RESEARCH ARTICLE

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EFFECT OF MID-SEASON DROUGHT AND RECOVERY ON PHYSIOLOGICAL TRAITS AND ROOT SYSTEM IN PEANUT GENOTYPES (*Arachis hypogaea* L.)

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SUMMARY

Physiological traits are useful as representative characters for drought tolerance in peanut. The information on the responses of diverse peanut genotypes for physiological characters under mid-season drought is rather limited. The aim of this study was to examine the physiological traits for drought tolerance in diverse peanut genotypes responses under mid-season drought. The experiment was conducted from November 2011 to March 2012 and from November 2012 to March 2013. The experimental design was a split plot in randomized complete block. Two water regimes were assigned as the main plot (field capacity and mid-season drought). Five peanut genotypes were assigned in sub plot. Data were recorded for percent of root length density, relative water content (RWC) and stomatal conductance at 30, 45, 60, 75 and 90 days after planting. Shoot growth and pod growth rate were calculated. Drought significantly decreased RWC and stomatal conductance, but it increased root length density. High genotypic variation for root and physiological traits were observed at mid-season drought and after recovery. Associated of physiological traits and biomass and pod yield were higher at mid-season drought and after recovery than at the initiation of drought. Genotypes KKU 60, ICGV 98305 and Tifton 8 increase high water uptake by root system except for Tainan 9 and KS 2. Selection for physiological traits using RWC and stomatal conductance might be effective improving peanut for drought tolerance. The knowledge of this study will be useful for breeding of peanut for mid-season drought condition.

Key words: Drought tolerance, groundnut, pod dry weight, re-watering, water status

Key findings: Two physiological traits namely RWC and stomatal conductance along with root length density can be used to evaluate gentoypes that are tolerant to mid-season drought to improve breeding program.

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INTRODUCTION

Peanut productivity is often limited by drought at different growth stage during growing season. Yield losses due to water deficit depend on crop growth stage (Reddy *et al*., 2003), drought duration and drought intensity (Nigam *et al*., 2005). In peanut, drought stress during the flowering and pod filling stage is critical for yield and agronomic characters. This would result in severe reduction in crop yield and magnitude of reduction would depend on peanut cultivars. Terminal drought occurred during seed filling and maturity until harvesting that affected to dry weight, seed quality and extended aflatoxin contamination (Girdthai *et al*., 2010; Wright *et al*., 1991).

Development of drought resistance varieties during the growing season can alleviate the drought problem. Several drought resistance cultivars have been identified and release based on high pod yield in drought condition. However, high effect of G x E interaction and low heritability is a main problem in selection for high pod yield (Holbrook and Stalker, 2003). The ability of plants to modify their root system may be main apparatus to avoid drought stress for uptake of water for transpiration (Songsri *et al*., 2009). High level of drought resistance in peanut should maintain pod production under drought stress. However, root traits have been recognized as the adaptability to water stress in many plants including sugarcane (Jangpromma *et al*., 2012), wheat (Gesimba *et al*., 2004) and chickpea (Serraj *et al*., 2004). The prior study reported that the selection for drought tolerance and water use efficiency in plant can be used as root system. However, more rapid progress may be achieved by a previous knowledge of the physiological traits such as stomatal conductance, specific leaf area (SLA), relative water content (RWC) and crop growth rate have been reported as main surrogate traits for drought tolerance in peanut (Pimratch *et al*., 2008; Songsri *et al*., 2009). Moreover, the ability of plant to maintain a high water status and reduce water loss

The stomatal control of transpiration related with the reduction of water loss while deep root system correlated with the increasing water uptake. The previous study reported that stomatal conductance was by far the most important of RWC and water use efficiency (WUE) determining water use in plant (Nerkar *et al*., 1981). Therefore, an understanding of traits associated with drought tolerance such as large root system increase water uptake, maintain high photosynthesis capacity and maintain plant water potential should be useful in contributing to crop yield under water stress.

The response of peanut genotypes for physiological traits under mid-season drought have not been reported elsewhere. The aim of this experiment was to examine the physiological traits for peanut drought resistance responses during mid-season drought.

MATERIALS AND METHODS

Experiment detail and treatments

The trial was managed at Khon Kaen University, Thailand from November 2011 to March 2012 and was repeated from November 2012 to March 2013. Four replications in a split plot in randomized complete block design were used in two years. Field capacity (FC) and mid-season drought (MD) were assigned to main plots. The FC treatment was maintained from planting until to final harvest. For MD treatment, irrigation was withheld at 30-60 day after planting (DAP). After drought period, MD was re-watering to FC and the soil water was maintained until harvest. Sub plot treatments were assigned to genotypes namely ICGV 98305, Tifton 8, KKU 60, Tainan 9 and KS 2.

Crop management

The soil was pulverized to break the hard pan of the soil (0 to 60 cm) in the experimental field experiment. Three seed were planted per hill and the seedlings were thinned to one plant per hill at 7 DAP. Weed was controlled by hand during growing season. Gypsum ($CaSO_4$) at a rate of 312 kg ha^{-1} was incorporated into the soil to improve pod development at 40 DAP. Plot was irrigated with adequate soil water to reach at FC to 60 cm of the depth .Soil water was sustained to FC until harvest and soil moisture content was maintained with less than 1% moisture change from FC treatment after emergence. Irrigation treatment was withheld starting at 30-60 DAP for drought treatment. The stress plots were irrigated to FC until harvest and stress period was relieved from 60 DAP. The amount of water applied was calculated following by Doorenbos and Pruitt (1992) and Singh and Russel (1981).

Data collection

Soil moisture content

Soil moisture content was determined 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).Soil moisture content was collected with a neutron probe every week. Neutron soil moisture reading was made at a depth of 30, 60 and 90 cm. The soil moisture contents between drought and irrigated treatments were not significantly different at 30 and 90 DAP in 2011/12 and 2012/13. However, significant differences in soil moisture contents between drought treatment and well-irrigated treatment were observed at 60 DAP in 2011/12 and 2012/13, and soil moisture contents of drought treatment were much lower than irrigated treatment in both years.

Meteorological conditions

Rainfall, relative humidity (RH), evaporation (E_0), maximum and minimum temperature and solar radiation were recorded daily from planting to harvest. The averaged air temperature in 2011/12 was 24 °C and the averaged air temperature in 2012/13 was 26°C, which was slightly higher than in 2011/12. Rainfall did not occur during the drought period in both years, and water supplied to the crop was dependent totally from irrigation. RH in 2011/12 was 73% and RH in 2012/13 was 75%, which was slightly higher than in 2011/12.

Relative water content (RWC)

The second fully expanded leaf from the top of the main stem was measured. Leaf fresh weight was measured from the five leaves in each plot.Water saturated leaf weight was recorded.After oven-drying at 80°C for 48 h, leaf dry weight was measured. Relative water content was calculated as:

$$\text{RWC (\%)} = \frac{\text{(Fresh weight – Dry weight)}}{\text{(Turgid weight – Dry weight)}} \times 100$$

Stomatal conductance

Stomatal conductance was measured at 30, 45, 60, 75 and 90 DAP. Stomatal conductance was recorded from 10.00 and 12.00 h using by porometer (Delta-T Devices in Cambridge, U.K.).

Percent of root length density (% RLD)

Root samples were collected at 30, 45, 60, 75 and 90 DAP using an auger. RLD divide at 0–30 cm(upper soil stratum) and 30–90 cm (lower soil stratum). Root length densities were analyzed with the Winrhizo program. RLD divide at 0–30 cm (upper soil stratum) and 30–90 cm (lower soil stratum).Percent of root length density was calculated as the following equation:

$$\text{RLD (\%)} = \frac{\text{Root length density at upper or lower soil stratum}}{\text{Total root length}} \times 100$$

Shoot growth rate and pod growth rate

Total shoot and pod dry matters were obtained at 30, 45, 60, 75 and 90 DAP. Shoot and pod sample were collected from 5 plants in each plot. The shoot samples were oven-dried at 80°C for 48 h until constant weight then dry weights were obtained. Pod samples were removed from plants and oven-dried at 80°C until for constant weight and pod dry weight was determined. Shoot and pod growth rate (GR) were determined to dry matter accumulation rate per five plants.

Statistical analysis

Statistic 8 program (Analytical Software, Tallahassee, FL, USA) was use in this study. Error variance was tested for homogeneity in two years (Gomez and Gomez, 1984). The data for each year were combined after homogeneity test. The comparison of peanut genotypes was performed by least significant difference (LSD)

RESULTS

Combined analysis of variance

Years were not significantly different for % RLD at the lower soil layer at all periods. % RLD at 45, 60 and 75 DAP were significantly different between two water regimes (Table 1). Genotypes were significantly different at 60, 75 and 90 DAP. Y x W, W x G and Y x W x G interactions were not significant different except for Y x G. Year and genotype (Y x G) interaction were significant for % RLD at 90 DAP.

Table 1. Mean squares percent of root length density (%RLD) of five peanut genotypes at the lower soil layers (30-90 cm) at 30, 45, 60, 75 and 90days after planting (DAP) grown under field capacity (FC) and mid-season drought (MD) in the dry seasons 2011/12 (year 1) and 2012/13 (year 2).

Source	df	%RLD				
		30 DAP	45 DAP	60 DAP	75 DAP	90 DAP
Year (Y)	1	437.31	5.72	31.13	121.70	110.03
Rep within year	6	178.54	60.30	112.67	13.37	89.38
Water regimes (W)	1	46.15	2477.65*	3370.84**	1664.13*	525.93
Y x W	1	1.73	21.96	64.36	33.89	46.67
Error (a)	6	107.36	202.60	111.07	217.44	129.66
Genotypes (G)	4	128.25	173.58	551.17**	617.04**	627.99**
Y x G	4	37.26	160.46	48.09	17.51	279.97*
W x G	4	41.48	60.00	187.38	127.65	41.43
Y x W x G	48	13.25	48.97	13.91	47.04	15.65
Error (b)	79	90.94	93.08	92.89	109.40	103.82
CV (a) %		80.39	48.26	39.15	31.48	17.13
CV (b) %		45.24	77.16	57.79	56.57	55.23

Within rows means followed by the same letters are not significantly different according to LSD at 0.05 and0.01 levels.
*,** significant at $P \leq 0.05$ and $P \leq 0.01$ probability levels, respectively.

RWC at 45, 60, 75 and 90 DAP and stomatal conductance at 30, 45, 60, 75 and 90 DAP were significantly different between years ($P \leq 0.05$ and $P \leq 0.01$) (Table 2). RWC and stomatal conductance at 45, 60 and 90 DAP were significantly different between Water regimes ($P \leq 0.05$ and $P \leq 0.01$). Year and water interaction (Y x W) were significant for RWC at 45, 60, 75 and 90 DAP whereas stomatal conductance were found significant at 90 DAP. Genotypes were significantly different for RWC at 45, 60, 75 and 90 DAP, whereas the differences between genotypes were significant for stomatal conductance at all days after planting. Year and genotype interaction (Y × G) were significant ($P \leq 0.01$) for RWC at 60 and 90 DAP, whereas stomatal conductance were found at 30, 60 and 90 DAP. Moreover, the interactions between water and genotype (W × G) showed significantly different for RWC at 60 DAP, and there was significant difference for stomatal conductance at 45 and 90 DAP. The interaction among year, water regime and genotype (Y × W × G) were significantly different ($P \leq 0.05$ and $P \leq 0.01$) for RWC at 60 and 75 DAP, and stomatal conductance were found significant at 90 DAP.

Years were significantly different ($P \leq 0.05$ and $P \leq 0.01$) for shoot growth rate at 45 and 90 DAP, whereas the difference were found for pod growth rate at 60, 75 and 90 DAP (Table 3). Water regimes were difference for shoot growth rate at 60 and 75 DAP and also were different for pod growth rate at 60, 75 and 90 DAP, respectively. Year and water (Y x W) interaction were significant for pod growth rate at 60, 75 and 90 DAP except for shoot growth rate. Genotypes were significantly different for shoot growth rate at 30 and 90 DAP, whereas pod growth rate were found significantly different at 60, 75 and 90 DAP. Year and genotype (Y x G) interaction were significant for shoot growth rate at 30 and 90 DAP and also were found for pod growth rate at 90 DAP, respectively. Moreover, water and genotype (W x G) interaction were significant for shoot growth rate and pod growth rate at 90 DAP. Water regime and genotype (Y × W × G) interaction were significant for pod growth rate at 90 DAP.

The responses of root length density to mid-season drought of peanut genotypes

Percent of root length density at Year 1 (2011/12)

Mid-season drought increased % RLD in the lower soil stratum and significant difference between two water regimes were observed (Figure 1a).ICGV 98305, Tifton 8, Tainan 9 and KKU 60 showed high increasing in % RLD under drought than FC except for KS 2. Difference in % RLD in the lower soil layer between two water regimes were not significant at 30 DAP in the 2011/12 because

Table 2. Mean squares for relative water content (RWC) and stomatal conductance of five peanut genotypes at 30, 45, 60, 75 and 90days after planting (DAP) grown under field capacity (FC) and mid-season drought (MD) in the dry seasons 2011/12 (year 1) and 2012/13 (year 2).

Source	df	RWC					Stomatal conductance				
		30 DAP	45 DAP	60 DAP	75 DAP	90 DAP	30 DAP	45 DAP	60 DAP	75 DAP	90 DAP
Year (Y)	1	3.78	43.24*	80.67**	43.21**	186.94**	11390000**	200701**	3176842**	277419*	17130000**
Rep within year	6	0.70	3.86	0.97	1.37	2.74	12884	5347	27052	72685	40732
Water regimes (W)	1	0.10	42.69*	177.12**	0.08	12.71**	2726	2758388**	2373605**	82883	678409**
Y x W	1	0.19	48.68*	15.37**	7.97**	12.29**	68973	149	137780	153914	296340*
Error (a)	6	5.03	4.07	0.60	0.55	0.74	35508	8198	39075	36996	45430
Genotypes (G)	4	1.99	2.39*	15.11**	2.04**	2.04**	63984**	695234**	945060**	436445**	1472745**
Y x G	4	1.53	0.12	4.13**	0.40	3.09**	102347**	26237	271343**	62396	1055613**
W x G	4	0.76	1.09	4.66**	0.10	0.42	31197	161510**	87508	30053	336709**
Y x W x G	48	0.32	1.49	2.89*	0.73*	0.29	8050	50662	54767	153023	415217**
Error (b)	79	0.80	0.96	0.88	0.28	0.48	17084	25700	40779	65578	60977
CV (a) %		2.33	2.1	0.82	0.77	0.89	19.93	19.06	42.29	31.16	24.15
CV (b) %		0.93	1.02	0.99	0.55	0.72	13.82	33.75	43.21	41.49	27.98

Within rows means followed by the same letters are not significantly different according to LSD at 0.05 and 0.01 levels

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

Table 3. Mean squares shoot growth rate and pod growth rate of five peanut genotypes at 30, 45, 60, 75 and 90days after planting (DAP) grown under field capacity (FC) and mid-season drought (MD) in the dry seasons 2011/12 (year 1) and 2012/13 (year 2).

Source	df	Shoot growth rate					Pod growth rate		
		30 DAP	45 DAP	60 DAP	75 DAP	90 DAP	60 DAP	75 DAP	90 DAP
Year (Y)	1	0.0002	0.9257**	0.0442	0.0565	0.7962**	0.02016*	0.0529**	0.0747*
Rep within year	6	0.0014	0.0465	0.0217	0.0276	0.0304	0.0023	0.0044	0.0072
Water regimes (W)	1	0.0001	0.0176	0.4062*	0.1534*	0.0860	0.0510**	0.3308**	0.2508**
Y x W	1	0.0003	0.0020	0.1059	0.0045	0.0281	0.0361**	0.0857**	0.1038*
Error (a)	6	0.0006	0.0143	0.0459	0.0259	0.0191	0.0016	0.0034	0.0095
Genotypes (G)	4	0.0040**	0.0080	0.0204	0.0083	0.0364**	0.0234**	0.0721**	0.1150**
Y x G	4	0.0038**	0.0074	0.0097	0.0026	0.0271*	0.0025	0.0061	0.0487**
W x G	4	0.0005	0.0345	0.0119	0.0077	0.0250*	0.0002	0.0033	0.0142**
Y x W x G	48	0.0001	0.0028	0.0043	0.0078	0.0089	0.0002	0.0063	0.0093*
Error (b)	79	0.0005	0.0146	0.0157	0.0138	0.0078	0.0011	0.0034	0.0035
CV (a) %		25.56	30.86	47.35	32.64	28.54	78.63	43.41	40.95
CV (b) %		23.68	31.19	27.68	23.84	18.28	63.69	43.41	24.71

Within rows means followed by the same letters are not significantly different according to LSD at 0.05 and 0.01 levels

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

peanut genotypes did not show differences in root growth at the beginning. At initiation of drought (45 DAP), KS 2, Tainan 9 and KKU 60 were different for % RLD between two water regimes except for ICGV 98305 and Tifton 8. Drought increased % RLD at 60 DAP for all peanut genotypes. All peanut genotypes showed significantly difference in % RLD between two water regimes, in which peanut grown under MD had significantly higher % RLD than those grown under FC treatment. After re-watering (45 DAP), most of peanut genotypes slowly reduced % RLD in the lower soil layer except for KKU 60 (Figure 1a). At 90 DAP, the difference of % RLD between two water regimes of peanut genotypes were absented except for Tainan 9 and KKU 60.

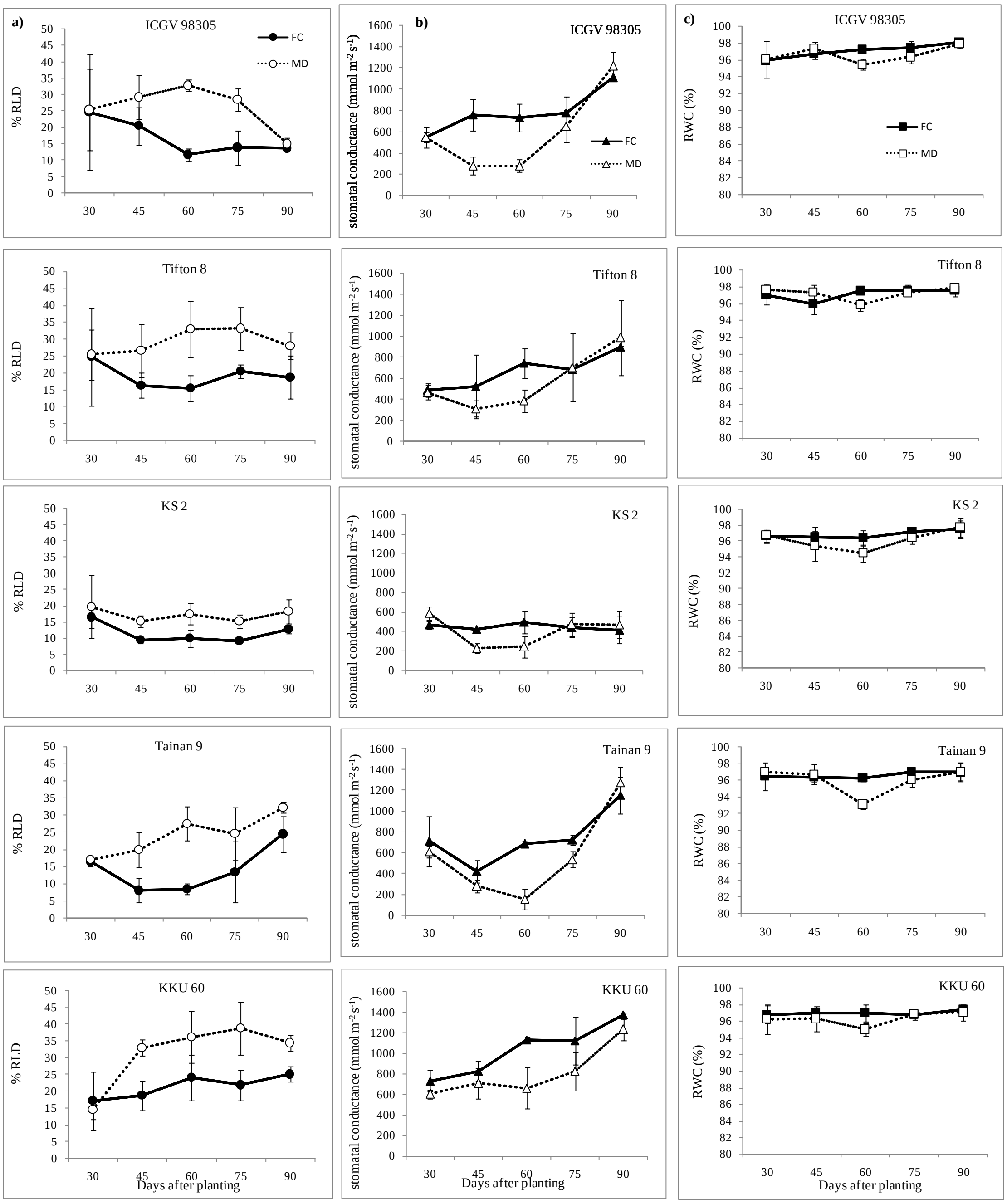

Figure 1. Percent of root length density (% RLD) in the lower soil stratum (30-90 cm), stomatal conductance (mmol m^2 s^{-1}) and relative water content (%) of five peanut genotypes at 30, 45, 60, 75 and 90days after planting (DAP). The field experiment was managed at Khon Kaen University in the dry seasons 2011/12 (year 1).

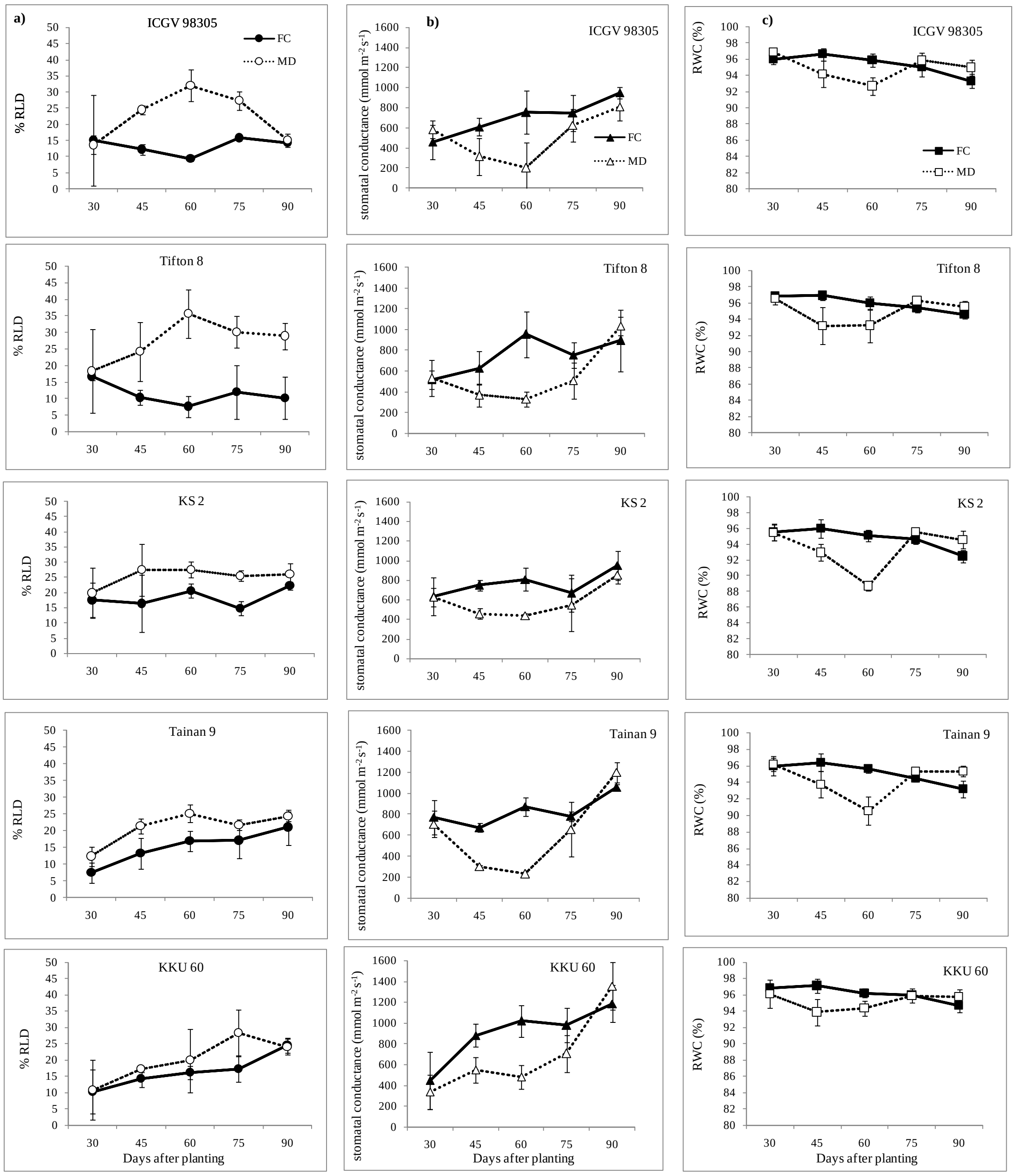

Figure 2. Percent of root length density (% RLD) in the lower soil stratum (30-90 cm), stomatal conductance (mmol m^2 s^{-1}) and relative water content (%) of five peanut genotypes at 30, 45, 60, 75 and 90days after planting (DAP). The experiment was managed at Khon Kaen University in the dry seasons 2012/13 (year 2).

Percent of root length density at Year 2 (2012/13)

The percent RLD increased in the lower soil layer and significant differences between two water regimes under mid-season drought were noticed (Figure 2a).ICGV 98305 and Tifton 8 showed high increasing in % RLD under drought than FC except for Tainan 9, KS 2 and KKU 60. Difference in % RLD in the lower soil layer between two water regimes were not significant at 30 DAP in the 2012/13 because peanut genotype may not be different in root growth at the beginning. At initiation of drought (45 DAP), ICGV 98305, Tifton 8 and Tainan 9 were different for % RLD between two water regimes. At severe drought (60 DAP), % RLD increased significantly higher than MD treatments at 60 DAP for ICGV 98305, Tifton 8, KS 2 and Tainan 9 except for KKU 60. KKU 60, KS 2 and Tainan 9 were the best genotypes because they still have high

% RLD under FC and MD conditions. After fifteen days of re-watering (75 DAP), most of peanut genotypes slowly decreased % RLD at the lower soil layer and reached the FC value during the recovery period (Figure 2a). At 90 DAP, the difference for % RLD between two water regimes of peanut genotypes were absented except for Tifton 8. The increasing in % RLD under drought were small in KS 2, Tainan 9 and KKU 60 whereas high increasing for % RLD were found in ICGV 98305 and Tifton 8 at 90 DAP in the 2012/13. High % RLD might promote peanut to extract soil water under drought stress.

The response of water loss, stomatal conductance and plant water status to mid-season drought of peanut genotypes

Stomatal conductance at Year 1 (2011/12)

Mid-season drought decreased stomatal conductance and significant difference among peanut genotypes (Figure 1b). ICGV 98305, Tifton 8, Tainan 9 and KKU 60 showed high reduction in stomatal conductance under drought than FC except for KS 2.Stomatal conductance of peanut genotypes were not significant different under FC and MD conditions at 30 DAP because peanut genotypes were similar stomatal conductance at the beginning. ICGV 98305 and KS 2 showed decreased in stomatal conductance gradually after fifteen days of stress except for Tifton 8, Tainan 9 and KKU 60. ICGV 98305, Tifton 8, Tainan 9 and KKU 60 showed high reduction in stomatal conductance at 60 DAP. In contrast, stomatal conductance of KS 2 showed low reduction.

Stomatal conductance at Year 2 (2012/13)

Mid-season drought decreased stomatal conductance (Figure 2b). Stomatal conductance was significantly different between two water regimes between peanut genotypes. However, stomatal conductance were not significant different under FC and MD conditions at 30 DAP between peanut genotypes. Peanut genotypes showed decrease in stomatal conductance gradually after fifteen days of withheld irrigation (45 DAP). Most of peanut genotypes showed high reduction in stomatal conductance except for KS. The significant different for stomatal conductance were found in KS 2, Tainan 9 and KKU 60 except for ICGV 98305 and Tifton 8 at 45 DAP. Moreover, most of peanut genotypes showed large reductions in stomatal conductance at 60 DAP except for KS 2.

Relative water content at Year 1 (2011/12)

Mid-season drought decreased RWC and significant difference among peanut genotypes were presented in Figure 1c. ICGV 98305, Tifton 8, KS 2 and KKU 60 showed low reduction in RWC under drought than FC except for Tainan 9. Peanut genotypes were not different for RWC under FC and MD conditions at initiation drought (45 DAP), indicated that no effect on RWC after a fifteen days of withhold irrigation (Figure 1c). RWC showed small reduction and dropped significantly below FC treatment on 60 DAP in ICGV 98305, Tifton 8, KS 2 and KKU 60, whereas large reductions were found in Tainan 9.

Relative water content at Year 2 (2012/13)

Mid-season drought decreased RWC and significant difference among peanut genotypes for RWC at 60 DAP were presented in Figure 2c. All the five peanut genotypes were not significantly different for RWC between two water regimes at 30 DAP in the 2012/13. At 45 DAP, RWC under stress and non-stress conditions were different in Tifton 8, KS 2 and KKU 60, indicating that drought affected on RWC after fifteen day of withhold irrigation. RWC showed large reduction and dropped significantly below FC treatment on 60 DAP in ICGV 98305, KS 2, Tainan 9 and KKU 60, whereas small reductions were found in Tifton 8. As re-watering continued, the recoveries of RWC would appear immediately to close or near FC value for all peanut genotypes.

Shoot and pod growth rate

All of peanut genotypes decreased pod yield when subjected MD treatment in both years. Shoot growth rate at 30 DAP were not significant different in most of peanut genotypes under two water regimes in both years (Table 4). At 45 DAP, Tainan 9 and KKU 60 had significantly higher shoot growth rate during FC than MD conditions in 2011/12. At the serious drought treatment (60 DAP),

Table 4. Shoot growth rate and pod growth rate of five peanut genotypes with different yield under mid-season drought at 30, 45, 60, 75 and 90 days after planting (DAP) in the dry seasons 2011/12 (year 1) and 2012/13 (year 2).

Growth rate	Growth stage	Water regimes	ICGV 98305		Tifton 8		KS 2		Tainan 9		KKU 60	
			2011/12	2012/13	2011/12	2012/13	2011/12	2012/13	2011/12	2012/13	2011/12	2012/13
Shoot growth rate	30 DAP	FC	0.07	0.09	0.09	0.10	0.10	0.08	0.09	0.11	0.13	0.14
		MD	0.05	0.09	0.09	0.12	0.09	0.08	0.10	0.11	0.14	0.15
	45 DAP	FC	0.22	0.48	0.28	0.48	0.25	0.41	0.33 a	0.61	0.41 a	0.55
		MD	0.26	0.54	0.27	0.48	0.29	0.5	0.24 b	0.46	0.25 b	0.45
	60 DAP	FC	0.43	0.63 a	0.42	0.60	0.40	0.49	0.55 a	0.57 a	0.52	0.63
		MD	0.41	0.46 b	0.42	0.46	0.36	0.45	0.40 b	0.31 b	0.59	0.67
	75 DAP	FC	0.49	0.48 a	0.53	0.50	0.55	0.43	0.55	0.52	0.54 a	0.52
		MD	0.43	0.36 b	0.51	0.41	0.47	0.45	0.49	0.43	0.43 b	0.45
	90 DAP	FC	0.57	0.42	0.79 a	0.41	0.54	0.41	0.69 a	0.40	0.55 a	0.55 a
		MD	0.51	0.37	0.59 b	0.43	0.52	0.44	0.53 b	0.47	0.46 b	0.34 b
Pod growth rate	60 DAP	FC	0.016	0.099 a	0.006	0.115 a	0.020	0.089 a	0.023	0.104 a	0.133 a	0.164 a
		MD	0.004	0.005 b	0.002	0.007 b	0.012	0.014 b	0.025	0.012 b	0.115 b	0.067 b
	75 DAP	FC	0.068	0.297 a	0.049	0.179 a	0.124 a	0.228 a	0.132	0.285 a	0.331 a	0.328 a
		MD	0.050	0.054 b	0.025	0.025 b	0.046 b	0.033 b	0.100	0.048 b	0.168 b	0.158 b
	90 DAP	FC	0.127	0.453 a	0.173	0.262 a	0.174	0.327 a	0.178	0.319 a	0.516 a	0.469 a
		MD	0.144	0.195 b	0.184	0.138 b	0.118	0.137 b	0.196	0.172 b	0.372 b	0.241 b

Withincolumn means of water regime of date followed by the same letters are not significantly different according to LSD at 0.05 level.

most of peanut genotypes did not significantly different for shoot growth rate under two water regimes in two years, whereas ICGV 98305 and Tainan 9 showed significant decrease for shoot growth rate between two water regimes in 2011/12 and 2012/13. After re-watering (75 DAP), most of peanut genotypes did not affect from MD in both years, whereas ICGV 98305 and KKU 60 showed the significant difference between two water regimes in 2011/12 and 2012/13 when compared to the other genotypes. Both peanut genotypes recovered to pre-stress values of shoot growth rate following re-watering fifteen days from MD. At 90 DAP, Tifton 8, Tainan 9 and KKU 60 showed difference for shoot growth rate between stress and non-stress conditions in both years. However, KS 2 is non-responsive growth because shoot growth rate among soil water treatments were not different with any days after planting.

Peanut genotypes under MD treatment had lower pod growth rate than the peanut genotypes having sufficient soil water. ICGV 98305, Tifton 8, KS 2 Tainan 9 had higher pod growth rate at 60, 75 and 90 DAP than MD in 2012/13 except for 2011/12. KKU 60 gave higher pod growth rate at all periods than MD in both years. In contrast, KS 2 was found significant difference for pod growth rate between two water regimes under stress and re-watering in the 2012/13.

DISCUSSION

Our results showed that the initiation of drought affected % RLD after fifteen days of withhold of irrigation (45 DAP). The increase in % RLD recognized that plants absorbed soil water content and nutrients from lower soil stratums and support plant growth and yield (Songsri *et al*., 2008; Turner *et al*., 2001).At severe drought (60 DAP), % RLD increased significantly higher than MD treatments at 60 DAP for ICGV 98305, Tifton 8, KS 2 and Tainan 9 except for KKU 60. It has showed that drought induced increase in growth of root system from the deeper layers to extract soil water from deeper layers under drought condition (Simpson, 1981).KKU 60, KS 2 and Tainan 9 were the best genotypes because they still have high % RLD under FC and MD conditions as indicated that these genotypes provide sufficient soil water and nutrient uptake under water stress conditions.

After fifteen days of withholding irrigation, peanut genotypes showed decrease in stomatal conductance in 2011/12 gradually. Similar to Cornic and Massacci (1996) reported that the first choice for plant to close stomata when the soil water limited. Yokata *et al*. (2002) reported that stomatal closer was an important mechanism for reduced photosynthesis under mild water stress. Moreover, stomatal closer correlated with higher water use efficiency, which decrease transpiration rate (Lazaridou and Koutroubas, 2004).Most of peanut genotypes showed high reduction in stomatal conductance at 60 DAP, indicating reduced transpirational water use under mid-season drought. In contrast, stomatal conductance of KS 2 showed low reduction, indicating maintained high transpirational water use under drought. In fact, leaf water status interacted with stomatal conductance and also a good correlation between stomatal conductance and leaf water potential (Anjum *et al*., 2011). The result agrees with Samarah *et al*. (2009), who reported that drought induced stomatal closer which result in declined rate of photosynthesis. Moreover, stomatal conductance recovered fully after fifteen and thirty days after re-watering in all peanut genotypes in 2011/12. However, the response of stomatal conductance might be related with the capacity of root system under drought condition. Jongrungklang *et al*. (2011) reported that peanut under well watered maintained a normal transpiration, whereas peanut under insufficient soil water had low water transpiration due to no reaction of root system to sustain transpiration. However, stomatal conductance was not only controlled by water stress but also operated by a complex interaction of the internal and external factors.

In 2012/13, stomata close under mid-season drought due to increase in abscisic acid. The rate of transpiration may be related with main mechanism conferring drought tolerance in plants can control with abscisic acid (Morgan, 1990). A decline of stomatal conductance may limit the net carbon dioxide absorb and water transpiration. The carbon dioxide insufficiency will decrease photosynthetic efficiency and dry matter production (Galmés *et al*., 2007; Lei *et al*., 2006). After re-watering, stomatal conductance regained fully close FC value after re-watering at 75 DAP and 90 DAP. Recovery stomatal conductance may result in increased carbon dioxide diffusion into the leaves to attain high photosynthesis rates (Vurayai *et al*., 2011). Moreover, plant increased reproductive growth and development since the enhanced photosynthetic capacity after re-watering (Müller *et al*., 2010).

Peanut genotypes grown under FC had significantly higher RWC than those grown under drought in 2011/12. This result decreased leaf water potential, relative water content and also increased in leaf temperature (Siddique *et al*., 2001). RWC showed small reduction and dropped significantly below FC treatment on 60 DAP. In fact, leaves exhibited large reduction in RWC under drought due to RWC related to water uptake by the roots as well as water loss by transpiration (Nayyar and Gupta, 2006). However, drought tolerance genotypes controlled leaf water status and maintained water use efficiency by reducing water loss. When the plants were re-watering after withholding at 75 DAP that has fully recover on RWC. A fast recovery of water potential could be possible to early and strong stomatal closer and the maintenance of leaf water content. The RWC of stressed plant were recovered following supplied with water again at 90 DAP. The result indicated that these characters were recovered to a higher level after 15 days of re-watering. However, most of peanut genotypes have probably better ability to maintain high leaf water status than Tainan 9 under MD conditions. The study at this time indicated that RWC could be a physiological trait to drought tolerance in peanut. In contrast of this study, some plant keeps high RWC under drought condition which may not be associated with drought tolerance (Martin and Ruiz-Torres, 1992).

Significant difference in RWC between stressed and non-stressed treatments were found in all peanut genotypes in 2012/13, in which peanut genotypes grown under FC had higher RWC than those grown under drought. RWC showed large reduction and dropped significantly below FC treatment on 60 DAP. Similar results were also found that in maize (Efeoglu *et al*., 2009) and rice (Lafitte, 2002), who reported that plants could maintain RWC as high as those for non-stressed plant when subjected to drought stress. From the result suggested that peanut genotypes had high RWC under mid -season drought indicating high water potential for a longer duration under water stress and control water loss through the stomata (Khan *et al*., 2010; Painawadee *et al*., 2009).In contrast, peanut genotypes had low RWC under mid-season drought indicated that they were susceptible to drought. RWC is a very importance traits which indicates drought tolerance as plant which showed restricted change in RWC per unit reduction of water potential are considered to be relatively drought resistance genotypes.

All of peanut genotypes showed high reduction for pod yield when subjected MD treatment in both years. This result indicated that peanut genotypes did not enhanced the assimilate portion to produce root growth to uptake more soil moisture during water stress condition. At 30 DAP, shoot growth rate were not significant different in most of peanut genotypes under two water regimes in both years, indicating that the peanut genotype may not be different growth at the beginning. At 45 DAP, most of peanut genotypes had higher shoot growth rate during FC than MD conditions in 2011/12. Our results are in agreement with the prior study that water stress during the vegetative stage increased root length while plant growth and plant development decreased (Zeid and Shedeed, 2006). However, one of the drought sensitive physiological mechanisms was cell growth that caused the reduction in turgor pressure (Taiz and Zeiger, 2006). While ICGV 98305 and Tainan 9 showed high reduction for shoot growth rate between two water regimes in 2011/12 and 2012/13. The result showed that growth is sensitive to drought and is influenced by the capacity of the roots to take up soil water and maintain an optimal plant water status (Tyree and Alexander, 1993). Moreover, plant growth decreased under water stress which is the result of the loosening water availability for turgor maintenance in cell (Smith and Stitt, 2007).Shoot growth rate response to MD could be associated with several mechanism that influence cell growth and expansion.

Pod growth rate is sensitive to MD than shoot growth rate because vegetative growth is severely constrained and photo-assimilate is diverted to reproductive structures. Peanut genotypes under MD treatment had lower pod growth rate than the peanut genotypes having sufficient soil water. The results showed that MD limited assimilated translocation and dry matter portioning in peanut. Moreover, most of peanut genotypes had higher pod growth rate at 60, 75 and 90 DAP than MD in 2012/13 except for 2011/12. The results revealed that pod development are progressively inhibited by drought due to insufficient soil moisture and lack of assimilate (Reddy *et al*., 2003). Girdthai *et al*. (2010) found that peanut pod yield is decreased when subjected to drought stress due to reduction in the photosynthetic rate and disrupts the carbohydrate metabolism (Farooq *et al*., 2009). Moreover, most of stressed peanut genotypes had lower pod growth rate than peanut having FC treatment, indicating that the assimilate portion may enhance to support the economic part. Prabawo *et al*. (1990) reported that re-watering after pod filling stages increased pod yields of Spanish type peanuts.

Finally, the induction of various morphological, physiological and biochemical responses were plants respond and adapt under drought condition. Mid-season drought affected on a series of process from growth, water relation, photosynthesis to yield formation. Peanut genotypes showed the difference response to mid-season drought for morphological and physiological characters. For morphological traits the shoot and root are the main components of plant adaptation under drought. Currently, peanut were the drought tolerance as indicating that genotypes are able to increase % RLD in the lower soil stratum under drought such as ICGV 98305, Tifton 8 and KKU 60 except for Tainan 9 and KS 2. The results revealed that peanut with high % RLD could help to extract soil water from deeper layers and sustain high plant water status and photosynthesis under drought then resulted in high pod yield (Farooq *et al*., 2009). Likewise, the response of plant to drought stress is complex mechanism. Drought stress greatly reduced stomatal conductance and RWC, which was dependent on the intensity and duration of drought (Reddy *et al*., 2003). From the result, most peanut genotypes greatly reduced stomatal conductance and RWC under drought except for KS 2. It is defined that decrease of RWC, close stomata and also blocks photosynthetic rate (Puangbut *et al*., 2010). However, mid-season drought decreased water use efficiency and photosynthesis, leading to the reduction on growth and yield. In our study, peanut genotypes recovered stomatal conductance and RWC after re-watering. In this study, peanut was good recovery genotypes as indicating that increase plant water status and photosynthetic capacity after re-watering. Likewise, drought tolerance mechanism involved various morphological and physiological processes may be useful in screening breeding material for drought tolerance program.

CONCLUSION

In our study, mid-season drought has been shown to both decrease stomatal conductance and relative water content and increase % RLD in all peanut cultivars. KKU 60, Tifton 8 and ICGV 98305 were the best genotypes under mid-season drought because of high% RLD, RWC and stomatal conductance under water stress. These peanut genotypes might be identified as the best genotypes having drought tolerance mechanism. Moreover, root length density is the importance trait associated with stomatal conductance and water potential in plant. The current study indicated that the response of peanut genotypes under re-watering condition is the best for high maintain plant water potential and photosynthesis which related to high pod yield. Also, RWC and stomatal conductance will be useful for screening criteria for drought resistance cultivars. Finally, the selection of peanut genotypes under mid-season drought pattern would improve breeding program.

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