-d	262b	157.0b-c	2.3a-b
Comet	13.8a	1.82b-e	223b	138.5c	1.3b
Starr	13.6a	2.44a-c	310a-b	154.3b-c	2.1a-b
Chico	13.0a	1.85b-e	256b	153.7b-c	1.2b
Pronto	12.9a	1.76d-e	255b	164.9b	1.6b
EM-9	12.0a	2.73a	292b	165.0b	1.8a-b
Goldin 1	10.6a	1.23e	264b	95.0d	1.0b
Tamnut 74	10.5a	2.57a-b	308a-b	164.0b-c	3.1a
$\bar{X}$	13.5	2.06	277	152	1.9
Virginia-types					
PI 405915	17.1a	2.21b-c	270b-c	156.0b-c	4.0b-c
Dixie Runner	16.2a	1.35c	180c	122.4d	1.6c
T811	15.2a	1.89b-c	262c	155.4c	4.4b
NC-13	14.9a	2.47b	280b-c	161.9b-c	4.2b
Early Bunch	14.4a	3.23a	460a	173.1a-c	7.1a
PI 360860	14.2a	1.44c	170c	141.6c	1.3c
UF 77318	14.0a	3.01a-b	383a-b	186.6a	4.9b
Florunner	13.7a	2.22b	293b-c	192.6a	4.9b
Early Runner	13.3a	2.19b-c	246c	183.3a-b	1.3c
PI 280688	13.2a	1.28c	135c	155.3c	1.0c
Florigiant	10.1a	3.20a-b	331a-b	170.0a-c	3.0b-c
$\bar{X}$	14.2	2.27	274	163	3.4

1/ Means of each type within columns followed by different letters were significantly different ($P < 0.05$) as determined by Duncan's multiple range test. Spanish- and virginia-types were analyzed separately.

Generally, the same kinds of procedures were used at Stillwater, OK. Six genotypes (Tables 2 and 3) were used in these studies. Seeds were from the same growing season and location. They were grown on the Oklahoma Agricultural Experiment Station at Perkins, OK in 1979. Seeds were pregerminated in water, incubated at 30 C constant temperature for 40 h, selected for uniformity, and planted in acrylic tubes containing vermiculite. Tubes were watered and roots measured daily. Hoagland solution (200 ml) was applied weekly to each tube. Plants were grown in a fiberglass (90% light transmission) greenhouse. Temperatures recorded within the chamber about midmorning ranged from 21 to 25 C. Greenhouse temperatures were set for constant 24 C.

At the conclusion of the tests, maximum taproot length was measured and number of strong downward-growing lateral roots at specified depths were counted. Also, shoot height, leaf area, and dry weight were measured for each plant.

Statistical Analyses. Experimental design was a randomized block with 6 to 10 replicates; one plant per entry constituted a replication. Duncan's multiple range test was used to determine significant differences among mean values. At least one standard cultivar was included in each test for comparison with the other genotypes, and Dunnett's test

Table 2. Shoot and root growth characteristics of five selected peanut genotypes grown for 34 days in acrylic tubes in a fiberglass greenhouse at Stillwater, OK., during November and December, 1979.

Genotypes	Shoot: Height	Shoot: Dry wt.	Shoot: Leaf area	Shoot: Leaf	Root: Length	Root: Depth 60 cm
	cm	g	cm^2	no.	cm	no.
Virginia-type						
PI 404021	10.9a[1/]	1.88a	318.1a	23ab	127.8a	5ab
Spanish-type						
PI 404020	10.2a*[2/]	1.12a	194.2a*	12c**	95.5c***	3b
Tamnut 74	7.8b	1.56a	274.7a	16bc	110.9b	7a
Valencia-type						
PI 261966	9.9a***	1.50a	291.2a	19abc	110.3b*	5ab
PI 355993	6.6b	1.64a	303.8a	24a	127.8a	3b

1/ Means within columns followed by different letters were significantly different ($P < 0.05$) as determined by Duncan's multiple range test.

2/ The symbols *, **, and *** represent significant differences between genotypes within botanical classifications, i.e., spanish-type, at the 10%, 5%, and 1% levels of probability, respectively.

Table 3. Shoot and root growth characteristics of six selected peanut genotypes grown for 47 days in acrylic tubes in a fiberglass greenhouse at Stillwater, OK., during January and February, 1980.

Genotypes	Shoot: Height	Shoot: Dry wt.	Shoot: Leaf area	Shoot: Leaf	Root: Length	Root: Depth at 30-	Root: Depth 60-	Root: Depth 100-cm
	cm	g	cm^2	no.	cm	no.	no.	no.
Virginia-type								
PI 405915	18.9a[1/]	2.06a	254.1a	22ab	144.0b***[2/]	5b	4a	3a
PI 404021	18.6a	2.06a	289.6a	23a	163.3a	5b	5a	4a
Spanish-type								
PI 404020	17.3a***	1.54b	241.7a	14c	126.6d**	5b	5a	3a
Tamnut 74	13.9b	1.62ab	249.3a	17bc	136.7c	6b	6a	3a
Valencia-type								
PI 261966	12.9b***	1.08c**	217.8a**	16c***	144.1b**	4b**	3a	3a
PI 355993	8.5c	1.77ab	325.7a	27a	161.8a	9a	5a	3a

1/ Means within columns followed by different letters were significantly different ($P < 0.05$) as determined by Duncan's multiple range test.

2/ The symbols *, **, and *** represent significant differences between genotypes within botanical classifications, i.e., spanish type, etc., at the 10%, 5%, and 1% levels of probability, respectively.

(6) was used to scale the performance of 120 genotypes to that of the standard genotype, Starr (Fig. 1).

Results and Discussion

Even though procedural details used at the two locations were slightly different, both sufficed to show differences in shoot and root growth characteristics among peanut genotypes (Tables 1, 2, 3). Differences were evident as early as 34 days after planting (Table 3).

Among the spanish types, Spancross seedlings had the longest taproot, and largest leaf area and shoot dry weight (Table 1). These plants also averaged nearly three strong downward-growing lateral roots at 1 m depth. Two other closely related spanish genotypes, Tamnut 74 and Starr, had similar shoot charactristics, but Tamnut 74, although not significantly different, had somewhat longer taproots and more roots at 1 m depth than Starr. Comet, which was the leading cultivar grown in Oklahoma for many years and a selection from Starr, was among the smallest plants, with the shortest taproots and fewest number of roots at 1 m depth. However, among selections from Comet X Chico crosses (EC-5, EM-9, and Pronto) taproot lengths were equal to or longer than the longest rooted parent, Chico. Perhaps, in addition to contributing earliness of maturity to the progeny from the crosses, Chico also provides a tendency for deep rootedness. The recently released longer-rooted cultivar Pronto is replacing the

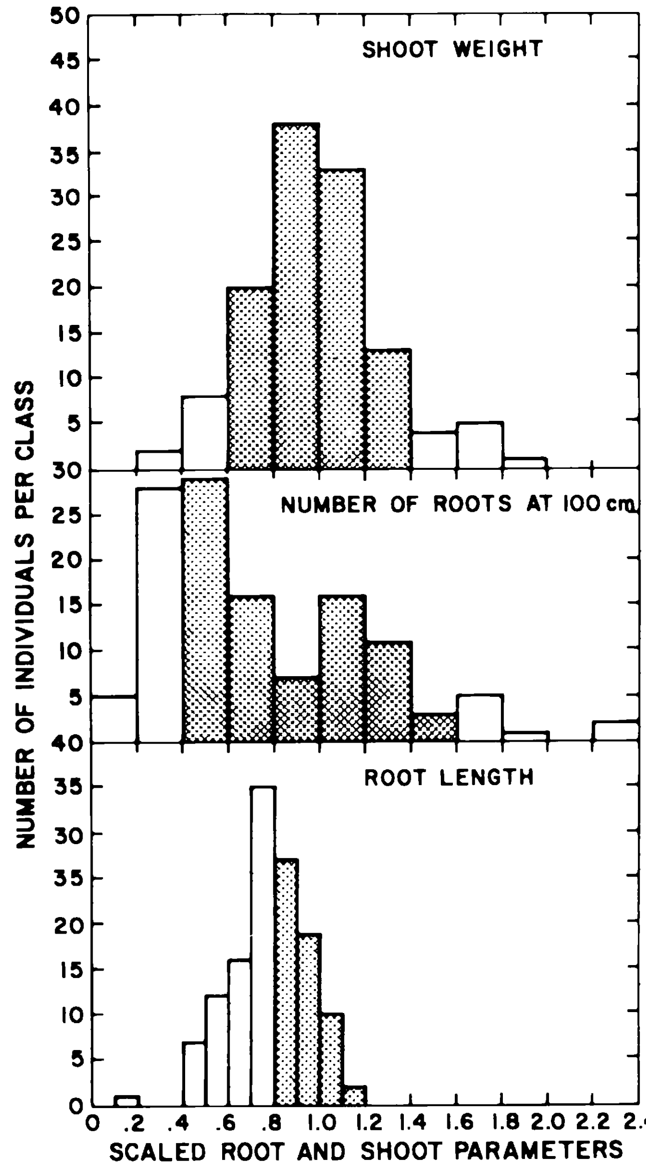

Fig. 1. Shoot and root growth characteristics of 120 genotypes from three experiments (October 9 to December 2, 1980; January 14 to March 11, 1981; May 1 to June 6, 1981; 54, 56, and 37 days, respectively). Because of differences in day length and growth duration among experiments, the data were scaled to the performance of Starr for each parameter (Starr = 1.0). The shaded portion of each graph represents ±1 critical value (v = 0.01) calculated according to Dunnett's test.

short-rooted Comet parent in much of the acreage in Oklahoma. Although Pronto was not selected based on rooting traits, these may be an advantage of this cultivar. The rapid growth of Spancross compared to the other spanish entries was somewhat unexpected based on field observations. Tamnut 74 is noted for rapid emergence compared to most cultivars in the southwestern peanut region.

Among the virginia types, Florunner and the University of Florida breeding line UF 77318 had the longest taproots, followed closely by Early Runner, Early Bunch, and Florigiant (Table 1). Early Bunch seedlings had the largest dry weight, leaf area, and number of roots at 1 m depth. Dixie Runner was among those entires with the smallest plants and the fewest roots at 1 m, and it had the shortest taproot. Dixie Runner was the first release in a series of improved virginia peanut varieties from Florida. It was followed by Early Runner, Florunner, and Early Bunch. Early Runner showed a 50% yield advantage over Dixie Runner, Florunner a 20% advantage over Early Runner, and Early Bunch a 10% advantage over Florunner in Florida (5). The largest increment in increased rooting depth occurred between Dixie Runner and Early Runner, while the other cultivars had more roots at 1 m depth than Early Runner. Perhaps improved rooting traits have contributed to increased peanut yields as it has for wheat (9). Bhan (1) reported significant linear correlation between root depth, number of roots, dry weight of roots, and peanut pod yield.

Of 120 other peanut genotypes that have been screened, ten (PI 119075, PI 162596, US 16, US 28, US 29, US 30, US 31, US 32, US 52, and US 105) yielded significantly more shoot dry matter than Starr and seven (PI 162596, US 72, US 86W, US 121D, US 122, US 124, and US 126) had greater root numbers at 1 m depth than Starr (Fig. 1). But in only one case (PI 162596) was greater root number associated with more vigorous shoot growth. The remainder of the genotypes had root lengths shorter or equal to that of Starr. Only one genotype (US 86W) that had root numbers greater than Starr had a root length shorter than Starr. Thus, it appears possible to select for high root numbers without sacrificing root length.

Further tests with additional plant introductions at growth periods of 34 and 47 days (Tables 2 and 3, respectively) showed differences in root length among the genotypes and between genotypes within each botanical classification. None of the entries had more roots at 60 cm depth than the standard cultivar, Tamnut 74, at 34 days (Table 2), but PI 355993 had more roots at 30 cm depth than the other genotypes at 47 days after planting (Table 3). The root counts at 30 and 100 cm were not made for the 34-day test. Differences in shoot height and leaf number (Tables 2 and 3) and dry weight (Table 3) were found among the genotypes, but leaf area differences were statistically significant only among some genotypes within botanical classifications.

Linear correlations between shoot and root growth parameters are given in Table 4 for the 23 genotypes shown in Table 1. Shoot dry weight and leaf area are highly correlated with root length and root numbers (Table 4). Seed weight also was correlated with shoot dry weight, leaf area, and number of roots. However, when the data were analyzed separately for spanish- and virginia-types, some differences were evident. The correlation of leaf area and root numbers was not as strong for spanish-types as it was for virginia-types (Table 5). Root length and numbers were highly correlated for the spanish, but not for virginia selections. Apparently, taproot extension and lateral root growth are not as closely related for virginia as for spanish peanuts. In addition, there was a distinct contrast in the relation of seed weight to shoot and root growth for the two botanical types. Seed weight was only negatively correlated with plant height for the spanish entries (Table 5), while for the virginia entries seed weight was positively correlated with shoot growth (dry weight and leaf area) and number of roots (Table 5). These data suggest that in

Table 4. Correlation matrix for charactristics of 23 peanut lines grown for 55 days in acrylic tubes in a glasshouse at Temple, TX, during October and November, 1979.

	Plant height	Shoot dry wt.	Leaf area	Number of roots	Root length
Shoot dry wt.	-0.204	---			
Leaf area	-0.122	0.849***1/	---		
Number of roots	0.215	0.666***	0.712***	---	
Root length	0.004	0.700***	0.535***	0.522**	---
Seed weight	-0.150	0.627***	0.518**	0.750***	0.353

1/ The symbols ** and *** represent significance of the correlation coefficient at the 5% and 1% levels of probability, respectively.

Table 5. Correlation matrices for characteristics of spanish- and virginia-type peanut lines grown for 55 days in acrylic tubes in a glasshouse at Temple, TX, during October and November, 1979.

Spanish-type	Plant height	Shoot dry wt.	Leaf area	Number of roots	Root length
Shoot dry wt.	-0.060	---			
Leaf area	-0.087	0.673**1/	---		
Number of roots	0.287	0.746***	0.537*	---	
Root length	0.282	0.785***	0.557*	0.784***	---
Seed weight	-0.597**	0.293	0.146	-0.175	-0.136

Virginia-type	Plant height	Shoot dry wt.	Leaf area	Number of roots	Root length
Shoot dry wt.	-0.376	---			
Leaf area	-0.149	0.937***	---		
Number of roots	0.161	0.721**	0.881***	---	
Root length	-0.440	0.660**	0.616**	0.484	---
Seed weight	-0.346	0.764**	0.712**	0.713**	0.423

1/ The symbols *, **, and *** represent significance of the correlation coefficient at the 10%, 5%, and 1% levels of probability, respectively.

initial screening of virginia-type plants for seedling vigor (shoot and root growth) could be based on selection for large seeded genotypes; however, this would not be the case for spanish.

The data from Tables 2 and 3 also showed strong correlations between aspects of shoot and root growth. Leaf area and root length were strongly correlated in both tests (r = 0.91** and 0.76**, respectively, asterisks **, *** indicate 0.05 and 0.01 levels of probability). Root numbers at 30 cm depth (Table 3) also were correlated with leaf area (r = 0.84**), and root length and shoot dry weight (Table 2) were highly correlated (r = 0.92***). However, the correlation of leaf area and root numbers at 60 and 100 cm depths (Table 3) was not statistically significant (r = 0.43 and 0.34, respectively).

Most of the tests reported here were done without supplemental lighting during months of the year with naturally short photoperiods (10 to 11 h). Twelve hour photoperiods were near optimum for growth and development of the spanish-type cultivar Starr. Longer photoperiods (16 h) enhanced shoot growth of Starr while yield of pods and mature seeds was reduced (14). If for most genotypes partitioning of assimilates for root growth occurs in a manner similar to yield, these studies would tend to show the most positive correlation between root and shoot growth that occurs during the life cycle of these plants. Crop establishment is taking place during shorter photoperiods in the spring which could be advantageous for root development of this crop.

Plant water deficits which occur under conditions of low soil moisture limit leaf area development (13). Selections with more extensive root systems should extract more soil water from greater soil volumes than selections with limited root systems. Hence, the former should be able to develop and maintain a greater leaf area during periods of drought.

These studies indicate that there is considerable diversity in root growth among peanut germplasm. As has been reported for wheat (16), oats (4), rice (23), sorghum (3, 12), soybean (26), and some other peanut genotypes (1), there is strong coordination between aerial and subterranean growth. Advantages of extensive root systems that have been reported for other crops include higher yields and better drought tolerance. Selection among peanut genotypes for rooting traits to improve drought tolerance and nutrient uptake should prove advantageous for this crop as well.

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Literature Cited

1. Bhan, S. 1973. Suitable plant type of groundnut (*Arachis hypogaea* L.) for arid zone 2. Root development studies. Oilseeds J. 3:17-22.
2. Blum, A., G. F. Arkin, and W. R. Jordan. 1977. Sorghum root morphogenesis and growth. I. Effect of maturity genes. Crop Sci. 17:149-153.
3. Blum, A., W. R. Jordan, and G. F. Arkin. 1977. Sorghum root morphogenesis and growth. II. Manifestation of heterosis. Crop Sci. 17:153-157.
4. Carrigan, L., and K. J. Frey. 1980. Root volumes of *Avena* species. Crop Sci. 20:407-408.
5. Duncan, W. G., D. E. McCloud, R. L. McGraw, and K. J. Boote. 1978. Physiological aspects of peanut yield improvement. Crop Sci. 18:1015-1020.
6. Dunnett, C. W. 1955. A multiple comparison procedure for comparing several treatments with a control. Amer. Stat. Assoc. J. 50:1096-1121.
7. Hackett, C. 1968. A study of the root system of barley. I. Effects of nutrition and two varieties. New Phytol. 67:287-299.
8. Hurd, E. A. 1964. Root studies of three wheat varieties and their resistance to drought and damage by soil cracking. Can. J. Plant Sci. 44:240-248.
9. Hurd, E. A. 1968. Growth of roots of seven varieties of spring wheat at high and low moisture levels. Agron. J. 60:201-205.
10. Hurd, E. A. 1974. Phenotype and drought tolerance in wheat. Agric. Meterol. 14:39-55.
11. Jenison, J. R., D. B. Shank, and L. H. Penny. 1981. Root characteristics of 44 maize inbreds evaluated in four environments. Crop Sci. 21:233-237.
12. Jordan, W. R., and F. R. Miller. 1980. Genetic variability in sorghum root systems; implications for drought tolerance. pp. 383-399. *In* N. C. Turner and P. J. Kramer (eds.) Adaptation of Plants to Water and High Temperature Stress. John Wiley and Sons, New York.
13. Jordan, W. R. 1982. Whole plant response to water deficits. An overview. *In* H. Taylor, W. Jordan, and T. Sinclair (eds.) Limitations to Efficient Water Use in Crop Production. Amer. Soc. Agron. (In Press)
14. Ketring, D. L. 1979. Light effects on development of an indeterminate plant. Plant Physiol. 64:665-667.
15. Lupton, F. G. H., R. H. Oliver, F. B. Ellis, B. T. Barnes, K. R. Howse, P. J. Welbank, and P. J. Taylor. 1974. Root and shoot growth of semi-dwarf and taller winter wheat. Ann. Appl. Biol. 77:129-144.
16. MacKey, J. 1974. The wheat root. Proc. Fourth Int. Wheat Genetic Symp., Missouri Agr. Exp. Stn., Columbia. pp. 827-842.
17. Milthorpe, F. L., and J. Moorby. 1974. An introduction to crop physiology. Cambridge Univ. Press, Cambridge, 202 pp.
18. Nour, A. E. M., and D. E. Weibel. 1978. Evaluation of root characteristics in grain sorghum. Agron. J. 70:217-218.
19. Quisenberry, J. E., W. R. Jordan, B. A. Roark, and D. W. Fryrear. 1981. Exotic cottons as genetic sources for drought resistance. Crop Sci. 21:889-895.
20. Robertson, W. K., L. C. Hammond, J. T. Johnson, and K. F. Boote. 1980. Effects of plant-water stress on root distribution of corn, soybeans, and peanuts in sandy soil. Agron. J. 72:548-550.
21. Russell, R. S. 1977. Plant root systems: their function and interaction with soil. McGraw-Hill Book Co. (UK), Ltd., 298 pp.
22. Spencer, J. T. 1940. A comparative study of the seasonal root development of some inbred lines and hybrids of maize. J. Agr. Res. 61:521-548.
23. Steponkus, P. J., J. M. Cutler, and J. C. O'Tolle. 1980. Adaptation to water stress in rice. pp. 401-418. *In* N. C. Turner and P. J. Kramer (eds.) Adaptation of Plants to Water and High Temperature Stress. John Wiley and Sons, New York.
24. Subbiah, B. V., J. C. Katyal, R. L. Narasimham, and C. Dakshinamurti. 1968. Preliminary investigations on root distribution of high yielding wheat varieties. Int. J. of App. Rad. Isotopes 19:385-390.
25. Taylor, H. M., M. G. Huck, B. Klepper, and T. F. Lund. 1970. Measurement of soil-grown roots in a rhizotron. Agron. J. 62:807-809.
26. Taylor, H. M., E. Burnett, and G. D. Booth. 1978. Taproot elongation rates of soybeans. Zeit Acker-und Pflanzenbau. 146:33-39.
27. Taylor, H. M., and B. Klepper. 1978. The role of rooting characteristics in the supply of water to plants. Adv. Agron. 30:99-127.

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