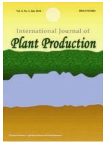

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Responses of rooting traits in peanut genotypes under pre-flowering drought stress

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Abstract

The root is an important plant part contributing to peanut productivity under water-limited conditions. Root volume, root surface area and root diameter may be characters responding to pre-flowering drought (PFD) in peanut. The objectives of this study were to investigate the responses to PFD for root surface area, root volume and root diameter and to determine the inter-relationships among the response of rooting traits and the response of yield. The experiment was conducted under field conditions in the dry season 2007 and 2009. A split-plot experiment in a randomized complete block design was used. The main plots were field capacity (FC) and PFD and six peanut genotypes as the sub-plots. Root volume, root diameter and root surface were measured by auger method at 25 days after emergence (DAE), first seed (R5) and physiological maturity (R7). Total dry weight and pod yield were measured at harvest. Root surface area of ICGV 98305 with increase in pod yield was greater in deeper soil layers under PFD compared to FC treatment at both stress and recovery periods. Under PFD conditions, the correlations between drought tolerance index (DTI) for root surface area at deeper soil layer and DTI for pod yield in both seasons were positive and significant at stress and recovery periods, but the correlations were not significant for root diameter and root volume. The response of peanut for root surface area at deeper soil layer contributed to pod yield. This finding could be useful for peanut production in these drought conditions.

Keywords: Early season drought; Drought tolerance index; Root volume; Root diameter; Root surface area.

Introduction

In peanut (*Arachis hypogaea* L.), water stress during the early season normally is not detrimental and sometimes actually increases pod yield. The responses of peanut genotypes have been reported for physio-morphological characters of above ground plant parts (Nageswara Rao et al., 1985; Nautiyal et al., 1999; Awal and Ikeda, 2002; Puangbut et al., 2009). Puangbut et al. (2011a) revealed that SPAD chlorophyll meter reading (SCMR) and harvest index were important traits contributing to pod yield of peanut under early drought condition. Ability of peanut genotypes to improve transpiration efficiency and water uptake under early drought condition were associated with high nitrogen fixation and contributed to pod yield (Puangbut et al., 2011b). The ability to maintain high N_2 fixation under drought conditions could also improve resistance to aflatoxin contamination (Arunyanark et al., 2012) and contribute to biomass production and water use efficiency (Pimratch et al., 2013). Moreover, root characters such as root dry weight and root length density were defined as important traits for response to early season drought in peanut and also contributed to yield (Jongrungklang et al., 2011). Hence, root traits are related to peanut productivity under water-limited conditions.

However, other rooting traits such as root volume, root surface area and root diameter may also be important characters in response to early season drought in peanut. In sugarcane, biomass and water use efficiency were positively correlated with root surface area and volume after re-watering conditions (Jangpromma et al., 2012). For legumes, chick pea and field pea response to drought conditions was associated with increased proportion of root surface area and root weight into deeper soil layers, but the response was not present in soybean (Benjamin and Nielson, 2006).

In comparison for root characters of 12 peanut genotypes grown in hydroponics, small pots and large pots, roots of peanut genotypes grown in hydroponics were positively correlated with those of peanut genotypes grown in pots Girdthai et al. (2010). Peanut genotypes increased root length density in lower soil layers in response to long duration drought conditions (Songsri et al., 2008), mid season drought conditions (Jongrungklang et al., 2012) and pre-flowering drought conditions (Jongrungklang et al., 2011). Under long duration drought, moreover, root dry weight, root length, root surface area and root volume were positively correlated with each other and these traits were also positively correlated with biomass production under pot conditions, but not pod yield (Painawadee et al., 2009). However, these rooting traits and correlations were mostly studied under well-irrigated and drought condition and the responses to PFD for these traits have not been reported.

Currently, information on the responses of root surface area, root volume and root diameter of diverse peanut genotypes to PFD under field conditions is still lacking and further investigations are necessary. In addition, the relationships among the response of root surface area, root volume and root diameter and the response of yield to PFD has been very limited in the literature. Thus, the objectives of this study were to investigate the responses to PFD for root surface area, root volume and root diameter and to determine the inter-relationships among the response of rooting traits and the response of yield. The information should be useful for a better understanding of the responses of peanut cultivars to PFD and it could help peanut production in these conditions.

Materials and Methods

Experimental details

Field experiments were conducted for two years (February-July 2007 and repeated February-July 2009) at the Field Crop Research Station of Khon Kaen University, Khon Kaen, Thailand (lat 16° 28´ N, long 102° 48´ E, 200 masl). The experiment was laid out in a split-plot design in a randomized complete block design with four replications. Two water regime managements (FC and PFD) were assigned as main plots and six peanut genotypes with different yield response to PFD (Jongrungklang et al., 2011) were assigned in sub-plots. Soil moisture in the FC treatment was controlled at FC from planting to harvest. Irrigation was withheld from 1 to 25 DAE for PFD treatment and, after the stress period, irrigation was continued at FC until harvest. Peanut was planted at a spacing of 50x20 cm (10 plants per m^2). Seven-row plots with a 5.2 m row length were used, as a plot size of sub plot was 18.2 m^2.

Crop management

Subsoiler was used to break up hard pan to the depth of 60 cm prior to planting. Disc plowing was performed three times to prepare the soil for the experiment. During soil preparation, lime ($CaCO_3$) was incorporated into the soil at a rate of 625 kg ha^{-1}. Urea was applied at a rate of 23.4 kg N ha^{-1}, phosphorus fertilizer as triple superphosphate was applied at the rate of 24.7 kg P ha^{-1} and potassium fertilizer as potassium chloride was applied at the rate of 31.1 kg K ha^{-1} shortly prior to planting. Seeds were treated with Captan (3a, 4, 7, 7a-tetrahydro-2-[(trichloromethyl)thio]-1H-isoindole-1, 3(2H)-dione) at the rate of 5 g kg^{-1}. Three seeds were planted per hill and the seedlings were thinned to one plant per hill at 7 DAE. Gypsum ($CaSO_4$) was applied to the soil surface at the rate of 312 kg ha^{-1} at 45 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 the rate of 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}.

Each plot was irrigated at FC to the depth of 60 cm by drip-irrigation system. Soil moisture content was maintained uniformly at FC for all treatments from planting to 50% emergence. After emergence, FC treatment was maintained at FC until harvest, irrigation was withheld for PFD treatment for 25 days starting at 1 DAE to 25 DAE. As a result, the soil moisture content of stressed treatment was gradually decreased. After a stress period of 25 DAE, PFD plots were re-irrigated to FC and maintained at FC until harvest. The amount of water supplied was calculated using crop water requirement and surface evaporation as described by Songsri et al. (2008) and Jongrungklang et al. (2011).

Soil moisture content

Neutron probe (Type I.H. II SER. N° NO 152, Ambe Diccot Instruments CO. Ltd., England) was used for measurement of soil moisture content. In each sub-plot, an aluminum tube was installed and 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.

The data of soil moisture content indicated that the control of soil moisture at FC and PFD in this experiment was reasonably good, as were revealed in Jongrungklang et al. (2011). Soil moisture volume fractions for FC were quite constant across the experiment, whereas the moisture volume fractions for PFD treatment were gradually decreased after withholding irrigation. After re-watering, the soil moisture volume fractions of PFD treatment were increased to reach FC treatment. The differences in soil moisture content between FC and PFD treatments were clearly shown at a soil depth of 30 cm, whereas the differences were small at 60 cm and the differences between soil moisture content at FC and stressed treatment were not significant at 90 cm.

Relative water content (RWC)

Five plants in each plot were randomly chosen and the second fully-expanded leaves from the top of the main stems were used for determination of relative water content. The leaves were detached from the plants at 10:00-12:00 am and fresh weight was recorded in laboratory. The leaves were soaked in distilled water for 8 h, blotted at the outer surface and then saturated leaf weight was determined. The leaves were then oven-dried at 80 °C for 48 hours or until constant weight and leaf dry weight was recorded. RWC was calculated using the expression suggested by Barrs and Weatherley (1962).

In previous work, peanut genotypes were not significantly different for leaf relative water content in response to pre-flowering drought at early days after withholding of water, but differential responses were observed at about 20 days after withholding of water (Jongrungklang et al., 2013). The authors found during stress period that the reductions in relative water content in all peanut genotypes as affected by pre-flowering drought were observed and the differences were faded out after re-watering. In addition, Jongrungklang et al. (2013) also found that ICGV 98305, ICGV 98324 and ICGV 98330 had small reduction in RWC for PFD stress.

Root traits

Root surface area, root volume and root diameter were measured at 25 DAE, at first seed growth stage (R5; 53-59 DAE) and at physiological maturity growth stage (R7; 79-91 DAE) (Boote, 1982) using an auger with coring tube of 76 mm in diameter and 1.15 m in length (Welbank et al., 1974). The tube was designed for reduction of soil compaction by improving the cutting edge and reduction of the tube thickness (Welbank et al., 1974; Ford et al., 2006). Roots were sampled at two positions, including the center of the plant and the position between rows. Root samples were collected 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. Soil and debris were removed by washing the roots in tap water and then define root volume, root diameter and root surface area were determined using Winrhizo program (Winrhizo Pro (s) V. 2004a, Regent Instruments, Inc). Rooting traits from 0-15 cm and 15-30 cm soil depth layers were combined and identified as a single upper soil layer (0-30 cm), while the root data for each corresponding trait from 30-90 cm were combined to form a single lower soil layer.

Biomass and pod yield

Biomass samples, including shoots and pods, were recorded at 25 DAE, R5 and R7 from five plants in each plot. Shoot samples were oven-dried at 80 ^{o}C for 48 h or until constant weight and then dry weight was determined. Total dry weight was then calculated and used for calculation of biomass per plant. At final harvest (112-132 DAE), a total area of 7.5 m^2 was harvested from each plot. The pods were removed from the plants and sun-dried to approximately 8% moisture content, pod dry weight of total pods was determined and then pod dry weight per plant was calculated.

Drought tolerance index

Drought tolerance index (DTI) was computed for pod yield, root surface area root volume and root diameter by comparing means under stress treatment to means 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

Analysis of variance was performed for each character in each year according to a split plot design and error variances were tested variance homogeneity of two year data using Bartlett's test (Gomez and Gomez, 1984). All analyses were carried out using MSTAT-C package (Bricker, 1989). The data were reported separately for each year because of significant genotype by year interaction for all variables (data not shown), and Least Significant Difference (LSD) test was used to compare mean differences under two water regimes for all traits (Gomez and Gomez, 1984). Simple correlation was used to determine the relationship among DTI of rooting traits in lower soil layer and DTI of pod yield.

Results

The responses of rooting traits to PFD at stress period

At 25 DAE, ICGV 98305 showed a significantly higher root surface area at lower soil layer under PFD treatment than under non-stress treatment in both seasons, whereas other genotypes did not showed consistent responses of all root characteristics on this study (Table 1). In addition, the genotypes with increased pod yield in response to PFD were generally the same as the genotypes that presented a response of root surface area by the end of the PFD period. ICGV 98324, ICGV 98330, Tifton-8, Tainan 9 and KK 60-3 did not show significant differences between root surface area under PFD and root surface area under non-stress conditions. ICGV 98324, ICGV 98330, Tifton-8, Tainan 9 and KK 60-3 did not respond to pre-flowering drought for root surface area and pod yield. Peanut genotypes showed different response to PFD for root diameter and root volume. However, all genotypes did not show consistent responses of root diameter and root volume at 25 DAE (Table 1).

The responses of rooting traits to PFD at recovery period

At R5 growth stage, water treatments were not significantly different for root traits in upper 30-cm soil layer (Table 2). ICGV 98305 and Tainan 9 showed a higher root surface area, root diameter and root volume in deeper soil layer under PFD treatment than under sufficient water treatment in the first season, whereas the differences in these traits were not significant in the second season. Positive and significant relationships between the responses for pod yield and root traits were observed in the first season. The differences between PFD treatment and FC treatment were not significant for root surface area in ICGV 98324, ICGV 98330, Tifton-8, Tainan 9 and KK 60-3 (Table 2). These genotypes did not respond to pre-flowering drought for root surface area and they also did not respond for pod yield. The results imply that adaptation in root traits in response to PFD could improve pod yield.

At R7 growth stage, the plants had sufficiently long time for recovery. Peanut genotypes grown under PFD were not statistically different from those grown under FC for root traits in both soil layers (Table 3). The results indicate high recovery ability of peanut genotypes after drought and this should be largely due to root response to drought.

Table 1. Root surface area, root diameter and root volume in upper soil layer (0-30 cm) and deeper soil layer (30-90 cm) 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	Upper layer (0-30 cm)			Lower layer (30-90 cm)		
			root surface area	root diameter	root volume	root surface area	root diameter	root volume
ICGV98305	season 1	FC	34.37	0.382	0.362	8.15[b]	0.323	0.097
		PFD	27.88	0.396	0.289	11.67[a]	0.365	0.115
		DTI	0.81	1.04	0.80	1.43	1.13	1.18
	season 2	FC	27.07	0.444[a]	0.3141	7.69[b]	0.372[a]	0.091
		PFD	24.93	0.337[b]	0.2724	12.85[a]	0.319[b]	0.140
		DTI	0.92	0.76	0.87	1.67	0.86	1.55
ICGV98324	season 1	FC	31.12	0.366	0.321	8.70	0.329[b]	0.086
		PFD	29.48	0.409	0.312	9.19	0.416[a]	0.085
		DTI	0.95	1.12	0.97	1.06	1.26	0.99
	season 2	FC	22.95	0.376	0.2676	11.20	0.380	0.139
		PFD	29.21	0.426	0.3912	16.92	0.382	0.135
		DTI	1.27	1.13	1.46	1.51	1.01	0.97
ICGV98330	season 1	FC	22.00	0.408	0.255	6.23	0.341	0.068
		PFD	29.83	0.407	0.304	6.25	0.367	0.090
		DTI	1.36	1.00	1.19	1.00	1.08	1.32
	season 2	FC	26.75	0.451	0.3309	11.75	0.378[a]	0.136
		PFD	23.16	0.372	0.2985	7.22	0.310[b]	0.082
		DTI	0.87	0.83	0.90	0.61	0.82	0.60
KK60-3	season 1	FC	33.26	0.426	0.400	5.25	0.294	0.052
		PFD	29.58	0.406	0.309	4.94	0.326	0.038
		DTI	0.89	0.95	0.77	0.94	1.11	0.72
	season 2	FC	36.03	0.466	0.433	7.01	0.321	0.079
		PFD	26.05	0.418	0.340	6.54	0.336	0.075
		DTI	0.72	0.90	0.79	0.93	1.05	0.96
Tainan 9	season 1	FC	36.07	0.393	0.379	5.55	0.312	0.048
		PFD	37.41	0.383	0.376	7.21	0.317	0.068
		DTI	1.04	0.98	0.99	1.30	1.02	1.40
	season 2	FC	27.68	0.391	0.295	7.43	0.343	0.085
		PFD	31.08	0.364	0.327	5.60	0.314	0.067
		DTI	1.12	0.93	1.11	0.75	0.92	0.79
Tifton-8	season 1	FC	32.05	0.423	0.388	7.51	0.325	0.077
		PFD	31.47	0.434	0.370	7.19	0.353	0.075
		DTI	0.98	1.03	0.96	0.96	1.09	0.98
	season 2	FC	26.99	0.433	0.349	7.38	0.345	0.091
		PFD	26.39	0.458	0.350	11.61	0.367	0.143
		DTI	0.98	1.06	1.00	1.57	1.06	1.57

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).

Table 2. Root surface area, root diameter and root volume in upper soil layer (0-30 cm) and deeper soil layer (30-90 cm) at R5 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	Upper layer (0-30 cm)			Lower layer (30-90 cm)		
			root surface area	root diameter	root volume	root surface area	root diameter	root volume
ICGV98305	season 1	FC	38.90[b]	0.328	0.364	13.88[b]	0.286[b]	0.109[b]
		PFD	55.30[a]	0.360	0.514	17.15[a]	0.311[a]	0.146[a]
		DTI	1.42	1.10	1.42	1.24	1.09	1.33
	season 2	FC	76.34	0.4062	0.8161	18.99	0.364	0.197
		PFD	78.61	0.4109	0.8616	21.93	0.394	0.216
		DTI	1.03	1.01	1.06	1.15	1.08	1.10
ICGV98324	season 1	FC	42.23	0.370	0.419	15.09	0.315	0.131
		PFD	43.16	0.393	0.487	16.62	0.320	0.128
		DTI	1.02	1.06	1.16	1.10	1.01	0.98
	season 2	FC	45.97	0.4523	0.5973	9.29	0.363	0.097
		PFD	48.48	0.4558	0.5947	11.94	0.404	0.126
		DTI	1.05	1.01	1.00	1.28	1.11	1.30
ICGV98330	season 1	FC	38.00	0.367	0.395	13.64	0.332	0.125
		PFD	44.55	0.399	0.487	10.41	0.324	0.114
		DTI	1.17	1.09	1.23	0.76	0.98	0.92
	season 2	FC	49.33	0.4344	0.6286	9.13	0.333[b]	0.103
		PFD	42.74	0.4564	0.5405	8.59	0.409[a]	0.136
		DTI	0.87	1.05	0.86	0.94	1.23	1.32
KK60-3	season 1	FC	51.16	0.381	0.531	15.32	0.313	0.136
		PFD	43.44	0.383	0.493	14.33	0.301	0.102
		DTI	0.85	1.01	0.93	0.93	0.96	0.75
	season 2	FC	58.55	0.4728	0.7410	13.96	0.400	0.164
		PFD	61.50	0.4448	0.7652	11.89	0.327	0.121
		DTI	1.05	0.94	1.03	0.85	0.82	0.74
Tainan 9	season 1	FC	37.99	0.353	0.365	11.24[b]	0.283[b]	0.086[b]
		PFD	43.83	0.388	0.442	15.79[a]	0.305[a]	0.132[a]
		DTI	1.15	1.10	1.21	1.40	1.08	1.54
	season 2	FC	56.17	0.4242	0.6169	11.41	0.341	0.117
		PFD	53.55	0.4088	0.5919	13.05	0.333	0.132
		DTI	0.95	0.96	0.96	1.14	0.98	1.13
Tifton-8	season 1	FC	58.14	0.353	0.586	19.44	0.293[b]	0.165
		PFD	50.94	0.377	0.522	19.59	0.322[a]	0.165
		DTI	0.88	1.07	0.89	1.01	1.10	1.00
	season 2	FC	68.13	0.4536	0.8675	18.55	0.413	0.207
		PFD	51.95	0.4562	0.6768	17.44	0.399	0.169
		DTI	0.76	1.01	0.78	0.94	0.96	0.82

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).

Table 3. Root surface area, root diameter and root volume in upper soil layer (0-30 cm) and deeper soil layer (30-90 cm) at R7 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	Upper layer (0-30 cm)			Lower layer (30-90 cm)		
			root surface area	root diameter	root volume	root surface area	root diameter	root volume
ICGV98305	season 1	FC	85.88	0.321	0.817[b]	22.85	0.284	0.172
		PFD	111.71	0.354	1.085[a]	25.85	0.306	0.208
		DTI	1.30	1.10	1.33	1.13	1.07	1.20
	season 2	FC	61.88	0.4660	0.8192	15.33	0.401	0.174
		PFD	65.25	0.4803	0.8350	13.93	0.396	0.149
		DTI	1.05	1.03	1.02	0.91	0.99	0.86
ICGV98324	season 1	FC	84.29	0.346	0.871	22.44	0.289	0.164
		PFD	85.20	0.372	0.875	24.48	0.305	0.195
		DTI	1.01	1.07	1.00	1.09	1.06	1.19
	season 2	FC	48.34	0.454[b]	0.6745	11.25	0.406	0.130
		PFD	47.11	0.551[a]	0.7026	14.10	0.477	0.200
		DTI	0.97	1.21	1.04	1.25	1.18	1.54
ICGV98330	season 1	FC	100.08	0.351	0.999	20.99	0.302	0.167
		PFD	73.56	0.362	0.788	15.93	0.304	0.127
		DTI	0.73	1.03	0.79	0.76	1.01	0.76
	season 2	FC	52.78	0.5400	0.8584	12.76	0.454	0.173
		PFD	48.14	0.5071	0.7317	10.55	0.426	0.141
		DTI	0.91	0.94	0.85	0.83	0.94	0.82
KK60-3	season 1	FC	86.76	0.366	0.966	22.07	0.307	0.183
		PFD	92.94	0.347	0.898	21.60	0.300	0.167
		DTI	1.07	0.95	0.93	0.98	0.97	0.91
	season 2	FC	56.42	0.5235	0.7181	8.98	0.380	0.108
		PFD	68.21	0.5100	0.8629	12.60	0.460	0.180
		DTI	1.47	0.97	1.20	1.40	1.21	1.67
Tainan 9	season 1	FC	71.73	0.357	0.638	18.49	0.289	0.135
		PFD	98.78	0.335	0.897	26.69	0.276	0.198
		DTI	1.38	0.94	1.41	1.44	0.95	1.47
	season 2	FC	65.63	0.4371	0.7954	16.12	0.377	0.163
		PFD	51.42	0.4382	0.6384	13.01	0.377	0.135
		DTI	0.78	1.00	0.80	0.81	1.00	0.83
Tifton-8	season 1	FC	95.65	0.382	1.065	24.53	0.307	0.208
		PFD	82.67	0.404	0.962	22.03	0.309	0.188
		DTI	0.86	1.06	0.90	0.90	1.01	0.90
	season 2	FC	46.83	0.5348	0.6800	14.23	0.465	0.180
		PFD	63.97	0.5252	0.9551	16.23	0.471	0.227
		DTI	1.37	0.98	1.40	1.14	1.01	1.26

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).

Relationship among the responses of root traits and yield

The response of traits of peanut genotypes can be expressed as drought tolerance index (DTI) as illustrated in Tables 1, 2 and 3. In addition, this experiment determined relationships among the responses for rooting traits and the responses of pod yield. For the pre-flowering stress period, the correlation between DTI for root surface area at deeper soil layer (30-90 cm) and DTI for pod yield in both seasons was positive and significant and the correlation between DTI for root surface area at deeper soil layer and DTI for pod yield was also positive and significant at recovery period (Figure 1). Moreover, the relationship was statistically significant in the first season at R7 growth stage, but not significant in the second season. It is evident that response for root surface area in peanut was related to the response for pod yield and root surface area of peanut can be used as a parameter for selecting peanut genotypes for use in production areas where pre-flowering drought stress occurs.

The relationships among DTI for root diameter at deeper soil layer for all growth stages and DTI for pod yield were not significant (Figure 2). Even though the relationship between DTI for root volume at deeper soil layer at R7 stage and DTI for pod yield were significant, DTI for root volume at deeper soil layer at all growth stages were not consistently related with DTI for pod yield under PFD stress (Figure 3). Clearly, root diameter and root volume did not contribute greatly to pod production or the ability to increase high pod production under pre-flowering stress.

Discussion

Yield and the responses of rooting traits under PDF

In previous study, six peanut genotypes were divided into three groups based on their responses to pre-flowering drought for total dry weight and pod yield (Jongrungklang et al., 2011). ICGV 98305 was classified as a genotype with pod yield increase when subjected to PFD, whereas drought reduced pod yield in ICGV 98330 although the reduction was found in the first season only. However, ICGV 98324, Tainan 9, KK 60-3 and Tifton-8 did not respond to pre-flowering drought.

Peanut genotypes in this experiment have different yield response to pre-flowering stress. The genotype with increase in pod yield had better tolerance to drought stress in other reports. ICGV 98305 had high pod yield under early season drought (Wunna et al., 2009) because of small reduction in pod yield under long-period drought stress (Songsri et al., 2008).

In previous investigation, responses to pre-flowering drought of six peanut genotypes for total dry matter were not consistent when evaluated at 25 DAE, R5 and R7 growth stages (Jongrungklang et al., 2011). As this drought period is very short, it has small effect on total top dry weight (Nautiyal et al., 1999). Water stress during vegetative phase of peanut did not significantly affect leaf and stem dry weight (Meisner and Karnok, 1992). PDF changes root growth to improve the uptake of available water in lower soil layer (Jongrungklang et al., 2011).

In previous investigation, root volume and root diameter were not related with final pod yield under mid-season drought stress, whereas root traits were highly correlated with final biomass (Painawadee et al., 2009). The authors also reported that the relationships among root traits, pod yield and biomass were positive and significant at final harvest. Our results supported previous findings. Observation of the dynamics of root traits would clearly explain the responses of pod yield. Root traits of sugarcane were not correlated with biomass during stress period (Jangpromma et al., 2012).

Differences for root traits in upper soil layer were not significant for all peanut genotypes grown under PFD and well-watered conditions during drought period. ICGV 98305 was the only one genotype showing significant difference in root diameter between two water treatments in the second season and ICGV 98305 was the only one genotype showing significantly higher root surface area at lower soil layer under pre-flowering stress conditions compared to normal conditions during the same period (25 DAE). These results indicate that peanut genotypes with increase in pod yield associated with the pre-flowering drought stress period had higher root surface area at lower soil layer providing sufficient soil moisture content during the stress condition. The contribution of deeper root surface area to yield under drought stress conditions has not been clearly demonstrated. Benjamin and Nielson (2006) reported that drought conditions encouraged the increase in root surface area and root weight of chick pea and field pea in deeper soil layers.

Adaptation of root growth as affected by drought is a strategy of peanut to maintain water uptake (Turner, 1986). Peanut genotypes with large root system under non-stress conditions obtain higher yield under drought conditions (Rucker et al., 1995). Root dry weight contributed to shoot dry weight, leaf area and number of leaves under water-sufficient conditions (Ketring, 1984). Under drought conditions, peanut increased root length to extract more available water (Alycmeny, 1997; Mayaki et al., 1976). The response of root length density in deeper soil layers may allow plants to be able to mine more available water from the sub-soil (Songsri et al., 2008; Jongrungklang et al., 2011).

In previous investigation, yield increase under drought was associated with root traits. It was clear that root dry weight and root length density enhancement were associated with yield improvement under PFD conditions (Jongrungklang et al., 2011). This is possibly due to the change of assimilate proportion is able to contribute to improve pod yield in early drought conditions (Nageswara Rao et al., 1988). The growth of root is more promoted during PFD period by greater assimilate proportion, stopped at cessation of PFD period and then pod growth rate is promoted after re-watering (Jongrungklang et al., 2013).

The correlations between DTI for pod yield and DTI for root traits

Direct assessment of the correlations between DTI for pod yield and DTI for root traits is limited in the literature. Songsri et al. (2008) showed that the relationship between DTI for root length density in 40 to 100 cm zone and DTI for pod yield was significant in response to long duration drought conditions. Root dry weight, root length, root surface area and root volume were positively correlated with each other and they were also positively correlated with final biomass production, but not correlated with final pod yield under mid-season drought stress (Painawadee et al., 2009). In peanut, direct comparison with other studies are not possible because the differences of drought events that were imposed to the crop. In sugarcane, biomass and water use efficiency were positively correlated with root surface area and root volume after re-watering conditions (Jangpromma et al., 2012). In chick pea and field pea, root surface area and root weight in deeper soil layer increased in response to drought (Benjamin and Nielson, 2006). In peanut, root surface area in deeper soil layer is also an important character in response to early season drought and this trait contributes to enhance pod yield under drought conditions.

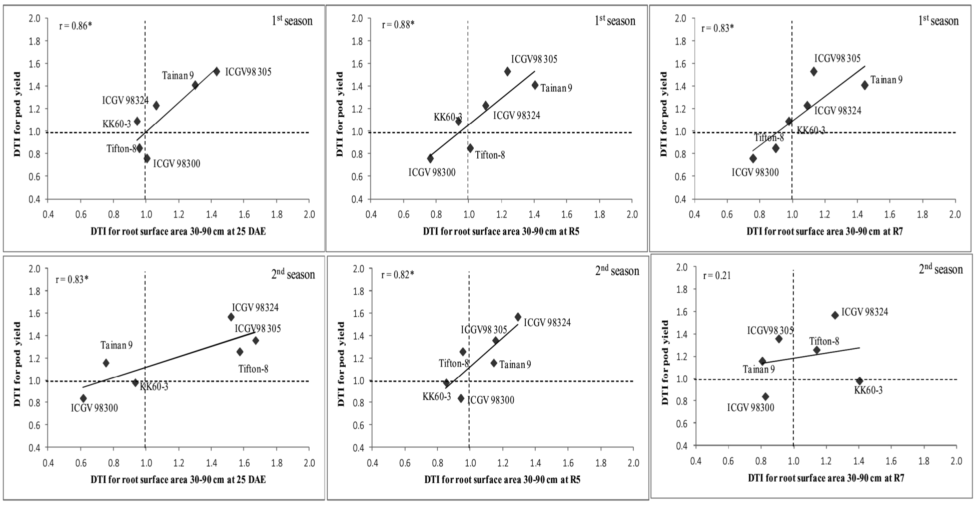

Figure 1. DTI for root surface area in 30 to 90 cm at 25 days after emergence (DAE) R5 and R7 in relation to DTI for pod yield of six peanut genotypes at the Field Crop Research Station of Khon Kaen University, Thailand during February-June 2007 (1st season) and in 2009 (2nd season). DTI, drought tolerance index (stress/FC; more than 1=increased, less than 1=decreased).

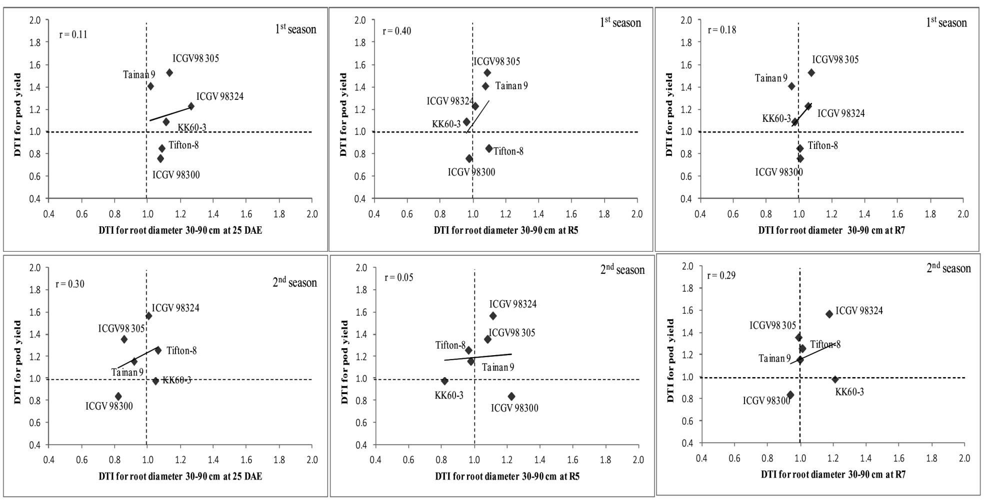

Figure 2. DTI for root diameter in 30 to 90 cm at 25 days after emergence (DAE) R5 and R7 in relations to DTI for pod yield of six peanut genotypes at the Field Crop Research Station of Khon Kaen University, Thailand during February-June 2007 (1st season) and in 2009 (2nd season). DTI, drought tolerance index (stress/FC; more than 1=increased, less than 1=decreased).

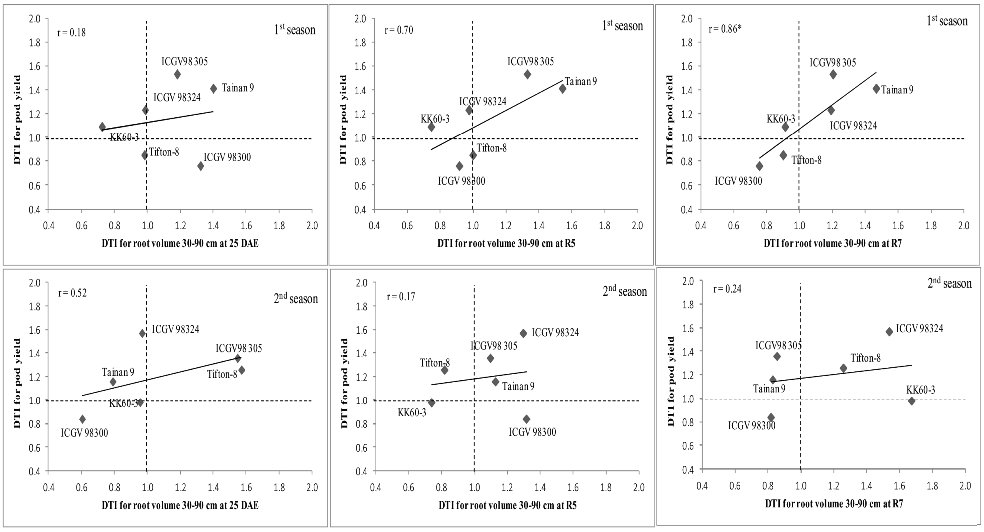

Figure 3. DTI for root volume in 30 to 90 cm at 25 days after emergence (DAE) R5 and R7 in relations to DTI for pod yield of six peanut genotypes at the Field Crop Research Station of Khon Kaen University, Thailand during February-June 2007 (1st season) and in 2009 (2nd season). DTI, drought tolerance index (stress/FC; more than 1=increased, less than 1=decreased).

Conclusions

Peanut genotypes with different responses for pod yield had differential responses for root surface area. ICGV 98305 with increased pod yield had higher root surface area in deeper soil layer under pre-flowering drought stress compared to under non-stress treatment both during the stress and recovery period. At R7 growth stage, peanut genotypes did not show significant differences for root traits between PFD and well-watered treatments both two soil depth layers. The correlations between DTI for root surface area at deeper soil layer and DTI of pod yield in both seasons were positive and significant under PFD conditions at pre-flowering stress and recovery period. The response of peanut genotypes for root surface area contributed to the response for pod yield. The relationships among DTI for root diameter and root volume at deeper soil layer for all growth stages and DTI for pod yield were not significant. Apparently, root diameter and root volume did not contribute greatly to pod yield under pre-flowering stress.

The information on the responses for root traits and the relationships between root traits and pod yield will be useful for improving peanut production under pre-flowering drought environment.

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