CHAPTER IV
ROOTING TRAITS OF PEANUT GENOTYPES WITH DIFFERENT YIELD RESPONSES TO PRE-FLOWERING DROUGHT STRESS

Introduction

Peanut is grown widely under rain-fed conditions in the semi-arid tropics. Drought is one of the major constraints, especially during the pod and seed formation stages, and it has been shown to reduce pod yield by 56-85% (Nageswara Rao et al. 1989). However, water stress during the vegetative or early flowering stages is not detrimental and sometimes actually increases yield (Nageswara Rao et al. 1985, Nautiyal et al. 1999).

Most studies have reported on the response of physio-morphological characters of above ground plant components, but there is limited information for root characteristics. Nageswara Rao et al. (1985), and Nautiyal et al. (1999) found that vegetative growth, crop growth rate (CGR), pod growth rate (PGR) and reproductive development were associated with increased yield after pre-flowering drought stress. Awal and Ikeda (2002) reported that chlorophyll concentration, stomatal conductance, photosynthesis and relative growth rate (RGR) increased after re-watering. For root traits of one peanut genotype grown under water deficit during pre-flowering, Nageswara Rao et al. (1989) assumed that the promotion of root growth during drought stress was an important character contributing to the increased yield, but they did not measure root growth.

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Drought resistance might be increased by improving the ability of the crop to extract water from the entire soil profile (Wright and Nageswara Rao, 1994). Rucker et al. (1995) found that some peanut genotypes that had a large root system (root dry weight) under non-stress conditions produced a higher yield under drought conditions and they suggested that these genotypes could possess drought avoidance traits. Rooting depth, root distribution and root length density (RLD) have been identified as drought avoidance traits (Passioura 1983, Turner 1986, Matsui and Singh 2003, Taiz and Zeiger 2006). However, Robertson et al. (1980) found no significant difference in rooting density of peanut cultivar Florunner under both irrigated and non-irrigated treatments. In contrast, Pandey et al. (1984) reported that drought increased root length density of a peanut genotype in the bottom part of the soil profile. Peanut genotypes that have a higher root length density in deeper soil layers have an enhanced drought tolerance, which can result in a higher pod yield and harvest index under long-term drought conditions (Songsri et al., 2008). Thus, root traits may be associated with differential yield responses to pre-flowering drought stress.

So far information about root response of peanut under pre-flowering drought conditions has been very limited in the literature. Awal and Ikeda (2002), who only studied one peanut genotype grown in containers, reported that drought significantly enhanced the root to shoot ratio which accelerated post-stress recovery. Meisner and Karnok (1992), who investigated root growth of a peanut genotype in a rhizotron chamber, found that the root growth rate was significantly reduced during stress from 20 to 50 days after planting (DAP) compared to non-stressed conditions under sufficient irrigation. After recovery, early drought-stressed peanut had more root growth than the non-stressed peanut of the control treatment. Most recently, Puangbut et al. (2009) reported differential pod yield responses to early season drought for six peanut genotypes under field conditions. However, the mechanisms underlying yield responses of these peanut genotypes have not been well understood because there was no information on rooting traits under these conditions. The results reported so far have been limited to experiments under greenhouse conditions and with a only a few peanut genotypes.

Roots could play an important role for yield increase in response to early season drought in peanut. Information on the responses of root characteristics of

diverse peanut genotypes to pre-flowering drought under field conditions is still lacking and further investigations are necessary. Therefore, the goal of this study was to investigate the responses of root dry weight and root length density of peanut genotypes having different yield responses to pre-flowering drought stress and their relationships with pod yield.

Materials and Methods

Experimental details

Six peanut genotypes (KK 60-3, Tainan 9, Tifton-8, ICGV 98305, ICGV 98324 and ICGV 98330), differing in yield response to early season drought were selected from the study conducted by Puangbut et al. (2009). The genotypes ICGV 98305, ICGV 98324 and ICGV 98330 were provided by International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) and have been reported to be drought resistant. Tifton-8 is a drought resistant Virginia-type peanut developed by the United States Department of Agriculture (USDA; Coffelt et al., 1985). KK 60-3 and Tainan 9 are high yielding cultivars that have been released in Thailand. Puangbut et al. (2009) found that the six genotypes could be separated into four different groups based on yield response to pre-flowering drought. The genotypes KK 60-3 and Tifton-8 were classified as having a highly positive response with significant yield increase. ICGV 98330 was classified as having a slight increase in pod yield. Tainan 9 and ICGV 98324 were classified as non-responsive, while ICGV 98305 was classified as having a reduction in pod yield.

Field experiments were conducted at the Field Crop Research Station of Khon Kaen University, Khon Kaen, Thailand (lat 16° 28′ N, long 102° 48′ E, 200 masl) from February to July, 2007 and from February to July, 2009. The experimental sites in the two seasons were adjacent fields. The soil type was a Yasothon series (Yt: fine-loamy; siliceous, isohypothermic, Oxic Paleustults). A split-plot experiment in a randomized complete block design with four replications was used. Two water management treatments were assigned as main plots and six peanut genotypes as sub-plots. The water management treatments were field capacity (FC) and pre-flowering drought (PFD). The FC treatment was maintained at FC from planting to harvest. For

the PFD treatment, irrigation was withheld from 1 to 25 DAE. After this stress period, the PFD treatment was irrigated to FC, and the soil moisture content was maintained at FC until harvest. Rainout shelters were used to shield the PDF plots from rain. Plot size was 18.2 m^2 consisting of a seven-row plot with a 5.2 m row length. The spacing between rows was 50 cm and the spacing between plants was 20 cm for a plant density of 10 plants m^2.

Crop management

The soil was sub-soiled to break-up the hard pan that was present in the top 60 cm of the soil profile. Disc plowing was performed three times to prepare the individual plots for the experiment. Lime ($CaCO_3$) at a rate of 625 kg ha^{-1} was incorporated into the soil during soil preparation. Nitrogen fertilizer in the form of urea was applied at a rate of 23.4 kg N ha^{-1}, phosphorus fertilizer as triple superphosphate was applied at a rate of 24.7 kg P ha^{-1} and potassium fertilizer as potassium chloride was applied at a rate of 31.1 kg K ha^{-1} shortly prior to planting. Gypsum ($CaSO_4$) was applied to the soil surface at a rate of 312 kg ha^{-1} at 45 DAE. Seeds were treated with Captan (3a, 4, 7, 7a-tetrahydro-2-[(trichloromethyl)thio]-1H-isoindole-1, 3(2H)-dione) at a rate of 5 g kg^{-1} seed before planting. The seeds were over-planted, and the seedlings were thinned to one plant per hill at 7 days after emergence (DAE).

Carbofuran (2,3-dihydro-2,2-dimethyl benzofuran-7-ylmethylcarbamate 3 % granular) was applied at the pod setting stage. Pest and diseases were controlled by weekly applications of carbosulfan [2-3-dihydro-2,2-dimethylbenzofuran-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 1.68 kg ha^{-1}.

A drip-irrigation system was installed prior to planting and each plot was supplied with sufficient water to reach field capacity (FC) up to a depth of 60 cm. Soil moisture content was maintained uniformly at FC from planting to 50% emergence for the latest emerging line for all treatments. After emergence, the non-stressed treatment was maintained at FC until harvest. For the stressed treatment, irrigation

was withheld starting at 1 DAE. As a result, the soil moisture content gradually decreased. After a stress period of 25 days, the stressed plots were irrigated to FC, and the soil moisture content was maintained at FC until harvest. A schematic presentation of soil moisture content for two water regimes is provided in Figure 1.

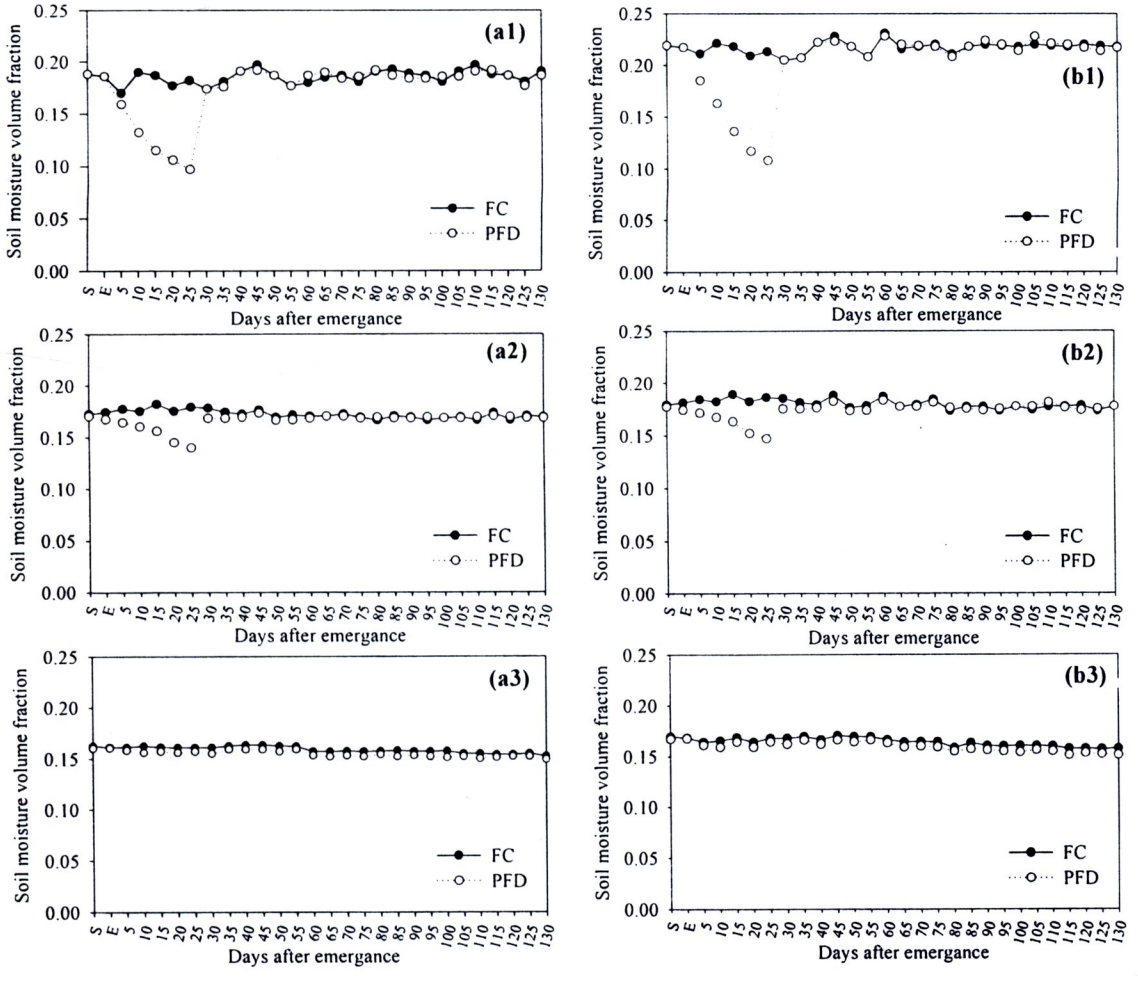

Figure 1 Volumetric soil moisture (fraction) in two water regimes as well-watered (FC;●) and pre-flowering drought (PFD;○) the experiments were conducted at the Field Crop Research Station of Khon Kaen University, Thailand during February-June 2007 (1st season) at 30 cm (a1), 60 cm (a2) and 90 cm (a3) of the soil level and repeated during February-June 2009 (2nd season) at 30 cm (b1), 60 cm (b2) and 90 cm (b3) of the soil level.

For treatment that had sufficient water, the soil water content was maintained uniformly at FC from planting until harvest, and moisture content was controlled with

no more than 1% moisture change from FC using a gravimetric sample at 25, 30, and 50 DAE and at final harvest to check whether the water treatments were providing sufficient water (Table 1). The amount of water that was applied was calculated using crop water requirement as described by Doorenbos and Pruitt (1992). However, our previous study found that the amount of water that was applied based on this methodology could not maintain the soil moisture content at FC, resulting in a soil moisture content that was less than FC. Therefore, the amount of water that was applied was based on crop water requirements using the Doorenbos and Pruitt (1992) methodology along with water loss from surface evaporation as described by Singh and Russel (1981). Thus, the amount of water that was supplied was calculated as the sum of crop water requirement and soil evaporation, and soil moisture content was determined using the gravimetric method.

Crop water requirement based Doorenbos and Pruitt (1992) was calculated as shown in Equation 1

$$ETcrop = ETo \times Kc, \qquad \text{Equation 1}$$

where, ETcrop = crop water requirement (mm/day), ETo = evapotranspiration of a reference crop under specified conditions calculated by pan evaporation method, Kc = the crop water requirement coefficient for peanut, which varied depending on growth stage (initial stage (1-15 DAE) Kc = 0.40, development stage (15-45 DAE) Kc = 0.70, mid-season (45-75 DAE) Kc = 0.95 and late season (75 DAE-harvest) Kc = 0.70).

Surface evaporation was calculated as (Singh and Russel, 1981):

$$Es = \beta \times (Eo/t) \qquad \text{Equation 2}$$

where, Es = soil evaporation (mm), ß = light transmission coefficient measured depending on crop cover, Eo = evaporation from class A pan (mm/day), t = days since the last irrigation (days).

Table 1 Soil moisture percentage (%) at 25 day after emergence (DAE), 30 DAE, 50 DAE and harvest under well-watered (FC) and pre-flowering drought (PFD) experiments conducted at the Field Crop Research Station of Khon Kaen University, Thailand during February-June 2007 (season 1) and in 2009 (season 2).

		Soil moisture percentage (%)			
Treatments	**Seasons**	**25 DAE**	**30 DAE**	**50 DAE**	**Harvest**
FC	Season 1	10.67	10.93	10.87	10.33
	Season 2	10.53	11.62	11.27	11.80
PFD	Season 1	6.06	11.14	10.36	10.74
	Season 2	6.75	11.55	10.55	10.84

FC level of season 1 = 10.44% and season 2 = 11.26% using pressure plate method.

Soil moisture content and meteorological conditions

Soil moisture content was determined using gravimetric method at planting, 25, 30, and 50 DAE and at final harvest at depths of 0-5 ,10-15, 25-30, 40-45, 55-60, 70-75 and 85-90 cm to verify that the irrigation treatments provided sufficient water. Soil moisture content was also measured with a neutron probe (Type I.H. II SER. No N0152, Ambe Diccot Instruments CO.Ltd., England). An aluminum access tube was installed between rows in each plot. Neutron probe readings were conducted at a depth of 30, 60 and 90 cm (30 cm intervals) at 5 day intervals throughout the course of the experiment. Rainfall, relative humidity (RH), evaporation (E_0), maximum and minimum temperature and solar radiation were recorded daily from sowing until harvest at a weather station located at a distance of 100 m from the experimental field.

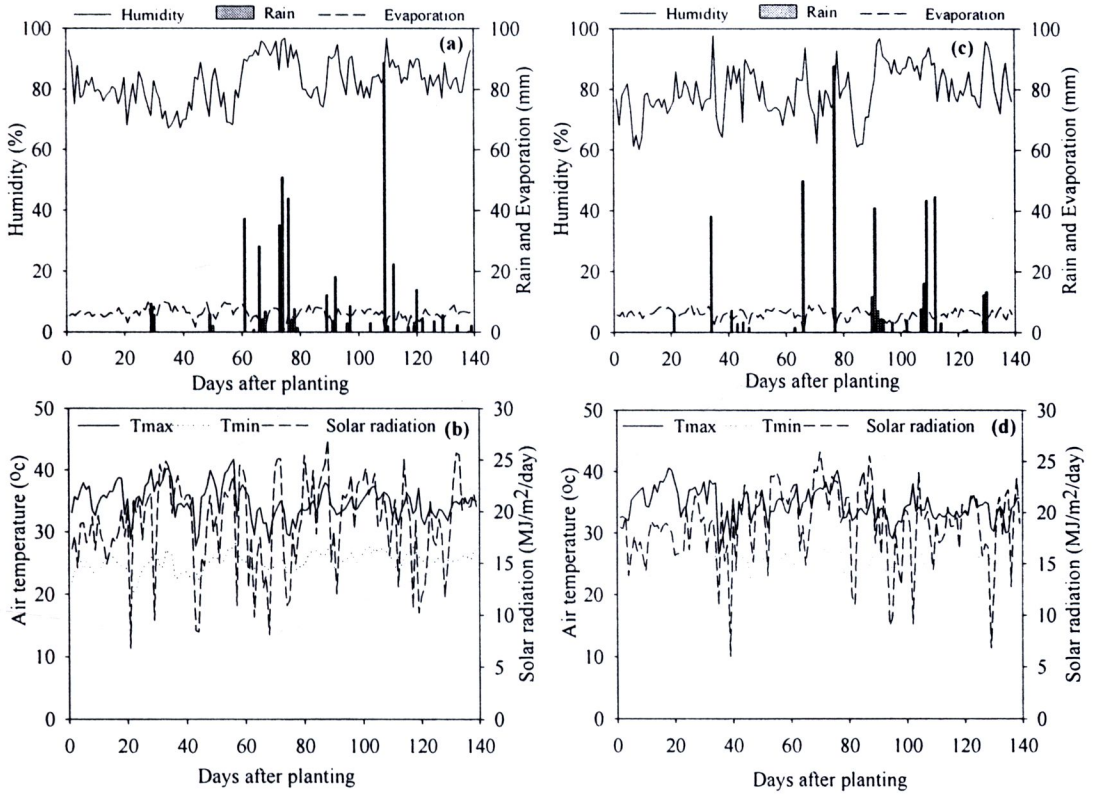

Figure 2 Rainfall, humidity (RH), evaporation (E0), maximum (T-max) and minimum (T-min) temperature and solar radiation during February-June 2007(a,b) and 2009 (c,d) at the meteorological station, Khon Kaen University, Thailand.

Root traits

Root length density (RLD) was measured at 25 DAE, at first seed (R5; 53-59 DAE) and at physiological maturity (R7; 79-91 DAE) (Boote 1982) using an auger. The auger consisted of a coring tube (Welbank et al. 1974) with a diameter of 76 mm and a length of 1.15 m. The sampler was designed to reduce compaction in the inner tube by improving the cutting edge and reducing the tube thickness (Welbank et al. 1974, Ford et al. 2006). Two positions were collected, including the center of plant and the position between two row positions at a distance of 22.5 cm from each plant. Root samples were taken to a depth of 90 cm and separated into six layers consisting of 0-15, 15-30, 30-45, 45-60, 60-75 and 75-90 cm. Root samples of each layer were washed manually with tap water to remove soil from the roots. The root samples were then analyzed with the Winrhizo program (Winrhizo Pro (s) V. 2004a, Regent

Instruments, Inc) to determine total root length per sample. RLD was calculated as the ratio between root length (cm) and soil volume (cm^3). RLD from the first (0–15 cm) and second (15–30 cm) layers were combined and defined as a single 0 to 30 cm layer or upper soil layer, while the RLD for the deeper layers (third to sixth) were combined to form a single 30 to 90 cm layer or lower soil layer. RLD was combined as upper and lower layers depending on tillage layer and differential soil moisture contents. The upper layer was defined as disc plowing layer, and soil moisture content of the two water regimes were clearly different at a soil depth of 30 cm (Figure 1). By contrast, the lower soil layer was defined as non tillage layer, and differences in soil moisture content between two treatments were small at 60 cm and soil moisture content was not significantly different at 90 cm (Figure 1).

Root dry weight was determined at 25 DAE, R5 (53-59 DAE) and R7 (79-91 DAE) using the monolith method for one plant per plot. The size of monolith was 50 x 20 cm with a depth of 50 cm. The roots were removed from the monolith soil sample using the same method described previously for the core sample. The root samples were oven-dried at 80 C^o for 48 hours or until constant weight and root dry weight was determined.

Biomass, pod yield and pod harvest index (PHI)

Biomass samples, including shoots, roots (not available at final harvest) and pods (available at R7 and harvest only), were obtained at 25 DAE, R5 (53-59 DAE) and R7 (79-91 DAE) and harvest (112-132 DAE). Five plants in each plot were harvested. The sample was oven-dried at 80 ^oC for 48 hrs or until constant weight and dry weight was measured. Biomass was then calculated and used in determining the total biomass per unit land area. At final harvest, a total area of 7.5 m^2 was harvested from each plot. The pods were removed from the plants and air-dried to approximately 8% moisture content and pod dry weight determined. Shoot fresh weight from the harvested plants was determined, oven-dried, and weighed. PHI was calculated as pod dry weight per unit total biomass at harvest.

The drought tolerance index (DTI) was computed for pod yield, biomass, PHI, root dry weight and root/shoot ratio by comparing values under stress treatment to

values for the field capacity treatment as suggested by Nautiyal et al. (2002) (more than 1= increased, less than 1 = decreased).

DTI = Data of stress treatment / Data of non stress treatment.

Statistical analysis

The statistical analysis was conducted using MSTAT-C package (Bricker, 1989). The measured data were subjected to analysis of variance according to a split plot design. Error variances for the two years were tested for homogeneity using the Bartlett's test (Gomez and Gomez 1984), and then data for each year were analyzed separately because the G x E interaction for all variables was significant (data not shown). Therefore, the results of each variable are shown for each year. The comparison between two means of each genotype under two water regimes for all parameters was done based on the Least Significant Difference (LSD) test (Gomez and Gomez 1984).

Results and Discussion

Meteorological conditions and soil moisture content

The first experiment was conducted from February to June 2007. The average air daily temperature ranged from 25.2 to 34.9°C during the growing season (Figure 2). Total rainfall during the drought-stress period was 15.1 mm, while total rainfall after the drought-stress period was 428.2 mm. The second experiment was conducted from February to June 2009. The average air daily temperature ranged from 24.9 to 34.5°C during the growing season (Figure 2). Total rainfall during the drought-stress period was 6.2 mm, while total rainfall after the drought-stress period was 414.9 mm. Due to the rain both experiments required the use of the rainout shelter during the water stress period. While the rainfall was large after the pre-flowering drought stress, this occurred after 25 DAE and, therefore, did not affect growth during the drought-stress period.

Soil moisture content of the two water regimes during both seasons was clearly different at a soil depth of 30 cm (Figure 1). The differences were small at 60 cm and soil moisture content was not significantly different at 90 cm. The

differences in soil moisture content between the two water regimes decreased with the depth of the soil profile. The soil moisture content measurements also confirmed adequate control of the irrigation applications.

The responses to pre-flowering drought conditions for yield and pod harvest index

The peanut genotypes were categorized into three groups based on the responses to pre-flowering drought for pod yield using the comparison between two means of water regime treatments of each genotype based on the LSD at $p<0.05$. The drought tolerance index (DTI) is the ratio of pod yield for pre-flowering drought treatment to pod yield for the non-stressed treatment, and this was used to represent the response.

In both seasons, ICGV 98305 was classified as an increasing genotype with a pod weight DTI of 1.53 for the first season and 1.36 for the second season (Table 2). There were significant increases for pod yield under PFD conditions of ICGV 98305 compared to sufficient water conditions. Tainan 9 and ICGV 98324 showed an increase in pod yield under pre-flowering drought conditions. However, pod yield under PFD conditions compared to non-water stress conditions for Tainan 9 was only significantly greater for the first season and the DTI of this genotype was 1.41. For ICGV 98324, there was a significant increase in pod yield under pre-flowering drought conditions in the second season and the DTI of this genotype was 1.57, but was not in the first season. ICGV 98330 was classified as decreasing in the first season and the DTI was 0.76. However, the second season was not significant, but it seemed likely that the response of this genotype could be classified as decreasing. KK 60-3 and Tifton-8 were non responsive genotypes (Table 2).

Table 2 Pod dry weight (kg/ha) and pod harvest index (PHI) of six peanut genotypes grown under well-watered (FC) and pre-flowering drought (PFD) experiments conducted at the Field Crop Research Station of Khon Kaen University, Thailand during February-June 2007 (season 1) and in 2009 (season 2).

Cultivar	Season	Water regime	Pod dry weight (kg/ha)	PHI
ICGV 98305	season 1	FC	1086b	0.103b
		PFD	1659a	0.161a
		DTI	1.53	1.56
	season 2	FC	1089b	0.114b
		PFD	1487a	0.166a
		DTI	1.36	1.45
Tainan 9	season 1	FC	1635b	0.171
		PFD	2308a	0.226
		DTI	1.41	1.32
	season 2	FC	1626	0.207
		PFD	1886	0.233
		DTI	1.16	1.13
ICGV 98324	season 1	FC	1739	0.181
		PFD	2145	0.221
		DTI	1.23	1.22
	season 2	FC	1141b	0.157
		PFD	1795a	0.197
		DTI	1.57	1.26
KK 60-3	season 1	FC	2321	0.176
		PFD	2528	0.193
		DTI	1.09	1.09
	season 2	FC	1549	0.194
		PFD	1521	0.176
		DTI	0.98	0.91
Tifton-8	season 1	FC	1567	0.152
		PFD	1338	0.118
		DTI	0.85	0.77
	season 2	FC	879	0.096
		PFD	1106	0.098
		DTI	1.26	1.02
ICGV 98330	season 1	FC	2060a	0.197
		PFD	1574b	0.159
		DTI	0.76	0.81
	season 2	FC	1515	0.196
		PFD	1272	0.158
		DTI	0.84	0.81

Different letters adjacent to data of a cultivar within a season in the same column show significance at $P < 0.05$ by LSD

DTI = drought tolerance index (stress/FC; more than 1= increased, less than 1 = decreased)

The responses of pod yield between Puangbut et al. (2009) and this study were different for the peanut genotypes that were selected based on the Puangbut et al. (2009) study. This could be due to the differences of the drought stress treatments. In Puangbut et al. (2009), irrigation was withheld from emergence onward until soil moisture content was reduced to 1/3 available water (1/3 AW; soil moisture content for AW was the values between FC and permanent wilting point that were proportional to soil moisture at FC) and the soil moisture was maintained at this level until 40 DAE. In this experiment, soil moisture was allowed to decline from emergence until 25 DAE. As no water was supplied during the drought period, the soil moisture content in this study was lower than 1/3 AW. The soil moisture content at 1/3 AW in these experiments was 6.63% in 2007 and 7.06% in 2009. On the most stressed date soil moisture content at the 0 to 30 cm soil depth was 6.06 and 6.75% in 2007 and 2009, respectively (Table 1). After re-watering to FC the soil moisture content of the PFD treatment were 11.14 % and 11.55 % in 2007 and 2009 by 30 DAE, respectively, and 10.36 % and 10.55 % in 2007 and 2009 by 50 DAE, respectively, (Table 1) The soil moisture content percentages measured after drought period showed values close to field capacity, e.g. 10.44 % and 11.26 % (Table 1). Drought in this study was similar to a naturally occurring drought in that it was rather severe and over a shorter period than the experiment of Puangbut et al. (2009).

Although some peanut genotypes had increased pod yield after early drought conditions, this was not true for all the genotypes in this study. Peanut genotypes have different yield response to pre-flowering stress. A similar drought tolerance response of ICGV 98305 was observed by Wunna et al. (2009) who showed that only the genotype ICGV 98305 out of eleven genotypes gave a higher pod yield after early drought stress. Songsri et al. (2008) studied the responses of reproductive traits in peanut genotypes to long-period drought stress and found that the genotype ICGV 98305 showed a small reduction in pod yield reduction under drought stress. Therefore this genotype has good maintenance of pod productivity when subject to drought stress.

In this study, at growth stage 25 DAE, R5 and R7 when growth analysis samples were collected, there was no genotype which showed consistent responses of biomass, to pre-flowering drought (Table 3). The short period of drought in this study

might not have affected total biomass, but only affected partitioning to root growth. A similar result was presented by Nautiyal et al. (1999). Meisner and Karnok (1992) reported that water stress during vegetative phase did not significantly affect leaf and stem dry weight.

At final harvest in both seasons, ICGV 98305 was the only genotype that showed significantly higher pod harvest index (PHI) under pre-flowering drought compared to FC (Table 2). A similar higher PHI under a long period of drought stress conditions has also previously been reported for ICGV 98305 (Songsri et al., 2008). Wunna et al. (2009) found that ICGV 98305 had a higher PHI after early drought stress. This confirms the consistency of performance of this genotype under drought stress conditions. The harvest index has been identified as a drought resistance trait in peanut (Nigam et al. 2003, 2005), and the ability to partition dry matter into harvestable yield under limited water supply is an important trait for drought tolerant genotypes (Chapman et al., 1993).

The responses of rooting traits to pre-flowering drought conditions

The genotypes of the different groups had differential responses for root dry weight and RLD. At 25 DAE, there was a tendency of higher root mass under PFD conditions than under well irrigated conditions. However, ICGV 98305, Tainan 9 and KK 60-3 showed a significantly higher root mass under PFD treatment than under well-irrigated treatment during the first season (Table 4). For the second season, at 25 DAE, ICGV 98305 and ICGV 98324 had a higher root dry weight under pre-flowering drought conditions. Those genotypes that were classified as having an increase in pod yield in the PFD treatment compared to the non-stressed treatment were generally the same as the genotypes that showed a response of root dry weight by the end of the PFD period. The significant differences in root dry weight existed at 25 DAE only as these significant differences did not persist for the root dry weights observed at R5 and R7 (*data not shown*).

Table 3 Biomass (kg/ha) of six peanut genotypes grown under well-watered (FC) and pre-flowering drought (PFD), measured at 25 day after emergence (DAE), first seed (R5; 53-59 DAE) and beginning maturity (R7; 79-91 DAE) at the Field Crop Research Station of Khon Kaen University, Thailand during February-June 2007 (season 1) and in 2009 (season 2).

Cultivar	Season	Water regime	Total crop biomass (kg/ha)		
			25 DAE	R5	R7
ICGV 98305	season 1	FC	578	2622	7264
		PFD	687	3263	7041
		DTI	1.19	1.24	0.95
	season 2	FC	559	2316	4345
		PFD	523	1718	3208
		DTI	0.94	0.74	0.74
Tainan 9	season 1	FC	614b	2770	7133
		PFD	794a	3393	7212
		DTI	1.29	1.23	1.02
	season 2	FC	652	3196a	8493a
		PFD	591	1947b	6594b
		DTI	0.91	0.61	0.64
ICGV 98324	season 1	FC	489b	2722	7796
		PFD	648a	2878	7119
		DTI	1.33	1.06	0.85
	season 2	FC	463	2257a	7302
		PFD	401	1013b	6006
		DTI	0.87	0.45	0.68
KK 60-3	season 1	FC	642	3201	8853a
		PFD	744	3398	6774b
		DTI	1.16	1.06	0.63
	season 2	FC	588	2327	7402
		PFD	545	1810	6652
		DTI	0.93	0.78	0.82
Tifton-8	season 1	FC	661	3690	7849
		PFD	712	3426	7058
		DTI	1.08	0.93	0.83
	season 2	FC	544	2279	6950
		PFD	533	2374	7645
		DTI	0.98	1.04	1.19
ICGV 98330	season 1	FC	558b	2610b	7103
		PFD	734a	3799a	7630
		DTI	1.31	1.46	1.14
	season 2	FC	435	1336	6165
		PFD	575	2390	7321
		DTI	1.32	1.79	1.39

Different letters adjacent to data of a cultivar within a season in the same column show significance at $P < 0.05$ by LSD

DTI = drought tolerance index (stress/FC; more than 1= increased, less than 1 = decreased)

Only the genotype ICGV 98305 had a higher root/shoot ratio under pre-flowering stress conditions when compared to normal conditions at 25 DAE, and its DTI values for root/shoot ratio were 1.80 and 1.69 for the first and second season, respectively (Table 4). For the genotypes ICGV 98324, ICGV 98330, Tifton-8, Tainan 9 and KK 60-3, the root/shoot ratios of the stressed treatment were not statistically different from the root/shoot ratios under well-watered conditions. A larger root/shoot ratio of peanut in response to drought stress conditions results from partitioning a larger proportion of assimilates to roots during this drought-stressed period compared to non-stressed conditions. Peanut appears to adapt to drought conditions by increasing root length to mine more available water (Alycmeny, 1997; Mayaki et al., 1976). Similar observations have also been reported in rice (Nemoto et al., 1998; Kondo et al., 2003), chickpea (Kashiwagi et al. 2006), cowpea (Matsui and Singh 2003), and soybean (Hoogenboom et al., 1987; 1988). The differences among peanut genotypes in response to early season drought in this study provide useful information, and suggest the value of selecting peanut genotypes with high root/shoot ratio for drought resistance breeding.

The value of a large root system related to pod yield has been well demonstrated in peanut. Rucker et al. (1995) found that some peanut genotypes with large root system (root dry weight) under non-stress conditions gave higher yield under drought conditions. Moreover, root dry weight was highly correlated to shoot dry weight, leaf area and number of leaves (Ketring, 1984). However, a deeper root system that contributes to maintaining yield under drought stress conditions has not been clearly demonstrated. A larger root system alone may not contribute much to pod yield if the increase in roots is not distributed into wetter or deeper soil. The response of RLD if into deeper soil layers may allow plants to be able to mine more available water in the sub-soil (Songsri et al., 2008).

At 25 DAE, the root distribution sampled at the center of the plant position was not significantly different between genotypes receiving different water treatments (*data not shown*). In Arabidopsis, mild drought stress had relatively little effect on the growth of primary roots (Xiong et al., 2006). In this study, pre-flowering drought might have slightly affected the RLD distribution of primary root. Therefore, RLD at the center of the plant position did not differ between the two water management

treatments. On the other hand, there were significant differences between the two water management treatments in root distribution sampled at the inter-row position (Table 4). The responses for root distribution sampled at the inter-row position were quite similar to those for root dry weight. For RLD of the upper soil layer (0-30 cm), only ICGV 98305 had a higher RLD under the water stress treatment than normal conditions. For the deeper soil layer (30-90 cm), ICGV 98305 and Tainan 9 had a significantly higher RLD under drought than under well-watered conditions in season 1 (DTI = 4.09 and 3.12 respectively). In season 2, ICGV 98305, ICGV 98324 and KK 60-3 had a significantly higher RLD under pre-flowering drought conditions (DTI = 7.24, 9.02 and 3.47 respectively). RLD at inter-row position and in deeper soil layer may be involved with differential yield responses to pre-flowering drought stress. Other studies have shown that drought increased root length density in the lower soil profile of peanut (Pandey et al., 1984). The peanut genotypes that had a higher root length density in the deeper soil layers potentially have an enhanced drought tolerance and this could aid peanut genotypes to obtain higher pod yield and harvest index under long-term drought conditions (Songsri et al., 2008).

The RLD differences occurred only at 25 DAE, and the differences did not persist up to R5 and R7. Based on this finding, greater RLD at inter-row position and in deeper soil layer is one important factor which may increase pod yield under pre-flowering drought stress. Since the effect is relatively minor in terms of total dry matter shift to roots in the deeper layer, the mechanism may be as much as modifying plant growth regulator regulation of partitioning as it is in the uptake of water from the deeper soil layers (Songsri et al., 2008).

In this study, average RLD at the 0-90 cm soil profile might be one factor affecting harvested yield even though some of the soil depth layers did not show significant differences in RLD under sufficient and stressed water treatment. However, there was a tendency of greater average RLD at the 0-90 cm soil profile in the PFD increasing pod yield group, and this remained high even after re-watering (Figure 3). On the other hand, the decreasing yield genotype such as ICGV 98330, had lower average RLD at R7 under PFD than in the sufficient irrigation treatment (Figure 3). In chickpea, Kashiwagi et al. (2006) studied variability of root length density and reported that average RLD at the 0-60 cm soil profile was highly

correlated with seed yield under sufficient water conditions. However, pod yield is a complex trait resulting from the contribution of many genetic characteristics, which may influence PHI (Chapman et al. 1993, Songsri et al. 2008, Wunna et al. 2009), vegetative growth, reproductive development (Nageswara Rao et al. 1985, Nautiyal et al. 1999), and transpiration efficiency (Puangbut et al, 2009). Therefore rooting is only one important trait contributing to pod yield.

Table 4 Root dry weight (RDW), root shoot ratio (R/S ratio) and root length density (RLD) in deeper soil layer (30-90 cm) at inter-row position at 25 day after emergence (DAE) of six peanut genotypes grown under well-watered (FC) and pre-flowering drought (PFD) at the Field Crop Research Station of Khon Kaen University, Thailand during February-June 2007 (season 1) and in 2009 (season 2).

Cultivar	Season	Water regime	RDW(kg/ha)	R/S ratio	RLD (cm/cm^3)
ICGV 98305	season 1	FC	64b	0.130b	0.024b
		PFD	135a	0.234a	0.098a
		DTI	2.12	1.80	4.09
	season 2	FC	92b	0.175b	0.026b
		PFD	103a	0.296a	0.195a
		DTI	1.13	1.69	7.24
Tainan 9	season 1	FC	83b	0.103	0.023b
		PFD	132a	0.168	0.074a
		DTI	1.58	1.63	3.12
	season 2	FC	100	0.197	0.011
		PFD	102	0.268	0.036
		DTI	1.02	1.36	3.34
ICGV 98324	season 1	FC	85	0.208	0.026
		PFD	79	0.138	0.062
		DTI	0.93	0.66	2.40
	season 2	FC	92b	0.272	0.019b
		PFD	100a	0.298	0.179a
		DTI	1.10	1.10	9.02
KK 60-3	season 1	FC	59b	0.159	0.009
		PFD	108a	0.199	0.03
		DTI	1.83	1.25	3.18
	season 2	FC	100	0.153	0.074b
		PFD	99	0.217	0.258a
		DTI	0.99	1.42	3.47
Tifton-8	season 1	FC	99	0.174	0.057
		PFD	127	0.215	0.078
		DTI	1.29	1.23	1.38
	season 2	FC	95	0.238	0.034
		PFD	100	0.266	0.102
		DTI	1.06	1.12	3.02
ICGV 98330	season 1	FC	71	0.147	0.061
		PFD	91	0.140	0.048
		DTI	1.27	0.95	0.784
	season 2	FC	93	0.253	0.020
		PFD	97	0.209	0.041
		DTI	1.05	0.83	2.01

Different letters adjacent to data of a cultivar within a season in the same column show significance at $P < 0.05$ by LSD

DTI = drought tolerance index (stress/FC; more than 1= increased, less than 1 = decreased)

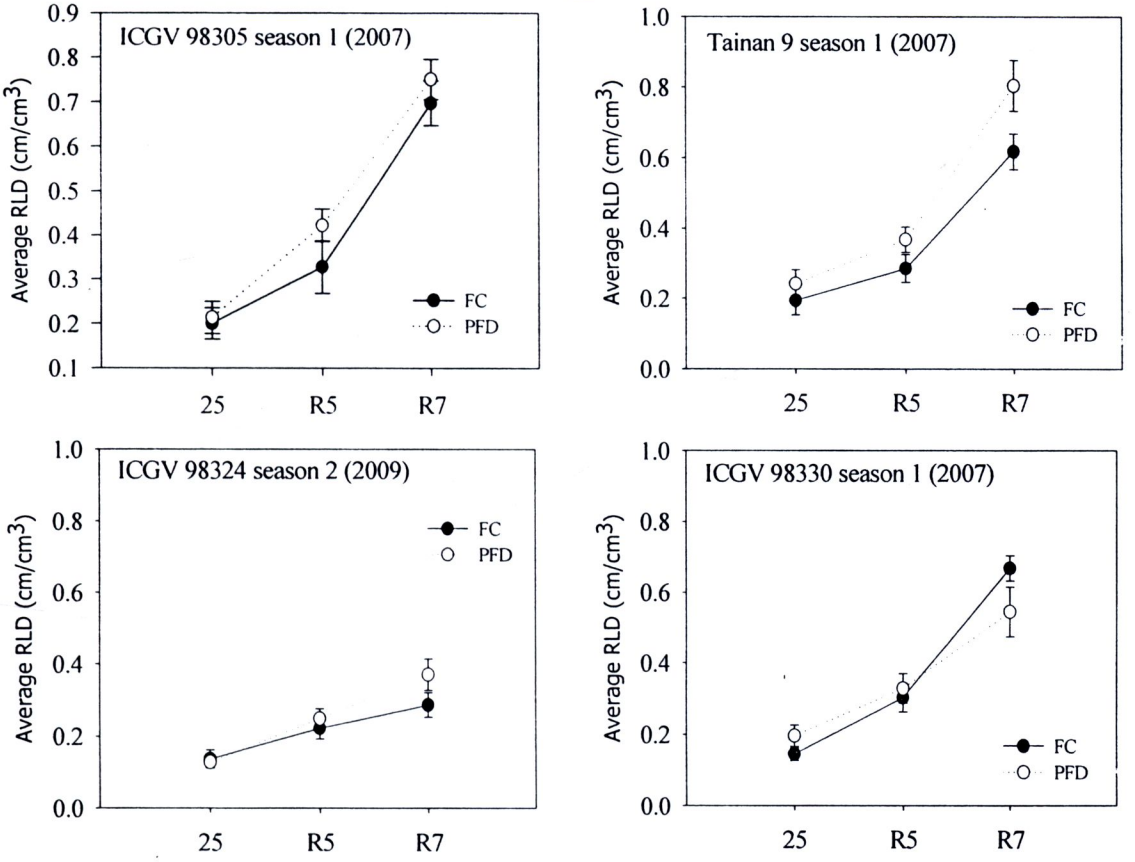

Figure 3 Average root length density (RLD) at the 0-90 cm soil profile of some peanut genotypes, measured over time, at 25 day after emergence (DAE), first seed (R5; 53-59 DAE) and beginning maturity (R7; 79-91 DAE) under well-watered (FC;●) and pre-flowering drought (PFD;○) experiments conducted at the Field Crop Research Station of Khon Kaen University, Thailand during February-June 2007 (season 1) and in 2009 (season 2).

Conclusions

In summary, peanut genotypes were classified into three groups based on the pod yield responses to pre-flowering drought, e.g. increasing, decreasing and non responsive yield groups. The genotypes in different groups had differential responses for root quantity and distribution. In the group with increased pod yield, such as ICGV 98305, root dry weight and root length density were greater in deeper soil layer in pre-flowering stress compare with non-stress treatment. In the genotype with

decreased pod yield, ICGV 98330 had small increase in root dry weight and root length density at deeper soil layer. Larger root system alone may not contribute much to pod yield if the large root portion is not distributed into moist soil. The response of RLD might allow plants to be able to mine more available water in sub-soil. However, PHI is also an important outcome for drought resistance. As yield is a complex result of many mechanisms and traits, root dry weight and RLD may be only two of several factors contributing to PHI and pod yield under PFD. The knowledge of responses of root traits and relationships with pod yield will be useful for breeding of peanut for pre-flowering drought environment.

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