RESEARCH ARTICLE

SABRAO Journal
of Breeding and Genetics
48 (3) 332-343, 2016

ROOT RESPONSES AND RELATIONSHIP TO POD YIELD IN DIFFERENCE PEANUT GENOTYPES (*Arachis hypogaea* L.) UNDER MID-SEASON DROUGHT

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SUMMARY

Large root system and good root distribution reduced yield loss from drought. There is limited detail on genotypic variation for root responses under mid-season drought and more importantly the correlation between root traits and peanut yield. Experiment was conducted in a split plot design with 4 replications at Khon Kaen University in 2011/12 and 2012/13. Sub-plots were assigned as 5 peanut genotypes and main plots were assigned as 2 soil moisture levels. Measurements of root traits and peanut yield were made at drought period and final harvest. Mid-season drought reduced biomass and pod yield. Yield of all peanut genotypes were correlated with percent of root length density (%RLD) and root surface under mid-season drought. The study revealed that genotypes with large root growth and high root distribution maintained high pod yield under mid-season drought. Cultivar KKU 60 maintained high pod yield and also had high %RLD and root surface at lower soil layers under mid-season drought. Tainan 9 and KS 2 had low %RLD at the lower soil stratum and did not maintain pod production under mid-season drought. Root traits in peanut genotypes were correlated with biomass and harvest index under water stress. Peanut genotypes have high %RLD and root surface at deeper soil stratum may use more water during drying cycle and had a potential to maintain peanut yield during mid-season drought. %RLD and root surface in the lower soil stratum are the criteria for selecting peanut genotypes for drought tolerance.

Key words: Drought resistance, groundnut, pod dry weight, root characters

Key findings: Detailed information on root development and relationship to pod yield has been developed to aid peanut breeding programs targeting response to drought conditions.

Manuscript received: March 16, 2016; Decision on manuscript: June 20, 2016; Manuscript accepted: July 26, 2016.

Communicating Editor: Bertrand Collard

INTRODUCTION

Peanut (*Arachis hypogaea* L.) is an important crop in rain-fed areas having uneven rain distribution, or low rainfall, and progressively decreasing soil moisture. The severity of drought depends on plant growth stage, intensity and distribution of rainfall and moisture storing capacity of soil. Drought reduces growth, pod yield and increases aflatoxin contamination in peanut (Pimratch *et al*., 2008; Girdthai *et al*., 2010). Studies have shown that pre-flowering droughts have little impact on peanut yield (Puangbut *et al*., 2010). In contrast, water stress during pod filling and the end of growing season usually results in significant reductions in peanut yield (Jongrungklang *et al*., 2011; Koolachart *et al*., 2013). Yet, only a few studies have investigated in mid-season drought, where water stress impacts both vegetative and reproductive growth nearly equally (Rahmianna *et al*., 2004). The use of drought resistant cultivars can help mitigate the impact of drought in many crops (Wright and Nageswara Rao, 1994). Drought resistant cultivars often have characteristics such as deep rooting, high water use efficiency and low stomatal conductance that aid plant survival.

Root traits, such as large and longer root systems that extract more of the water in deeper soil stratums, help maintain yield under drought condition (Matsui & Singh, 2003, Turner *et al*., 2001, Taiz and Zeiger, 2006). In general, water stress reduces root growth rates, and changes the distribution of roots within the soil profile – enhancing the density of roots at the deeper soil layers. Peanut genotypes with high RLD in lower soil layers had high pod production during long drought periods (Songsri *et al*., 2008). Vorasoot *et al*., 2003, noted that peanut genotypes vary in their response to water uptake under drought conditions, and Songsri *et al*., 2008, found strong positive correlations between RLD and pod yield under extended drought conditions. Yet, Koolachart *et al.* (2013) found peanut yields were not related with %RLD and root dry weight under terminal drought.

Jongrungklang *et al*. (2012) reported the differential root distribution patterns for several peanut cultivars during mid-season. Jongrungklang's work prompted this more extensive study. Therefore, the objectives of this study were to examine the mid-season drought's effect on the root responses of peanut genotypes and the relationships between root characters and yield.

MATERIALS AND METHODS

Experiment detail and treatments

This research was conducted at the Field Crop Research Station at Khon Kaen University, Thailand. The experiment started from November 2011 to March 2012 and was reproduced from November 2012 to March 2013. A split plot experiment in a randomized complete block design with 4 replications was used in both years. The plot size was 5.5 m × 5 m with spacing between rows of 50 cm and between plants of 20 cm. Soil moisture treatments at field capacity (FC) and mid-season drought (MD) were the main plots. FC treatment was maintained at field capacity soil moisture from planting until to harvest. Irrigation was withheld at 30 day after planting (DAP) to 60 DAP for MD treatment. After 60 DAP, plots were irrigated to maintain FC treatment until harvest. Sub plots consisted of 5 peanut lines including ICGV 98305 (a drought resistant line with high %RLD in a deeper layer under early season drought), Tifton 8 (a drought resistant line with large root system from USDA), Tainan 9 (a high yielding cultivar from Thailand), KKU 60 new recommended cultivar in Thailand with large root system at lower soil layer under drought condition and KS 2 (a released Valencia type with susceptible to drought from Thailand).

Crop Management

Sub-soil shanks were used (0 to 60 cm) to prepare the field experiment and break up a deep hard pan. Three seeds were planted per hill and the seedlings were thinned to one plant per hill at 7 DAP. The drip irrigation system provided sufficient water to keep soil water at FC to a depth of 60 cm. For MD, irrigation was withheld, starting at 30 DAP and lasting until to 60 DAP, after which FC was restored. The amount of water applied during non-stress periods was calculated as described by Doorenbos and Pruitt (1992) and Singh and Russel (1981).

Data collection

Soil moisture content and meteorological conditions

Soil moisture content was measured at planting, 30, 45, 60, 75 and 90 DAP at soil depth of 0–30 (upper soil stratum) and 30–90 cm (lower soil stratum) using the gravimetric method to assign whether irrigation provides adequate soil water. Soil moisture content was also measured weekly at 3 soil depths (30, 60 and 90 cm) with a neutron probe. Rainfall, relative humidity (RH), evaporation (E_0), solar radiation, maximum and minimum temperature were recorded daily from planting to harvest using an on-site a weather station.

Relative water content (RWC)

The second fully leaflet from the top of the main stem from each plot was measured for RWC. In a room with the temperature at 25-26°C, leaf fresh weight was measured followed by a water saturated leaf weight were measured after immersion in distilled water for 8 hours. Leaf samples were oven-dried until reaching constant weight at 80°C, and leaf dry weight was recorded. RWC was calculated following by Gonzalez and Gonzalea-Vilar (2001).

Root traits measurement

Percent of root length density (%RLD) and root surface (RS) (cm^2 per plant) were measured at 30, 45, 60, 75 and 90 DAP. A soil probe was used to collect a sample at the center of plant at 30, 45, 60, 75 and 90 DAP. Root samples were taken to a depth of 90 cm and separated into 2 levels consisting of the upper (0–30 cm) and lower (30–90 cm) layers. Root samples were washed manually with tap water to remove the soil after soil collection. RLD and RS per sample were analyzed with the Winrhizo program (Winrhizo Pro (s) V. 2004a, Regent Instruments, Inc.) then %RLD for upper and lower layers was calculated as the following equation:

$\%RLD_{lower\ layer} = (RLD_{at\ lower\ layer}/Total\ RLD)*100$

Pod yield, biomass and harvest index (HI)

Yield measurements were collected from a 9 m^2 area at final harvest (R8 stage). The peanut pods were air dried to approximately 8% moisture content and weighed. Pod dry weight per hectare was calculated. Shoot, root and pod were collected at 30, 45, 60, 75, 90 DAP. The samples were oven dried for 48 h or until constant weight at 80ºC. Plant dry weight was examined. Harvest index (HI) was calculated as the ratio of pod yield and biomass at final harvest.

Statistical analysis

Root traits, physiological traits, yield, biomass and HI in each year were analyzed following a split plot design in RCBD. Statistix 8 program were analyzed for calculation procedure. Error variances for the 2 years were tested for homogeneity and then data for each year were combined. For all characters, difference of 2 water regimes of each genotype was compared using T-test. The correlations between traits were estimated use Statistix 8. Means were compared using Duncan's Multiple Range Tests (DMRT).

RESULTS

Meteorological conditions, soil moisture content and plant water status

Weather conditions

The trial was conducted during November to March in 2011/12 and 2012/13. Mean air temperatures between years were different during the growing season (Figure 1b, 1d). There was zero rainfall during our experimental drought periods, (Figure 1a, 1c). RH was different between 2 years. The experiment was well managed as indicated by the differences in soil moisture contents at field capacity (Figure 1).

Soil water content

Soil moisture content between the 2 water regimes in both years were clearly different at a 30 cm soil depth. At a soil depth of 60 cm, we noted small differences, and soil water content was not significantly different at 90 cm (Figure 2).

Plant water status

The difference in RWC between FC and MD treatments were not significant at 30, 45 and 75 DAP in either year (Figure 3). RWC at 60 DAP was significantly different in both non-stress and stress treatments in 2011/12 and 2012/13. Non-stressed peanut had higher RWC than did the stressed peanut for both years.

Combined analysis of variance

Combined analysis of variance exhibited significant ($P \leq 0.05$ and $P \leq 0.01$) differences between years for biomass, HI and RS (Table 1). Biomass, pod yield and HI were not significant between 2 difference water

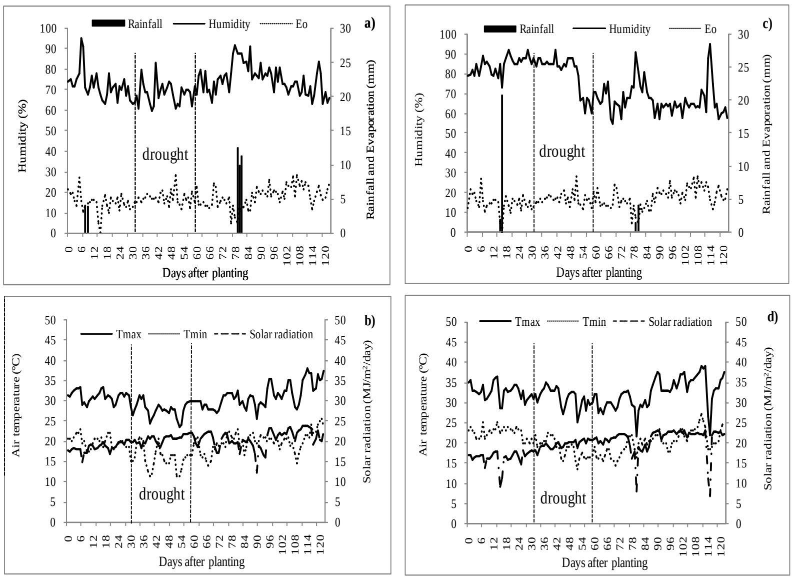

Figure 1. Rainfall, evaporation (Eo), relative humidity (RH), maximum (Tmax) and minimum (Tmin) temperature and solar radiation during November to February 2011/12 (year 1: a and b) and 2012/13 (year 2: c and d) at KhonKaen University, Thailand.

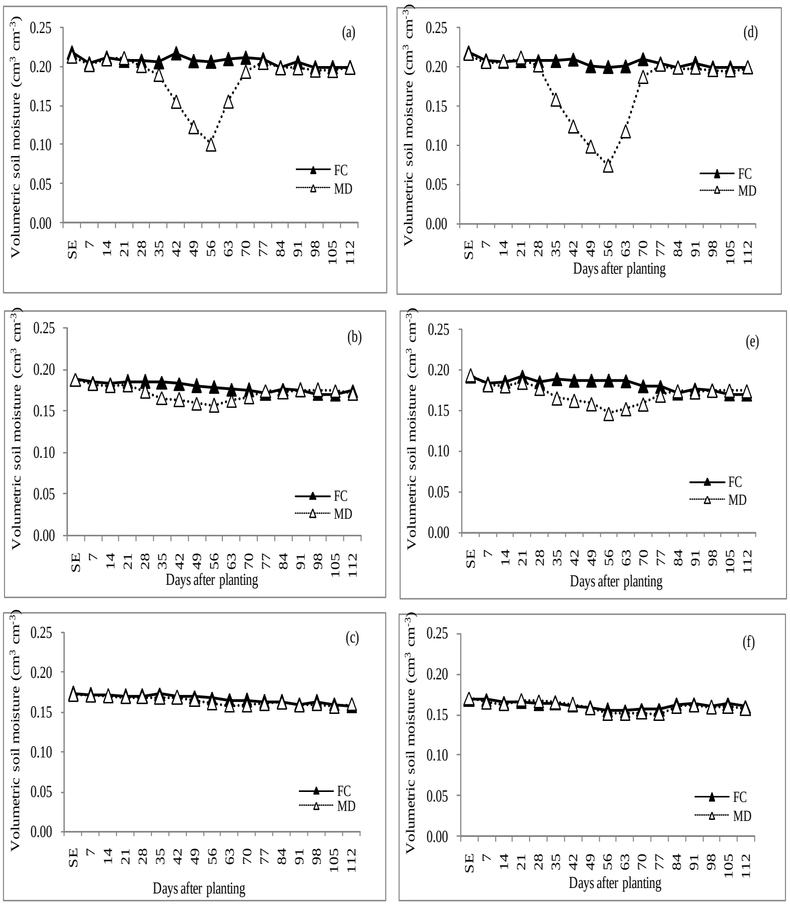

Figure 2. Volumetric soil moisture fraction under the mid-season drought experiment execute at Khon Kaen University during November 2011 to February 2012 at 30 cm (a), 60 cm (b) and 90 cm (d) of a depth and from November 2012 to February 2013 at 30 cm (d), 60 cm (e) and 90 cm (f)of a depth.

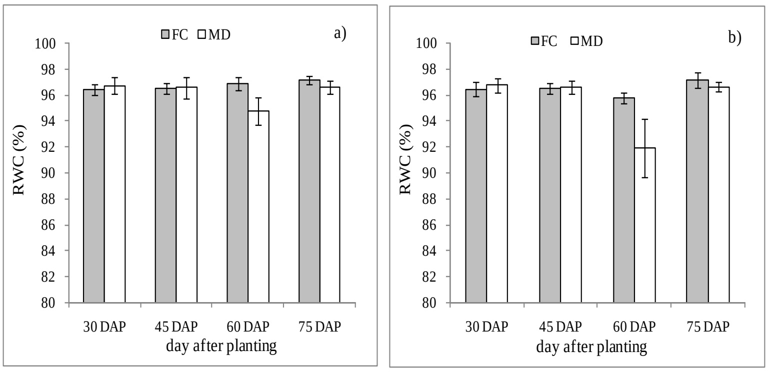

Figure 3. Relative water content (RWC) of five peanut genotypes grown under field capacity (FC) and mid-season drought (MD)at 30, 45, 60 and 75 day after planting (DAP) for the experiment conducted at Khon Kaen University during November 2011 to February 2012 (a) and from November 2012 to February 2013 (b).

Table 1. Mean squares for biomass, pod yield, harvest index (HI), percent root length density (%RLD) and root surface (RS) in the deeper soil stratum (30-90 cm) at 60 DAP of five peanut genotypes grown under field capacity (FC) and mid-season drought (MD) during the dry seasons 2011/12 and 2012/13.

Source	Df	Biomass (kg ha^{-1})	Pod yield (kg ha^{-1})	HI	%RLD	RS (cm^2 plant^{-1})
Year (Y)	1	309600000**	17641.8	2.9530**	31.13	2547*
Rep within year	6	871198	149051	0.0026	112.67	832
Water regimes (W)	1	569363	553114	0.0005	3370.84**	3753*
Y x W	1	87054	6195.2	0.0038	64.36	47
Error (a)	6	2049637	149768	0.0073	111.07	453
Genotypes (G)	4	17100000**	19350000**	0.1961**	551.17**	1676
Y x G	4	3163823**	54170.8	0.0581**	48.09	510
W x G	4	571718	264675	0.0093	187.38	785
Y x W x G	4	410931	153296	0.0101	13.91	683
Error (b)	48	418817	110781	0.0070	92.89	693

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

regimes, whereas %RLD and RS were significantly different. Genetic differences in biomass, pod yield, HI and %RLD were noted, yet not in RS Biomass and HI were highly significant between years and genotypes (Y × G). The ranks of peanut genotypes were different between years.

Effect of mid-season drought conditions for biomass, pod yield and HI

Year 1 (2011/12)

Drought reduced biomass and pod yield for 2011/12 (Table 2). Biomass, pod yield and HI of peanut genotypes showed significant differences under FC and MD conditions. KKU 60 and Tifton 8 showed high biomass under non-stressed and drought conditions, differences in biomass between water regimes for these varieties were not found. In contrast, KS 2 and Tainan 9 had low biomass production under FC and drought conditions and were significantly different between 2 water regimes. These genotypes also had low yields when grown under water stress.

Tifton 8 and KKU 60 had high pod production under MD conditions, and these varieties were not significantly different in biomass between 2 water treatments. In contrast, Tainan 9 and KS 2 gave low pod production under drought stress. There was significant difference in HI among peanut genotypes under FC and MD conditions. Tainan 9 and KKU 60 were the best peanut cultivars for HI under mid-season drought.

Table 2. Means for biomass (kg ha^{-1}), pod yield (kg ha^{-1}) and harvest index (HI) of 5 peanut genotypes grown under field capacity (FC) and mid-season drought (MD) experiments from November to March 2011/12.

Genotype	Biomass (kg ha^{-1})			Pod yield (kg ha^{-1})			HI		
	FC	MD	T-test[a]	FC	MD	T-test[a]	FC	MD	T-test[a]
Tifton 8	3519 b	4149 b	ns	2258 b	2371 b	ns	0.39 a	0.36 bc	ns
ICGV 98305	2647 c	2198 c	ns	1138 d	1163 c	ns	0.30 b	0.35 c	ns
KS 2	1819 d	1471 d	*	1375 cd	1021 c	**	0.43 a	0.40 ab	ns
Tainan 9	2299 c	1708 cd	*	1672 c	1342 c	ns	0.42 a	0.44 a	ns
KKU60	5174 a	4758 a	ns	3946 a	3806 a	ns	0.43 a	0.44 a	ns
Mean	3091A	2857B		2078A	1941B		0.39A	0.40A	

Means in the same column followed by the same letter(s) are not significantly different (at $P \leq 0.05$) by DMRT.

Mean in the same row followed by the same letter(s) of each trait are not significantly different (at $P \leq 0.05$) by LSD.

[a]T-test is the differences between two water regimes of each peanut genotypes and 5 peanut genotypes.

[ns,*,**] = non-significant and significant at $P \leq 0.05$ and $P \leq 0.01$ probability levels, respectively.

Year 2 (2012/13)

Drought reduced pod yield except for biomass and HI in 2012/13 (Table 3). KKU 60, Tifton 8 and ICGV 98305 had the highest biomass under FC and MD conditions, whereas KS 2 and Tainan 9 gave low biomass under 2 water regimes. KKU 60 gave the highest pod yield in FC and stress conditions. There was significant difference in pod yield between stress and non-stress conditions with mean values ranging from 1,890 and 2,074 kg ha^{-1}. In contrast, KS 2 and Tainan 9 gave high diminution in pod yield under stress conditions as showed by significant differences between stress and non-stress conditions. However, there was no significant difference for HI between 2 water regimes.

Effects of mid-season drought conditions on %RLD and RS

KKU 60 showed the highest %RLD under drought conditions in 2011/12 (36.27%) (Table 4). Tifton 8 and KS 2 showed an increase in %RLD under stress conditions. In contrast, Tainan 9 gave the lowest %RLD under drought conditions in the 2011/12. KKU 60 showed the highest %RLD under drought conditions in 2012/13 (34.74%). In contrast, KS 2 gave the lowest %RLD under drought condition in the 2012/13. Tifton 8 and ICGV 98305 showed significant differences between stress and non-stress conditions in the 2012/13. It seemed likely that KKU 60, Tifton 8 and ICGV 98305 had better adjusting for %RLD in mid-season drought.

Drought increased root surface in 2 years (Table 4). RS were significantly difference among peanut genotypes under FC in both years. KKU 60 and ICGV 98305 gave the highest RS under FC in 2011/12 and 2012/13. KKU 60 and Tainan 9 had the highest RS under water stress when compared with FC. Tainan 9 showed significant difference between stress and non-stress conditions in 2011/12.Tifton 8 gave the highest RS under MD, and had high yield potential and low yield reduction under insufficient soil water.

Table 3. Means for biomass (kg ha^{-1}), pod yield (kg ha^{-1}) and harvest index (HI) of 5 peanut genotypes grown under field capacity (FC) and mid-season drought (MD) experiments from November to March 2012/13.

	Biomass (kg ha^{-1})			Pod yield (kg ha^{-1})			HI		
Genotype	FC	MD	T-test[a]	FC	MD	T-test[a]	FC	MD	T-test[a]
Tifton 8	7423 ab	7473 a	ns	1307 cd	1281 c	ns	0.42	0.38	ns
ICGV 98305	7053 ab	7745 a	ns	2407 b	2045 b	ns	0.34	0.25	ns
KS 2	6282 b	5720 b	ns	1257 d	980 c	*	0.32	0.40	ns
Tainan 9	6342 b	5906 b	ns	1882 bc	1222 c	*	0.38	0.37	ns
KKU60	7701 a	7443 a	ns	3517 a	3922 a	ns	0.43	0.29	ns
Mean	6960A	6857A		2074A	1890B		0.39A	0.34A	

Means in the same column followed by the same letter(s) are not significantly different (at $P \leq 0.05$) by DMRT.

Mean in the same row followed by the same letter(s) of each trait are not significantly different (at $P \leq 0.05$) by LSD.

[a]T-test is the differences between two water regimes in each peanut genotypes and five peanut genotypes.

[ns,*,**] = non-significant and significant at $P \leq 0.05$ and $P \leq 0.01$ probability levels, respectively.

Table 4. Means for percent of root length density (%RLD) and root surface (RS) at lower soil stratum (30-90 cm) of 5 peanut genotypes grown under field capacity (FC) and mid-season drought (MD) in 2011/12 and 2012/13.

Genotype	%RLD 2011/12			%RLD 2012/13			RS (cm^2 plant^{-1}) 2011/12			RS (cm^2 plant^{-1}) 2012/13		
	FC	MD	T-test[a]	FC	MD	T-test[a]	FC	MD	T-test[a]	FC	MD	T-test[a]
Tifton 8	15.56	29.99 ab	**	16.12	23.48 ab	*	17 ab	22	ns	15 b	62	ns
ICGV 98305	11.74	32.83 ab	ns	9.49	27.56 ab	*	31 a	26	ns	41 ab	27	ns
KS 2	7.44	17.57 ab	*	7.35	10.35 b	ns	22 ab	23	ns	23 ab	52	ns
Tainan 9	8.52	14.58 b	ns	12.00	19.92 ab	ns	8 b	44	**	28 ab	26	ns
KKU 60	14.10	36.27 a	ns	15.14	34.74 a	*	31 a	56	ns	52 a	54	ns
Mean	11.47B	26.25A		12.02B	23.21A		22A	34A		32B	44A	

Means in the same column followed by the same letter(s) are not significantly different (at $P \leq 0.05$) by DMRT.

Mean in the same row followed by the same letter(s) of each trait are not significantly different (at $P \leq 0.05$) by LSD.

[a]T-test is the differences between two water regimes in each peanut genotypes and five peanut genotypes.

[ns,*,**] = non-significant and significant at $P \leq 0.05$ and $P \leq 0.01$ probability levels, respectively.

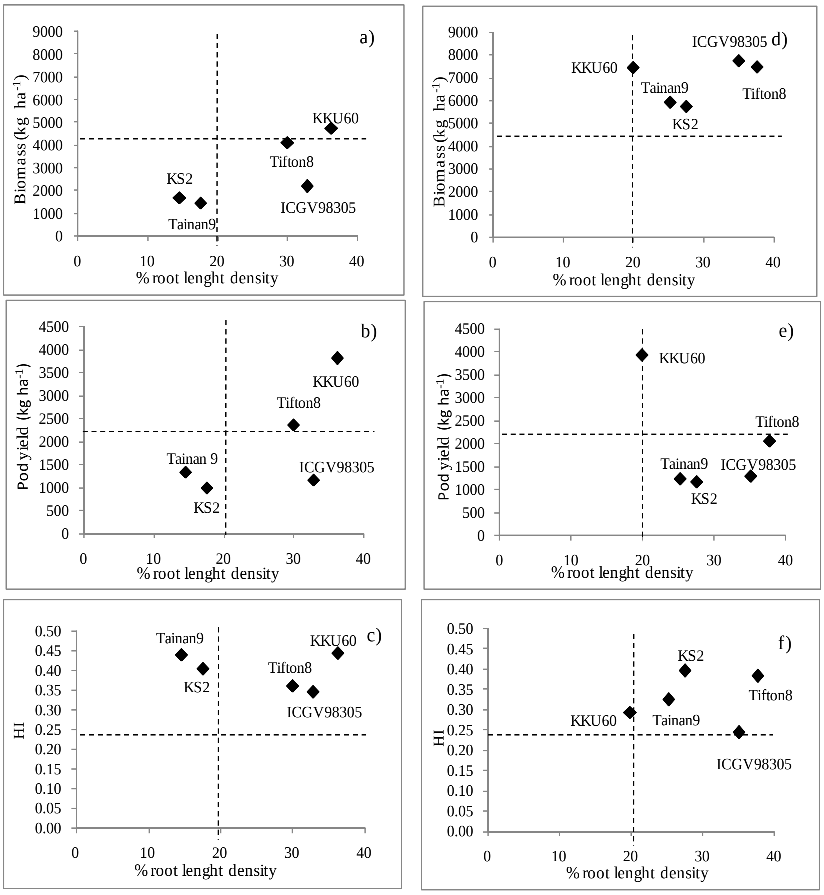

Figure 4. Relationship between percent of root length density (%RLD) of 5 peanut genotypes at lower soil stratum(30-90 cm) and biomass (a), pod yield (b), harvest index (c) in 2011/12 and relationship between percent of root length density (%RLD) and biomass (d), pod yield (e) and harvest index (f) in 2012/13 under mid-season drought.

Relationship between %RLD with pod yield, biomass and HI

Figure 4 showed the relationships among %RLD and biomass, pod yield and HI at MD in 2 years. Peanut genotypes did not show the same relationship between %RLD and biomass except for Tifton 8 and ICGV 98305 (Figure 4a, 4d). KKU 60 had high %RLD and biomass in 2011/12, but they gave high biomass and low %RLD in 2012/13 (Figure 4a, 4d). Tifton 8 and ICGV 98305 showed different patterns in both years. Tifton 8 and ICGV 98305 gave low %RLD and biomass in 2011/12 (Figure 4a), but they gave high %RLD and biomass under drought stress in 2012/13. KS 2 and Tainan 9 gave low %RLD and low biomass in 2011/12. In contrast, KS 2 and Tainan 9 gave high %RLD and biomass under MD in 2012/13 (Figure 4d).

The relationships between %RLD and pod yield were dependent on genotypes. KKU 60 had the most pod yield and high %RLD under MD in 2011/12 (Figure 4b). In contrast, KKU 60 had the highest pod yield, but had the lowest %RLD under drought in 2012/13 (Figure 4e). Tifton 8 and ICGV 98305 showed the same pattern under mid-season drought in 2 years – a high %RLD and intermediate pod yield in 2 years. KS 2 and Tainan 9 gave low pod yield in both years.

Relationship between %RLD and HI under MD were dependent on genotypes. Tifton 8 and ICGV 98305 showed the same pattern in both years (Figure 4c, 4f). Tifton 8 and ICGV 98305 gave high %RLD and HI in 2011/12, whereas ICGV 98305 had low HI in 2012/13. KKU 60 gave high %RLD and HI under MD in the first year (Figure 4c). In 2012/13, KKU 60 gave low %RLD and HI (Figure 4f). Tainan 9 and KS 2 showed different patterns in both years. KS 2 and Tainan 9 gave low %RLD but had high HI in 2011/12, whereas KS 2 and Tainan 9 gave high %RLD and high HI in 2012/13.

Relationship between RS with pod yield, biomass and HI

The relationships between root surface with biomass, pod yield and HI under stress treatment for 2 years are showed in Figure 5. Relationship of RS with biomass under mid-season drought, peanut genotypes did not show the same pattern in both years except for KKU 60 (Figure 5a, 5d). KKU 60 gave high RS and biomass in both years. Tifton 8, ICGV 98305 and KS2 gave low RS and biomass, whereas Tifton 8 had high biomass in 2011/12. Tainan 9 gave high RS, but had low biomass in the first year. In 2012/13, ICGV 98305 and Tainan 9 gave low RS, whereas these genotypes gave high biomass. In contrast, Tifton 8 and KS 2 had high RS and high biomass in the 2012/13.

The relationship between RS and pod yield, KKU 60 gave the highest RS and pod yield in both years (Figure 5b, 5e). Tifton 8, ICGV 98305 and KS 2 gave low RS in 2011/12, whereas Tifton 8 gave highest pod yield. Tainan 9 gave high RS, but had low pod yield in 2011/12. In contrast, Tainan 9 and ICGV 98305 gave low RS and pod yield in 2012/13. KS 2 gave the lowest pod yield but had high RS in 2012/13.

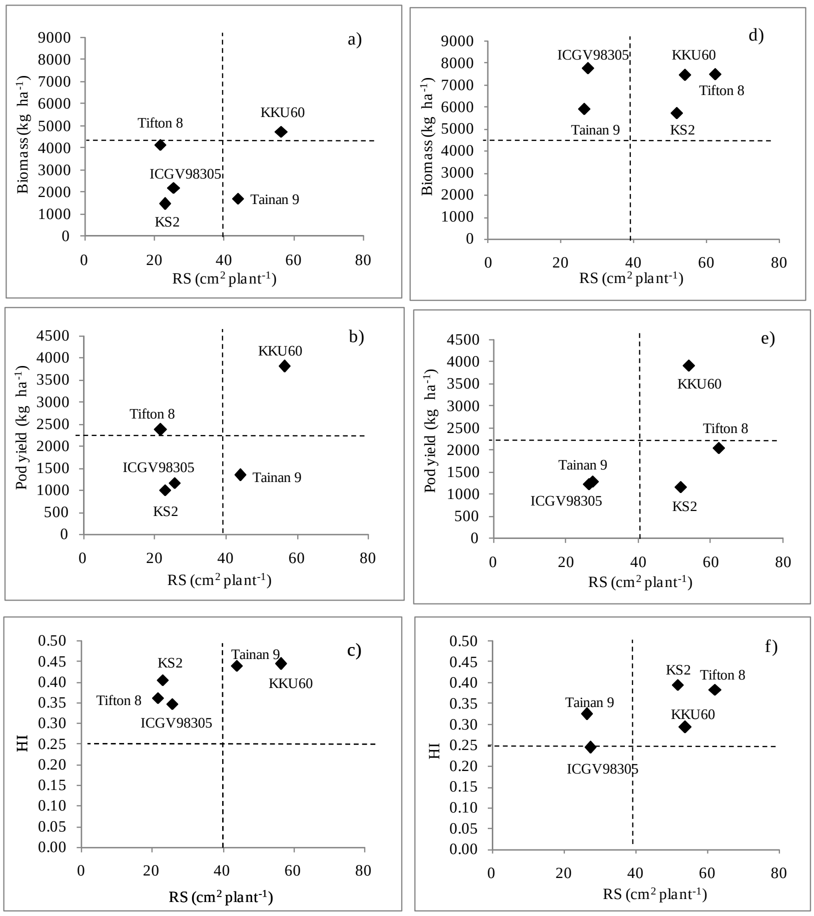

Figure 5. Relationship between root surface (RS) of 5 peanut genotypes at lower soil layer (30-90 cm)and biomass (a), pod yield (b), harvest index (c) in 2011/12 and relationship between root surface (RS) and biomass (d), pod yield (e) and harvest index (f) in 2012/13 under mid-season drought.

The relationship between RS and HI under MD was dependent on peanut genotypes. KKU 60 and Tainan 9 gave high RS and HI under water stress in 2011/12 (Figure 5c). KS 2, Tifton 8 and ICGV 98305 gave low RS, but they had high HI under stress in the first year. KS 2, Tifton 8 and KKU 60 gave high RS and HI under drought conditions in 2012/13 (Figure 5f). Tainan 9 gave low RS, but they had high HI. However, ICGV 98305 gave the lowest RS and HI under mid-season drought in 2012/13.

DISCUSSION

We noted, significant differences between genotypes during mid-season drought. Water deficit during pegging is known to impede successful pegging and maintenance of pod yield (Haro *et al*., 2007).

In this study, Tifton 8 and KKU 60 performed best peanut genotypes during mid-season drought as indicated by the highest biomass and pod yield under stress conditions and HI was not reduced greatly. However, high HI under drought conditions showed that HI is an important trait for sustaining pod production under stress conditions. KKU 60 had high yield potential for biomass and pod yield under FC and it also has high capacity to take up water and nutrients to maintain high HI (Boontang *et al*., 2010). In contrast, Nautiyal *et al*. (2002) found that HI was affected by drought condition.

KKU 60 and KS 2 gave high HI under mid-season drought. The high HI at drought conditions may point to that HI is a key for maintaining pod yield at stress condition. Peanut genotypes with high harvest index have the ability to partition dry matter into yield under water stress, and harvest index is an important character for drought tolerance (Nigam *et al*., 2005).

All peanut cultivars enhanced %RLD at lower soil layer during mid-season drought. Previous studies found that drought extended %RLD in the deeper soil layer (Pandey *et al*., 1984; Songsri *et al*., 2008). However, rooting density of peanut genotypes grown under stress conditions and those grown under non-stress conditions were not significantly difference (Roberson *et al*., 1980). The contrasting results of different studies because of peanut genotypes showed differential response to drought stress. In this study, KKU 60 and Tifton 8 gave high %RLD in the lower soil layers. These findings suggested that %RLD at the deeper soil stratum is an important character for pod production under drought stress. Additionally, KKU 60, Tifton 8 and ICGV 98305 were the best peanut cultivars during mid-season drought as they were not significantly different in pod yield under FC and MD conditions. The results suggested that theses genotypes had good partitioning of biomass to reproductive sink under water stress conditions. In this study, KS 2 and Tainan 9 gave low %RLD under drought conditions and had low pod yield and biomass. The results suggested that the peanut genotypes with low root growth have low ability to absorb soil water and nutrient from deeper soil layer under water stress. In other previous reports using peanut genotypes common to this study, Tainan 9 had high RLD under terminal drought stress (Koolachart *et al*., 2013).

Drying soil increased root production and total root dry weight in the lower soil depths where moisture was still available to aid root growth (Gregory, 2006). The peanut genotypes with high RS gave high pod yield and HI under drought conditions (Dorner *et al*., 1989). Moreover, root surface areas were related to nutrients absorption, and the increase in RS can cause a greater efficiency in absorption of nutrients (Imada *et al*., 2008).

The results indicated that the selection of peanut cultivars with good root characters for improved drought tolerance is appropriate. However, some peanut genotypes with high and deeper root growth and root distribution did not have high pod production under drought stress. Some peanut cultivars had other strategies to minimize drought impact, such as relative water content and stomatal conductance (Koolachart*et al*., 2013). Therefore, selecting of genotypes with superior root, relative water content and stomatal conductance traits may provide additional benefit in drought conditions.

CONCLUSION

In conclusion, mid-season drought decreased biomass, pod yield and HI in peanut cultivars. The differences between years and peanut genotypes for growth traits were significant for peanut experiencing mid-season drought likely due, in part, to the variation in air temperatures. The results indicated that some peanut genotypes had large and deep root system for extraction of soil water and maintenance of pod yield when subjected to drought stress. However, high pod yield in peanut genotypes were not always connected with deep root systems at mid-season drought. Some peanut genotypes also used other strategies to avoid drought's impact on pod yield. %RLD at the lower soil stratum is a good trait for a selection basis of pod yield under mid-season drought. Nevertheless, the selection of %RLD alone can be confounded because peanut may use different procedures to sustain pod and biomass under drought condition such as relative water content and stomatal conductance. The knowledge of this study will aid peanut breeding programs looking for rapid selection criteria to screen large numbers of genotypes.

ACKNOWLEDGMENTS

This research was supported by the Higher Education Research Promotion and National Research University Project of Thailand, Office of the Higher Education Commission through the Food and Functional Food Research Cluster of Khon Kaen University, Thailand. Assistance was also received from Peanut Improvement Project and Jerusalem artichoke for Functional Food Research Group, Plant Breeding Research Center for Sustainable Agriculture, and the Thailand Research Fund (TRF), for providing financial supports to this research through the Senior Research Scholar Project of Professor Dr. Sanun Jogloy (RTA5880003). Thailand Research Fund (TRF) (IRG 578003), Khon Kaen University (KKU) and Faculty of Agriculture, KKU are acknowledged for providing financial support for training on manuscript preparation.

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