CHAPTER III

RELATIONSHIP BETWEEN ROOT CHARACTERISTICS OF PEANUT (*Arachis hypogaea* L.) IN HYDROPONICS AND POT STUDIES

Introduction

Peanut (*Arachis hypogaea* L.) is cultivated widely in rainfed regions of the semiarid tropics where there is a high variation of rainfall and poor rain distribution. Drought is a major constraint limiting productivity and quality of peanut in these areas (Dwivedi et al., 1996; Rao et al., 1985; Ravindra et al., 1990; Wright et al., 1991). Breeding for drought tolerance can increase long-term productivity in drought-prone environments. Breeding approaches utilizing physiological and morphological traits have been proposed to improve selection efficiency for superior drought-tolerant genotypes and to supplement the selection on the basis of yield (Blum, 1988).

Root systems are important plant parts for taking up water and nutrients from the soil and to communicate with shoots to maintain integrated overall plant growth and health. Root responses when soil moisture dries out are important mechanisms for drought avoidance (Ketring, 1984; Songsri et al., 2008). In addition, the ability to extract soil water has been related to improved drought resistance in peanut. Peanut genotypes with large root systems, deeper rooting depth, and high root-to-shoot ratio (RSR) can maintain high plant water status and yield under water stress (Rucker et al., 1995; Songsri et al., 2008). Selection among peanut genotypes for extensive root systems may be effective and valuable for improving drought tolerance (Meisner and Karnok, 1992; Songsri et al., 2008).

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Several methods are available to study roots of different crops in field, pot, and rhizotron, but none of them is without shortcomings. Taking root samples, washing, and measuring are tedious, time consuming, and labor intensive. Timely, labor efficient methods for assessment of peanut root development that are applicable for breeding programs are needed.

Rhizotron and minirhizotron observations are nondestructive methods, thereby allowing repeated observation of roots (Karnok and Kucharski, 1982). Rhizotron facilities are expensive to construct. Furthermore, its operation is difficult and these methods can handle very few plants at any given time. Minirhizotrons are alternative forms of rhizotrons for viewing root growth under field conditions (Ingram and Leers, 2001). They are relatively inexpensive to construct and operate, and facilitate the study of a larger number of genotypes. However, quantifying root production from these observations remains difficult and time consuming (Merrill and Upchurch, 1994).

Hydroponic culture has been reported as a rapid and valuable method for evaluating roots in rice (*Oryza sativa* L.) (Ekanayake et al., 1985; Price et al., 1997), wheat (*Triticum aestivum* L.) (Mian et al., 1993), sorghum (*Sorghum bicolor* [L.] Moench) (Jordan et al., 1979), cowpea (*Vigna unguiculata* [L.] Walp.) (Ogbonnaya et al., 2003), and Kentucky bluegrass (*Poa pratensis* L.) (Erusha et al., 2002). Correlation between root characteristics in hydroponic and soil medium were also evident in wheat and cowpea (Mian et al., 1993; Ogbonnaya et al., 2003). Positive correlations between root fresh-weight of wheat (Mian et al., 1993) and between root volume of cowpea (Ogbonnaya et al., 2003) grown in hydroponic and those traits grown in pot conditions were significant.

Hydroponic culture has been used in peanut (Hill et al., 1992; Pandey and Pendleton, 1986; Stanciel et al., 2000; Zharare et al., 1993; Zharare et al., 1998) and could perhaps be useful in screening large numbers of germplasm lines or segregating populations in a breeding program to reject entries with poor root traits. However, none of the studies with peanuts have examined the relationship between root characteristics of peanut in hydroponic with those observed in pot culture. The objective of this study was to determine the association between root characteristics of peanut grown in hydroponic and in pot studies.

Materials and methods

Three parallel experiments were conducted at the Field Crops Research Station of Khon Kaen University, in Northeast Thailand (16°26' N lat., 102°50' E long, and 190 masl). This included a hydroponic experiment, a small pot, and a large pot experiment with irrigation. All experiments were initiated in the dry season 2004/05 (November 2004 to February 2005) and were repeated in the dry season 2005 (September to December). Twelve peanut genotypes were selected for these studies on the basis of yield their diversity in drought tolerance and root traits. The peanut genotypes comprised eight drought tolerant spanish genotypes from the International Crops Research Institute for the Semiarid Tropics (ICRISAT) (ICGV 98300, ICGV 98303, ICGV 98305, ICGV 98308, ICGV 98324, ICGV 98330, ICGV 98348, and ICGV 98353), one drought tolerant virginia-type (Tifton-8) with a large root system from the United States Department of Agriculture (USDA) (Coffelt et al., 1985), two commercial genotypes from Thailand (the spanish-type Tainan 9 and the Virginia-type KK 60-3), and one non-nodulating line with a small root system (Non-nod). The lines from ICRISAT were identified as drought resistant because they gave high total biomass and pod yield in screening tests under drought-stress conditions (Nageswara Rao et al., 1992; Nigam et al., 2003; 2005). KK 60-3 is sensitive to drought for pod yield, while Tainan 9 is a spanish-type peanut cultivar having low dry-matter production (Vorasoot et al., 2003).

Hydroponic experiment

The twelve peanut genotypes were grown in hydroponic in an open-sided greenhouse. The experiment was laid out in a randomized complete block design with four replications. The hydroponic system consisted of 24 flat containers with dimension of 70 x 325 x 30 cm. Each container was filled with 455 liters of Hoagland solution (Epstein, 1972). The nutrient solution was continuously circulated by an electric pump at a flow rate of 200 L hr^{-1} from reservoirs (3000 L) to the containers. The depth of the solution in the containers was maintained at 20 cm. The solution exceeding 20 cm was drained to the reservoirs by gravity through a PVC pipe. Two air blowers were installed to alternatively supply air to the containers. The nutrient solution was maintained at pH of 6.5 to 6.8 by adding NaOH or HNO_3 Electrical conductivity was maintained between 1100 – 1200 μS cm^{-1} by adding Hoagland stock solution. The temperature was maintained at 25 °C by a heat exchanger installed in the central reservoirs.

Seeds were treated with Captan (Q-Fac Co., Ltd., Pragsa Muang, Samut Prakarn, 10280 Thailand) (N-(trichloromethylthio) cyclohex-4-ene-1,2-dicarboximide 50 %, wettable power) at the rate of 5 g kg^{-1} seed before germination. Seeds of two virginia-type peanut genotypes (KK 60-3 and Tifton-8) were treated with ethrel 48% at the rate of 2 ml L^{-1} water to break dormancy. The seeds were germinated on sterile moist paper. After germination for 4 days or when the seedling showed 3 to 4 centimeters of radical, the seedlings with uniform size were transferred to the hydroponic system. The seedlings were placed on floating foam at a spacing of 20 X 20 cm, with 30 plants per treatment within a replication. Three genotypes were accommodated in a container. Care was taken to avoid root damage during the transfer of the seedling to the floating foam. Pest and diseases were controlled by weekly applications of carbosulfan [2-3-dihydro-2, 2-dimethylbenfuran-7-yl (dibutylaminothio) methylcarbamate 20 % w/v, water soluble concentrate] at 2.5 L ha^{-1}, methomyl [*S*-methyl-*N*-((methylcarbamoyl)oxy) thioacetimidate 40% soluble powder] at 1.0 kg ha^{-1} and carboxin [5, 6-dihydro-2-methyl-1, 4-oxath-ine-3-carboxanilide 75% wettable powder] at the rate of 1.68 kg ha^{-1}. Root data were collected from 4 plants of each plot at 10, 20, 40, 60, 80, 100, and 120 days after transplanting (DAT).

The roots of each plant were kept submerged in water while they were gently separated from those of the neighboring plants. Plants were divided into shoots and roots. The pods which penetrated into the solution were removed before taking shoot dry weight. Roots were washed to remove nutrient solution. Root length, root surface, average diameter of roots, and root volume were recorded with Win RHIZO version Pro (Regent Instruments, Quedec, Canada), an interactive scanner-based image analysis system. Root samples in each sampling date were separated and placed in the plastic tray (0.15 by 0.20 m) in 3 to 4 mm of water, and roots were untangled by hand to minimize overlapping. The tray was placed on the scanner that was linked to a Windows-based PC. The images were scanned through the Win RHIZO system (Costa et al., 2002). Dry matter production of shoots and roots were determined after oven drying for 48 hour at 80 °C.

Small pot experiment

The same twelve peanut genotypes were also grown in pot culture in the greenhouse at the same time as the hydroponic study. The experiment was arranged in a randomized complete block design with four replications each season for two seasons. Each genotype within a replication had five pots with two plant each, for a total of 240 plastic pots. Each plastic pot had a diameter of 23 cm and a height of 30 cm. Each pot was filled with 13.5 kg of Yasothon soil series (pH of 6.65) (Yt: fine-loamy; siliceous, isohypothermic, Oxic Paleustults) to obtain a bulk density of 1.42 g cm^{-3}. Soil texture was a sandy loam (sand 70.0 %, Silt 22.5 %) with low clay content (7.5 %). Water holding capacity of the soil at field capacity (FC) was 12.90 % by weight. Water was applied to the pots to obtain field capacity 1 day before planting, and the soil moisture was maintained at field capacity until harvest. Irrigation was applied regularly to prevent soil moisture from increasing or decreasing by more than 1 % in each pot. Soil moisture was measured by the gravimetric method at planting and five times after planting (20, 40, 60, 80, and 100 days after planting (DAP). The seeds were over-planted at the rate of four seeds per pot at a depth of 5 cm. The seedlings were later thinned to two plants per pot at seven days after emergence.

Nitrogen fertilizer as urea at the rate of 9.20 g N pot^{-1}, phosphorus fertilizer as triple superphosphate at the rate of 12.12 g P pot^{-1} and potassium fertilizer as muriate potash (KCl) at the rate of 15.26 g K pot^{-1} were incorporated into the top of the pot at planting. Seeds were pre-treated with Captan at the rate of 5 g kg^{-1} seed. Seeds of KK 60-3 and Tifton-8 were also treated with ethrel 48% at the rate of 2 ml L^{-1} water to break dormancy. Carbofuran (2, 3-dihydro-2, 2-dimethylbenzofuran-7-ylmethylcarbamate 3% granular) was applied at the pod setting stage. Gypsum ($CaSO_4$) was applied at pegging at a rate of 153.08 g pot^{-1}. Diseases and insect pests were adequately controlled throughout the study. Plants were maintained weed-free by hand weeding.

The amount of water to apply was calculated to meet crop water requirements and surface evaporation using the formula of Doorenbos and Pruitt (1992) and Singh and Russell (1981), respectively. The crop water requirements according to Doorenbos and Pruitt (1992) was calculated as follows:

$$ETcrop = ETo \times Kc$$

where ETcrop is crop water requirement (mm $days^{-1}$), ETo, is the reference evapotranspiration (mm) and was calculated using pan evaporation (mm) data, Kc is the crop water requirement coefficient for peanut depending on genotypes and growth stage. Surface evaporation was calculated according to Singh and Russell (1981) as follows:

$$S.E. = \sum [\beta \times (Eo/t)]$$

where S.E. is soil evaporation, β is light transmission coefficient, Eo is evaporation from class A pan (mm $days^{-1}$), t is days from the last irrigation or rain, Σ is the summation for the soil evaporation from the last irrigation.

For each sampling date, data were collected for the root traits mentioned previously in the hydroponic experiment from two plants of each pot at 10, 20, 40, 60, and 100 DAP. The shoot of each plant in a pot was cut at the soil surface, and the roots of both plants were carefully recovered from the soil by washing gently onto a wire mesh screen. Root length, root surface, average diameter of roots, and root volume were recorded using Win RHIZO version Pro. Pods were removed before taking shoot dry weight. Shoots and roots were then oven dried at 80 °C for 48 hour and weighed.

Large pot experiment

The same twelve peanut genotypes used in the previous studies were also grown in the same greenhouse using larger pots. The experiment was laid out in a randomized complete block design with four replications for two seasons. Ninety six cylinder pots which were 25 cm diameter and 70 cm high were used in this experiment. All pots were filled with 42 kg Yasothon soil series to obtain a bulk density of 1.42 g cm^{-3}. Soil columns were filled up to 60 cm high. Each treatment within the replication had two-pots with two plants in each pot. Three plastic tubes were installed to supply water at 25, 40 and 55 cm from the top of the pot. Agronomic practices were similar to the previous small pot experiment.

Water was applied to the pots to obtain field capacity 1 day before planting. Soil moisture in each pot was maintained at field capacity until harvest. The irrigation was applied regularly to prevent soil moisture from increasing or decreasing by more than 1 % in each pot. Soil moisture was measured by the gravimetric method at planting and five times after planting (20, 40, 60, 80, and 120 DAP). The amount of water to apply to each pot was calculated to meet crop water requirements and surface evaporation using the formula of Doorenbos and Pruitt (1992) and Singh and Russell (1981).

The total amount of water to apply was divided into four portions and supplied to four sections of the soil column in each pot by pouring one at the top surface and pouring the others into the three irrigation tubes. Data were collected from the two plants in each pot for each treatment at 80 DAP and at final harvest. Measurements for shoot and root characteristics were the same as those for the small pot experiment. Shoots and roots were oven dried at 80 °C for 48 hour and weighted.

Statistical analysis

Data were tested for normality of distribution by the Shapiro-Wilks test using Statistix 8 (Analytical Software, Tallahassee, FL, USA) before the statistical analysis. Almost the entire shoot and root characteristics data passed the normality test ($P>0.01$). The data of root-to-shoot ratio in hydroponic (in 2005), large pot (in 2004/05), and small pot (in 2004/05) experiments and the data of shoot dry weight in the small pot experiment (in 2005) were transformed using natural logs because they did not pass the normality test ($P< 0.01$). Shoot and root characteristics were combined over the two years and then analyzed using the SAS PROC MIXED analysis (SAS Statistical Institute, Cary, NC, USA) (SAS, 2003), with genotypes fixed and replications random. Shoot and root characteristics were considered as independent variables and peanut genotypes, years and replications were considered as dependent variable. Differences between genotypes were analyzed with the Least significant difference (LSD) means comparison test at an alpha level of 0.05, as determined by Saxton (1998). Simple correlation was used to determine the relationships between root characteristics of peanut grown in hydroponic, small pot, and large pot experiments and between small pot and large pot experiments.

Results and discussions

The relationship between root characteristics of peanut grown in hydroponic to those grown in soil medium has not been reported in the literature. Genetic variations in root characteristics in peanut have been well-demonstrated in field conditions (Rucker et al., 1995; Songsri et al., 2008), in pot experiments (Ketring, 1984; Rucker et al., 1995), in a rhizotron chamber (Meisner and Karnok, 1992), and in hydroponic (Pandey and Pendleton, 1986). Assessment of root characteristics in hydroponic is easiest, less labor intensive, and most economical. This method would be valuable if it provides information similar to that observed in soil medium.

Hydroponic conditions

Differences in root characteristics under hydroponic conditions among peanut genotypes were found as early as 10 DAT. However, the assessments at later dates (60-120 DAT) had higher genotypic variations than those at early dates (10-40 DAT) (data not shown). In a hydroponic study, Pandey and Pendleton (1986) found substantial genetic variation and also demonstrated that root length and root volume of peanut increased exponentially up to 70 DAP. However, they did not measure root characteristics after 70 DAP. In our study, the growth of all root characteristics showed typical sigmoid curves of plant growth in which the curves reached a plateau between 60-100 DAT and then declined. These results confirm those reported earlier by McCloud (1974) who found a maximum accumulation of dry weight for peanut root systems by 78 DAP. Meisner and Karnok (1992) found that root growth of peanut in soil medium can continue until 110 days after planting. Among the assessments from 60-120 DAT in the present hydroponic study, the assessment at 80 DAT was the best because of high F-ratios and low CVs, and, therefore, this assessment was selected and reported. However, for the experiment in small pots when the assessment at 80 DAP was not available, it was replaced by the best assessment available (100 DAP).

Average shoot dry weights and root-to-shoot ratios in the hydroponic treatment were 21.31 g plant^{-1}and 0.132, respectively (Table 1). Shoot dry weight ranged from 18.80 to 26.39 g plant^{-1} and root-to-shoot ratio ranged from 0.092 to 0.172. KK 60-3 and Tifton-8 had the highest value for shoot dry weight and ICGV 98305 had the highest value for root-to-shoot ratio. ICGV 98300 had the lowest value for shoot dry weight and root-to-shoot ratio.

Among root characteristics evaluated, diameter of roots had the lowest variation, whereas root dry weight, root length, root surface, and root volume could be well-differentiated among the peanut genotypes. Average root dry weight, root length, root surface, average diameter of roots, and root volume was 2.48 g $plant^{-1}$, 10395 cm $plant^{-1}$, 1657 cm^2 $plant^{-1}$, 0.582 mm $plant^{-1}$, and 18.6 cm^3 $plant^{-1}$, respectively.

Root dry weight for all genotypes ranged from 1.64 to 3.35 g $plant^{-1}$ (Table 1). Root length ranged from 6305 to 13851 cm $plant^{-1}$, root surface ranged from 1041 to 2096 cm^2 $plant^{-1}$, average diameter of roots ranged from 0.523 to 0.640 mm $plant^{-1}$, and root volume ranged from 11.5 to 25.7 cm^3 $plant^{-1}$. Among the different genotypes, KK 60-3 and Tifton-8 had consistently higher values for all root characteristics compared to the other genotypes. This could be due to the difference in plant types. KK 60-3 and Tifton-8 are virginia types, while the others are Spanish types. It should be noted that a non-nodulating genotype (referred to hereafter as Non-nod) had the lowest values for root characteristics in this study. Also, in hydroponic culture, all the peanut genotypes did not nodulate, and differences in nitrogen fixation should not have affected the results.

The genotypes with the overall lowest root characteristics were ICGV 98300, ICGV 98324, ICGV98330, ICGV 98348, and non-nod (Table 1). ICGV 98353 had poor root dry weight but had high root length, root surface, average diameter of roots, and root volume. ICGV 98330 exhibited relatively low root dry weight, root length, and root surface but had high average diameter of roots and root volume. ICGV 98303 and ICGV 98305 showed intermediate performance for all root characteristics.

Table 1 Means of shoot dry weight, root dry weight, root-to-shoot ratio, root length, root surface, average diameter of roots, and root volume of 12 peanut genotypes grown in hydroponic culture at 80 days after transplanting in 2004/05 and 2005.

Genotypes	Shoot dry weight (g plant^{-1})	Root dry weight (g plant^{-1})	Root-to-shoot ratio	Root length (cm plant^{-1})	Root surface (cm^2 plant^{-1})	Average diameter of roots (mm plant^{-1})	Root volume (mm^3 plant^{-1})
ICGV 98300	18.80 c †‡	1.64 f	0.092 d	6953 fg	1137 d	0.586 bcde	12.5 e
ICGV 98303	21.48 c	2.88 bc	0.149 ab	12133 bc	1991 ab	0.593 bcd	21.3 b
ICGV 98305	19.63 c	2.94 b	0.172 a	12402 bc	1996 ab	0.606 ab	22.9 ab
ICGV 98308	21.93 bc	2.77 bc	0.151 abc	11901 c	1823 b	0.560 defg	20.6 b
ICGV 98324	20.26 c	2.13 e	0.121 cd	8524 e	1492 c	0.567 cdef	15.6 cd
ICGV 98330	21.31 c	2.24 de	0.114 bcd	7809 ef	1395 c	0.599 bc	16.2 cd
ICGV 98348	19.33 c	2.09 e	0.123 cd	8816 e	1357 c	0.539 fg	13.9 de
ICGV 98353	20.41 c	2.58 cd	0.151 abc	12495 bc	1929 ab	0.581 bcde	21.4 b
Tainan9	21.28 c	2.28 de	0.132 cd	10198 d	1530 c	0.552 efg	16.9 c
KK 60-3	26.39 a	3.09 ab	0.133 abcd	13851 a	2096 a	0.640 a	24.8 a
Tifton-8	25.45 ab	3.35 a	0.153 abc	13350 ab	2094 a	0.640 a	25.7 a
Non-nod	19.37 c	1.72 f	0.095 d	6305 g	1041 d	0.523 g	11.5 e
Mean	21.31	2.48	0.132	10395	1657	0.582	18.6
SE	1.41	0.13	0.03	478.21	74.29	0.02	1.12

† For each genotype, along the column, means followed by the same letter are not significantly different ($P \leq 0.05$) according to Least significant difference (LSD) test.

‡ Mean of each genotype in this column is original mean and the means separation test was performed on the transformed data.

Small pot experiment

Average shoot dry weights and root-to-shoot ratios in the small pot experiment were 9.20 g plant^{-1}and 0.104, respectively (Table 2). Shoot dry weight ranged from 6.50 to 12.91 g plant^{-1} and root-to-shoot ratio ranged from 0.082 to 0.134. Highest values of shoot dry weight were observed for KK 60-3 and Tifton-8. Highest values of root-to-shoot ratio were observed for ICGV 98303, ICGV 98305, ICGV 98353, and Non-nod. Non-nod had the lowest value for shoot dry weight and ICGV 98300 had the lowest value for root-to-shoot ratio. Root dry weight for all genotypes varied from 0.69 to 1.15 g plant^{-1}. Root length varied from 3079 to 5054 cm plant^{-1} while root surface varied from 410 to 637 cm^{2} plant^{-1}. The average diameter of roots varied from 0.445 to 0.653 mm plant^{-1} and root volume varied from 3.3 to 6.0 cm^{3} plant^{-1}. Interestingly, KK 60-3 and Tifton-8, the genotypes that performed well in hydroponic culture also showed high root characteristics in the small-pot study. Similarly, ICGV 98300, ICGV 98324, ICGV98330, ICGV 98348, and non-nod performed poorly in hydroponic and also performed poorly for all characteristics in the small pot study. ICGV 98303, ICGV 98305, ICGV 98308, and ICGV 98353 were grouped to be high for root dry weight, root length, root surface, and root volume. Average root dry weight, root length, root surface, average diameter of roots, and root volume was 0.91 g plant^{-1}, 4045 cm plant^{-1}, 528 cm^{2} plant^{-1}, 0.534 mm plant^{-1}, and 4.75 cm^{3} plant^{-1}, respectively.

Means of root characteristics in the small-pot studies were lower than those observed in hydroponic conditions. In general, the relative performances of all genotypes for root characteristics in the small pot experiment were similar to those in hydroponic culture.

Table 2 Means of shoot dry weight, root dry weight, root-to-shoot ratio, root length, root surface, average diameter of roots, and root volume of 12 peanut genotypes grown in small pot experiment at 100 days after planting in 2004/05 and 2005.

Genotypes	Shoot dry weight (g plant^{-1})	Root dry weight (g plant^{-1})	Root-to-shoot ratio	Root length (cm plant^{-1})	Root surface (cm^2 plant^{-1})	Average diameter of roots (mm plant^{-1})	Root volume (mm^3 plant^{-1})
ICGV 98300	9.70 cde†‡	0.78 de	0.082 e	4040 c	519 c	0.512 d	4.5 ef
ICGV 98303	8.80 def	1.02 b	0.124 ab	4618 b	633 a	0.594 b	5.1 bcd
ICGV 98305	7.75 efgh	1.00 b	0.134 a	4527 b	589 b	0.539 cd	5.6 ab
ICGV 98308	9.55 bc	0.91 c	0.094 e	4343 bc	515 c	0.539 cd	5.1 cd
ICGV 98324	8.52 efg	0.87 c	0.100 de	3098 e	467 de	0.471 e	4.6 e
ICGV 98330	9.25 cde	0.84 cd	0.095 cde	3659 d	470 d	0.457 e	4.7 de
ICGV 98348	7.35 gh	0.73 e	0.105 bcd	3660 d	428 ef	0.445 e	4.0 g
ICGV 98353	7.63 fgh	0.92 c	0.128 ab	4095 c	583 b	0.552 c	4.5 ef
Tainan9	9.77 bcd	0.88 c	0.093 e	3374 de	453 de	0.553 c	4.0 fg
KK 60-3	12.91 ab	1.15 a	0.091 de	4997 a	632 a	0.641 a	5.6 abc
Tifton-8	12.73 a	1.14 a	0.089 e	5054 a	637 a	0.653 a	6.0 a
Non-nod	6.50 h	0.69 e	0.117 abc	3079 e	410 f	0.455 e	3.3 h
Mean	9.20	0.91	0.104	4045	528	0.534	4.75
SE	0.36	0.03	0.02	124.33	14.47	0.01	0.18

† For each genotype, along the column, means followed by the same letter are not significantly different ($P \leq 0.05$) according to Least significant difference (LSD) test.

‡ Mean of each genotype in this column is original mean and the means separation test was performed on the transformed data.

Large pot experiment

The large pot experiment was performed in a greenhouse and peanut genotypes were also maintained under well-watered conditions. Average shoot dry weight and root-to-shoot ratio were 12.35 g plant^{-1}and 0.095, respectively (Table 3). Shoot dry weight ranged from 9.59 to 15.98 g plant^{-1} and root-to-shoot ratio ranged from 0.081 to 0.117. KK 60-3 and Tifton-8 had the highest value for shoot dry weight and ICGV 98353 had the highest value for root-to-shoot ratio. Non-nod had the lowest value for shoot dry weight. ICGV 98348 had the lowest value for root-to-shoot ratio. Root dry weight for all genotypes ranged from 0.93 to 1.43 g plant^{-1}. Root length ranged from 4363 to 6597 cm plant^{-1}. Root surface ranged from 517 to 864 cm^{2} plant^{-1} while average diameter of roots ranged from 0.445 to 0.606 mm plant^{-1} and root volume ranged from 5.0 to 8.8 cm^{3} plant^{-1}. KK 60-3 and Tifton-8 were the highest in root characteristics, whereas non-nod was the lowest. ICGV 98303 and ICGV 98305 exhibited high root length, root surface, root average diameter, and root volume. In general, the performance of peanut genotypes for root characteristics in large pot conditions was quite similar to that of peanut genotypes grown in hydroponic culture and small pots.

The largest root production of peanut genotypes grown in pot conditions were virginia-types followed by spanish types. These results are consistent with those of Ketring (1984) and Rucker et al. (1995) who investigated the root diversity among different peanut genotypes. Root characteristics of peanut were also positively correlated with above ground plant characteristics especially dry weight, leaf area, and leaf number (Ketring, 1984).

Table 3 Means of shoot dry weight, root dry weight, root-to-shoot ratio, root length, root surface, average diameter of roots, and root volume of 12 peanut genotypes grown in large pot experiment at 80 days after planting in 2004/05 and 2005.

Genotypes	Shoot dry weight (g plant^{-1})	Root dry weight(g plant^{-1})	Root-to-shoot ratio	Root length (cm plant^{-1})	Root surface (cm^2 plant^{-1})	Average diameter of roots (mm plant^{-1})	Root volume (mm^3 plant^{-1})
ICGV 98300	13.11 cd †‡	1.06 bcde	0.082 d	5285 de	667 cde	0.526 bc	6.7 bcd
ICGV 98303	11.98 def	1.13 bcd	0.096 bcd	6177 ab	702 bcd	0.542 b	6.3 bcde
ICGV 98305	11.41 ef	1.20 b	0.106 ab	6017 abc	813 ab	0.533 bc	7.6 ab
ICGV 98308	10.59 fg	1.10 bcd	0.105 abc	5757 bcd	706 bcd	0.486 bcd	6.4 bcde
ICGV 98324	12.78 cde	1.13 bc	0.090 bcd	5929 abcd	779 abc	0.525 bc	7.2 abc
ICGV 98330	14.35 bc	1.16 bc	0.081 cd	5839 bcd	738 abcd	0.535 bc	7.3 abc
ICGV 98348	11.53 def	0.93 e	0.081 cd	5384 cde	612 def	0.491 bcd	5.4 de
ICGV 98353	10.54 fg	1.18 bc	0.117 a	5891 abcd	707 bcd	0.477 cd	6.6 bcd
Tainan9	11.29 ef	1.03 cde	0.092 bcd	4744 ef	551 ef	0.460 d	6.0 cde
KK 60-3	15.98 a	1.37 a	0.087 bcd	6408 ab	824 ab	0.542 b	7.9 ab
Tifton-8	15.06 ab	1.43 a	0.095 bcd	6597 a	864 a	0.606 a	8.8 a
Non-nod	9.59 g	0.98 de	0.102 bcd	4363 f	517 f	0.445 d	5.0 e
Mean	12.35	1.14	0.095	5699	707	0.514	6.8
SE	0.61	0.05	0.02	256.38	46.96	0.02	0.62

† For each genotype, along the column, means followed by the same letter are not significantly different ($P \leq 0.05$) according to Least significant difference (LSD) test.

‡ Mean of each genotype in this column is original mean and the means separation test was performed on the transformed data.

Relationship of root characteristics in hydroponic and pot experiments

Relationships between peanut grown in hydroponic and small pots for root dry weight (Figure 1a), root length (Figure 2a), root surface (Figure 3a), average diameter of roots (Figure 4a), and root volume (Figure 5a) were evident. Root characteristics of peanut in hydroponic were positively correlated with root characteristics in small pots (r = 0.74**- 0.93**). The results clearly indicated that root characteristics of peanut grown in hydroponic were closely related with those of peanut grown in small pot conditions and the absolute values of root characteristics in hydroponic were higher than the small pots. However, it is likely that this will be more meaningful if the results were also similar in the large pot experiment

The correlations between root dry weight (Figure 1b), root length (Figure 2b), root surface (Figure 3b), average diameter of roots (Figure 4b), and root volume (Figure 5b) of peanut grown in hydroponic and in the large pot experiment were all significant and positive, ranging from 0.72* to 0.86**. Means of root characteristics in the large pot experiment were lower than those root characteristics of peanut grown in hydroponic conditions, but not much different from those in the small pot experiment.

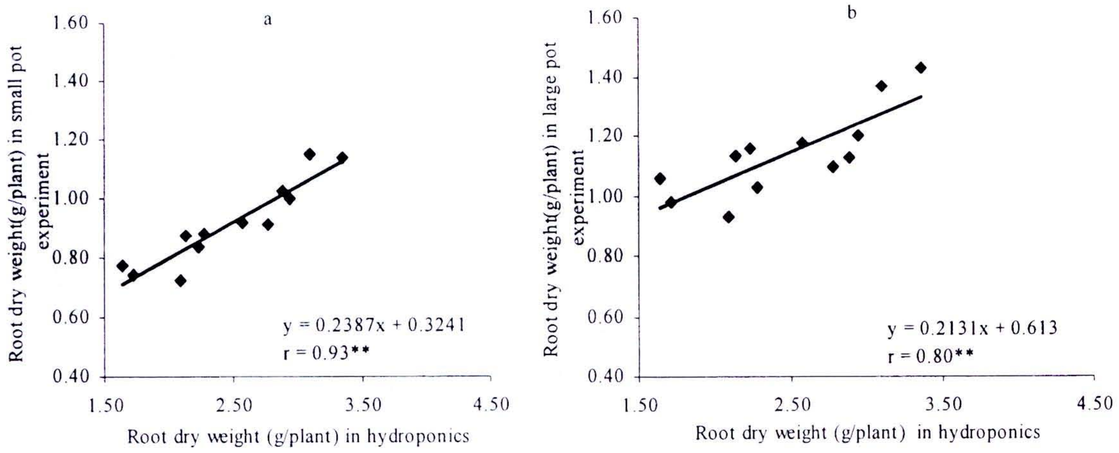
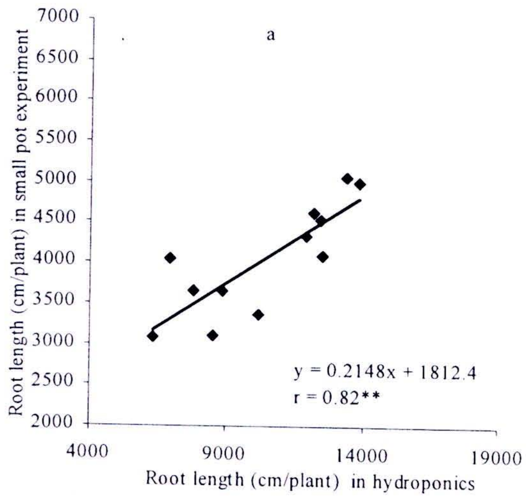


Figure 1 Relationship between root dry weight of peanut grown in hydroponic and small pot experiment (a) and between hydroponic and large pot experiment (b) (n=12).



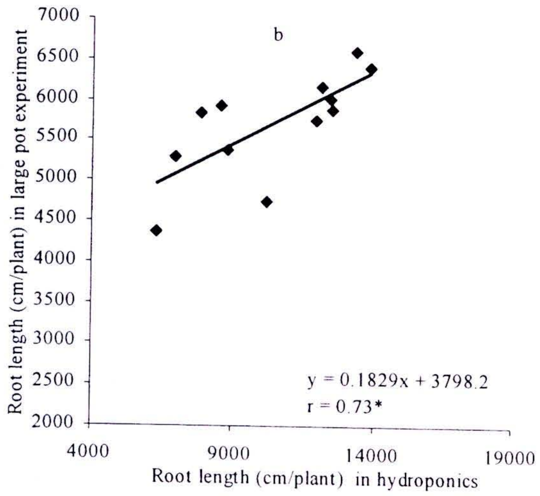
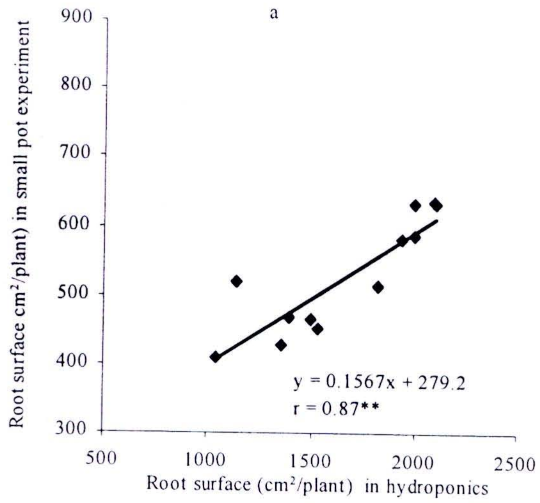


Figure 2 Relationship between root length of peanut grown in hydroponic and small pot experiment (a) and between hydroponic and large pot experiment (b) (n=12).



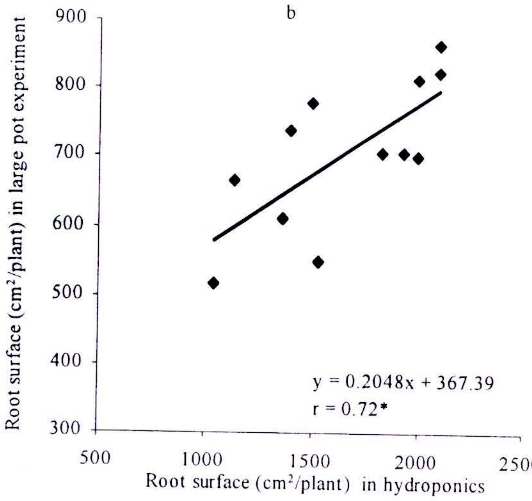


Figure 3 Relationship between root surface of peanut grown in hydroponic and small pot experiment (a) and between hydroponic and large pot experiment (n=12).

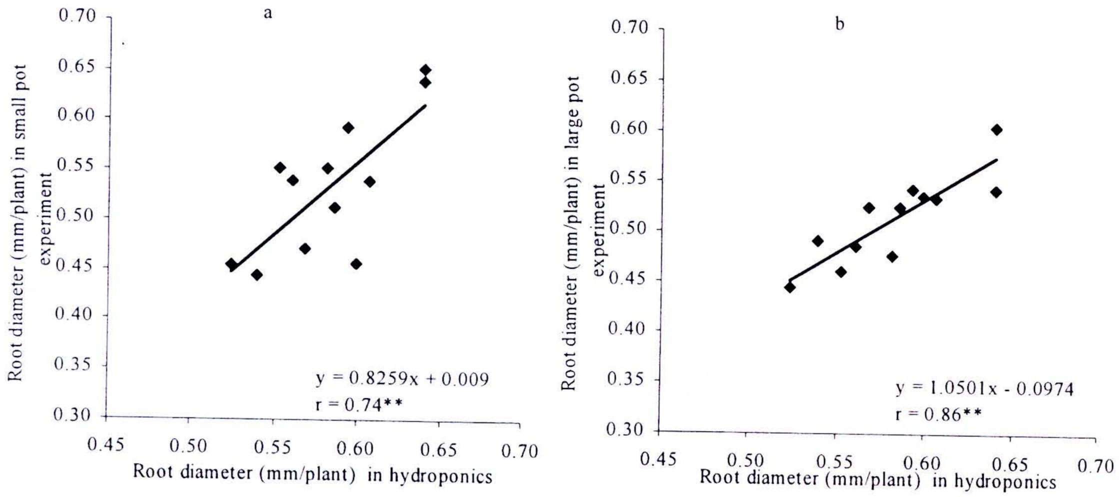


Figure 4 Relationship between root diameter of peanut grown in hydroponic and small pot experiment (a) and between hydroponic and large pot experiment (n=12).

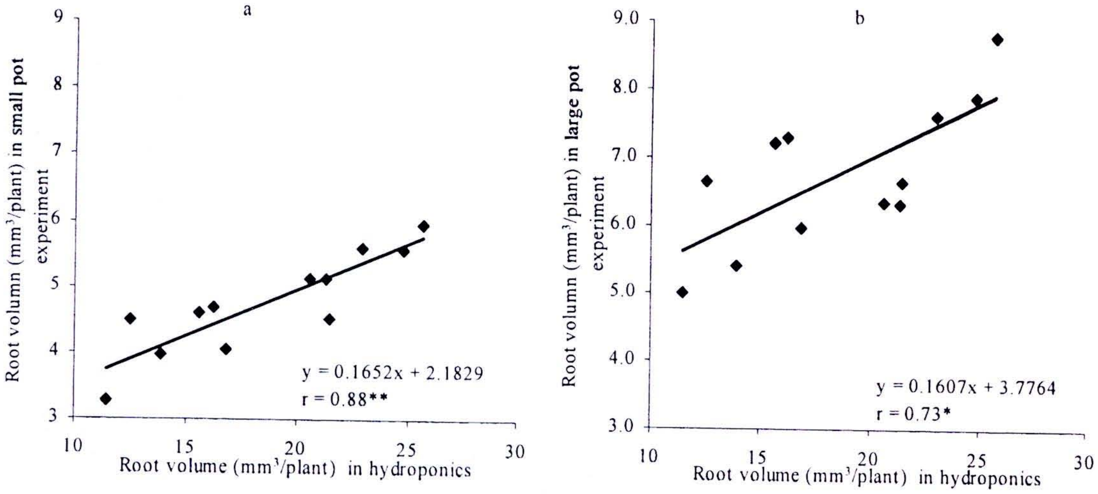


Figure 5 Relationship between root volume of peanut grown in hydroponic and small pot experiment (a) and between hydroponic and large pot experiment (n=12).

Under pot experiments, correlation analysis performed between traits in small pot with those in large pot were significant (r = 0.55* - 0.91**) (Table 4). Root dry weight and average diameter of roots of peanut grown in small pots had moderate positive correlations with those root characteristics of peanuts in large pots (r = 0.55* and 0.66*, respectively). Strong correlations of shoot dry weight, root shoot ratio, root length, root surface, and root volume between peanut grown in small pots and large pots were found.

Table 4 Correlation between root characteristics of peanut grown in small pot and those observed in large pot (n=12).

Small pot experiment	Large pot experiment						
	SDW†	RSR	RDW	RL	RS	ADR	RV
Shoot dry weight	0.83**						
Root-to-shoot ratio		0.91**					
Root dry weight			0.66*				
Root length				0.77**			
Root surface					0.73**		
Average diameter of roots						0.55*	
Root volume							0.88**

† SDW, shoot dry weight; RSR, root-to-shoot ratio; RDW, root dry weight; RL, root length; RS, root surface; ADR, average diameter of roots; RV, root volume.

* and ** significant at $P \leq 0.05$ and significant at $P \leq 0.01$, respectively.

Root characteristics of peanuts grown in hydroponic were highly correlated with those of peanuts grown in both small and large pot conditions. Hydroponic could also replace evaluations in both small pots and large pots if facilities are available. These results imply that hydroponic systems could be used to select peanuts with difference root characteristics, such as root dry weight, root length, root average diameter and root volume instead of selection of peanuts for these characteristics when grown in pots. Similar results have been observed when this issue was investigated using other field crops (Mian et al., 1993; Ogbonnaya et al., 2003). For example in wheat, Mian et al. (1993) found correlations between root and shoot fresh weight in hydroponic and for wheat grown in container with adequate or excess moisture. Their study indicated that the root and shoot growth of wheat in hydroponic culture are to some extent predictive of root and shoot growth in soil medium. Similar results were also observed by Ogbonnaya et al. (2003) who found the selection of cowpea for vigorous growth under well-watered condition could be conducted using hydroponic. In their study, the correlation between root volume of cowpea in hydroponic and pot conditions was significant. They also found significant relationships between water use efficiency of cowpea in field conditions and root biomass, root volume, and shoot biomass in hydroponic. In addition, Ekanayake et al. (1985) observed that root characteristics of rice grown in hydroponic culture were significantly correlated with visual field drought resistance scores and with leaf water potential. The results from those studies concluded that hydroponic could be used for screening cultivars with improved drought tolerance.

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