Asian Journal of Plant Sciences

ISSN 1682-3974

Asian Journal of Plant Sciences 9 (7): 423-431, 2010
ISSN 1682-3974

Responses of Released Cultivars of Peanut to Terminal Drought for Traits Related to Drought Tolerance

[1]S. Boontang, [1]T. Girdthai, [1]S. Jogloy, [1]C. Akkasaeng, [1]N. Vorasoot,
[1]A. Patanothai and [2]N. Tantisuwichwong
[1]Department of Plant Science and Agricultural Resources,
Faculty of Agriculture, Khon Kaen University, Thailand
[2]Department of Biology, Faculty of Sciences, Khon Kaen University,
Khon Kaen 40002, Thailand

Abstract: The use of the surrogate traits with simple inheritance as selection criteria for drought tolerance should speed up the selection programs. The objectives of this study were to investigate the responses of released cultivars of peanut to end of season drought for traits related to drought tolerance and agronomics traits and to identify the released cultivars with tolerance to end of season drought. Ten peanut genotypes and two water regimes (field capacity; FC and 1/3 available water; 1/3 AW) were laid out in a split plot design with four replications for two years. The data were recorded for SPAD chlorophyll meter reading (SCMR), Specific leaf weight (SLW), biomass, pod yield, harvest index (HI), number of mature pods, 100-seed weight and number of seeds per pod. Drought increased SCMR and SLW and reduced biomass production, pod yield and seed size, whereas harvest index and number of pods per plants were not significantly affected. Maintaining high pod yield and number of pods per plant depended solely on high potential under well-watered conditions, whereas maintaining high biomass production and seed size and harvest index was dependent on both high potential and low reduction. SCMR and SLW were well associated and they had high correlations with biomass and pod yield. SCMR seemed to be more stable than SLW and it is recommended to be used as a surrogate trait for drought tolerance in peanut. The released cultivar KKU 60 was identified as drought tolerant by SCMR and SLW and by pod yield.

Key words: Harvest index, biomass, pod yield, surrogate trait, water regime

INTRODUCTION

Drought is a serious problem effecting peanut (*Arachis hypogaea* L.) productivity and quality worldwide. Drought can occur in at any growth stage of peanut because of unpredictable rainfall and rain distribution. Drought at pod development stage severely reduces pod yield, high incidences of *Aspergillus flavus* colonization and high aflatoxin contamination (Dwivedi *et al*., 2007; Reddy *et al*., 2003; Girdthai *et al*., 2010). The use of drought tolerant cultivars might alleviate drought problem. Conventional breeding has been concentrated on phenotypic value. The phenotype consists of genotype (G), environment (E) and interaction between genotype and environment (G x E interaction). Breeding to improve drought tolerance in peanut has been concentrated on pod yields and this method has slow progress because of large effect of G x E interaction and low heritability (Holbrook and Stalker, 2003). Pod yield has a low heritability because it is greatly influence by environment. The use of the surrogate traits with simple inheritance as selection criteria for drought tolerance should speed up the selection programs.

Specific leaf weight (SLW) and SPAD chlorophyll meter reading (SCMR) are physiological traits related to drought tolerance. Songsri *et al*. (2009) reported low G x E interaction estimates for SLW and SCMR. Peanut genotypes with high SLW under drought could maintain higher transpiration efficiency (TE) (Brown and Byrd, 1996). Peanut genotypes with low SLA (closely associated to SLW) could maintain higher relative water content (RWC) in the leaf, water use efficiency (WUE) and harvest index (HI) (Wright and Nageswara Rao, 1994; Nautiyal *et al*., 2002; Songsri *et al*., 2009). Thus, it is possible to use SLA as a surrogate trait to evaluate drought tolerance (Upadhyaya, 2005). SCMR is a simple trait and it is much easier to evaluate using a portable hand held chlorophyll meter. Peanut genotypes with high

Corresponding Author: S. Jogloy, Department of Plant Science and Agricultural Resources, Faculty of Agriculture, Khon Kaen University, Thailand Tel:+66043364637 Fax:+66043364637

SCMR under drought could maintain higher rate of photosynthesis per unit leaf area because of SCMR had positive correlation with chlorophyll contents and chlorophyll density (Arunyanark *et al*., 2008). SCMR also has strongly correlated with TE under water limited conditions (Sheshshayee *et al*., 2006).

Peanut production areas in Thailand are mainly in the North and the Northeast and peanut is grown as a cash crop by small-holder farmers under rainfed conditions. Drought commonly occurs in any growing condition even under irrigation because insufficient water supply especially in late growing season (Sukharomana and Dobkuntod, 2003). Previous investigations found that some of released cultivars had some degrees of drought tolerance under long term drought. However, the responses of released cultivars under end of season drought have not been investigated. A better understanding on degree of drought tolerance in commercial cultivars could be useful information to improve peanut cultivars with tolerance to terminal drought conditions.

The objectives of this study were to investigate the responses of released cultivars of peanut to end of season drought for traits related to drought tolerance and agronomics traits and to identify the released cultivars with tolerance to end of season drought.

MATERIALS AND METHODS

Plant material: Ten peanut genotypes were used in this study (Table 1). They are four elite drought tolerant lines from ICRISAT (ICGV 98308, ICGV 98324, ICGV 98348 and ICGV 98353), one drought tolerance line (Tifton 8) from the United States Department of Agriculture (USDA) and five released cultivars commonly grown in Thailand (Tainan 9, KK 60-3, KKU 72-1, KKU 1and KKU 60).

The experiment was conducted in a split plot design with four replications for two years in the dry season 2006/07 and in the dry season 2007/08 at the Field Crop Research Station, Faculty of Agriculture Khon Kaen University located in Khon Kaen Province, Thailand (latitude 16° 28′ N, longitude 102° 48′ E, 200 m above sea level). Soil type is Yasothon series (loamy sand, Ocix Paleustults) with the soil moisture of FC is 10.2% and permanent wilting point is 3.1%. Two soil moisture levels, FC (10.2%) and 1/3 AW (5.5%) in 0-60 cm depth were assigned in main plots and 10 peanut lines were laid out in subplots. Each entry was planted in five-row plots with 3 m in length and spacing of 40 cm between rows and 20 cm between plants within a row.

Crop management: Conventional tillage was practiced to prepare soil for planting. Lime at the rate of 625 kg ha^{-1} was applied at the first ploughing. Nitrogen fertilizer as urea at the rate of 18.75 kg N ha^{-1}, phosphorus fertilizer as triple superphosphate at the rate of 56.25 kg P ha^{-1} and potassium fertilizer as potassium chloride at the rate of 37.5 kg K ha^{-1} were incorporated into the soil during soil preparation 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} seeds before planting and seeds of the large seeded genotypes were treated with ethrel (2-chloroethylphospphonic acid) 48% at the rate of 2 mL^{-1} water to break dormancy. The seeds were over-planted and later the seedlings were thinned to obtain one plant per hill at 14 DAP. Weeds were controlled by the application of alachlor (2-cholro-2, 6'-diethyl-N-(methoxymethyl) acetanilide 48%, w/v, emulsifiable concentrate) at the rate of 3 L ha^{-1} at planting and hand weeding during the remainder of the season. Gypsum ($CaSO_4$) at the rate of 312 kg ha^{-1} was applied at 47 DAP. Carbofuran (2,3-dihydro-2,2-dimethylbenzofuran-7-ylmethylcarbamate 3% granular) was applied at the pod setting stage. Pests 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 the rate of 1.0 kg ha^{-1} and carboxin [5, 6-dihydro- 2-methyl-1, 4-oxathine-3 carboxanilide 75% wettable powder] at the rate of 1.68 kg ha^{-1}.

Table 1: Peanut genotypes used and their botanical types, branching pattern, growth habit and maturity

Genotypes	Botanical types	Branching patterns	Growth habit	Maturity	Source
ICGV 98308	Virginia bunch	Irregular (with out flower on main stem)	Semi-spreading (Document-3)	Medium	ICRISAT
ICGV 98324	Spanish bunch	Sequential	Erect	Medium	ICRISAT
ICGV 98348	Spanish bunch	Sequential	Erect	Medium	ICRISAT
ICGV 98353	Spanish bunch	Sequential	Erect	Medium	ICRISAT
Tainan 9	Spanish bunch	Irregular (with out flower on main stem)	Erect	Early	Thailand
KK 60-3	Virginia	Alternate	Spreading (Document-2)	Late	Thailand
KKU 72-1	Virginia	Alternate	Spreading	Late	Thailand
KKU 1	Spanish	Sequential	Erect	Early	Thailand
KKU 60	Virginia	Alternate	Erect	Early	Thailand
Tifton 8	Virginia	Alternate	Spreading (Document-2)	Late	USDA

Water management: A subsurface drip irrigation system (Super typhoon®; Netafim Irrigation Equipment and Drip Systems, Tel Aviv, Israel) with a distance of 20 cm between emitters was installed with a spacing of 40 cm between drip lines at 10 cm below the soil surface midway between peanut rows to supply water to the crop and fitted with a pressure valve and a water meter to ensure a uniform supply of the required amounts of water. Soil water level was maintained at FC at 0-60 cm depth. This soil depth should reasonably cover the majority of the root zone. In stress treatments, water was withheld at 60 DAP for 20 days according to 20 years historical pan evaporation data to allow soil moisture to gradually decline until reaching the predetermined levels of 1/3 AW at 80 DAP and then the soil moistures were held fairly constant until harvest. Irrigation was applied regularly to prevent soil moisture from increasing or decreasing by more than 1% in each plot. In maintaining the specified soil moisture levels, water was added to the respective plots by subsurface drip irrigation based on crop water requirement and surface evaporation, which were calculated following the methods described by Songsri *et al.* (2008).

Total crop water use for each water treatment was calculated as the sum of crop water requirement and soil evaporation. Crop water requirement was calculated as:

$$ET_{crop} = ET_0 x K_c$$

where, Et_{crop} is crop water requirement (mm day^{-1}), Et_0 is evapotranspiration of a reference plant under specified conditions calculated by pan evaporation method, Kc is the crop water requirement coefficient for peanut. Surface evaporation (E_s) was calculated as:

$$E_s = \beta x(E_0/t)$$

where, E_s is soil evaporation (mm), β is light transmission coefficient measured depending on crop cover, E_0 is evaporation from class A pan (mm day^{-1}), t = days from the last irrigation or rain.

Data collection

Weather parameters: Relative humidity, pan evaporation, rainfall, maximum and minimum air temperature and solar radiation during two cropping seasons were recorded

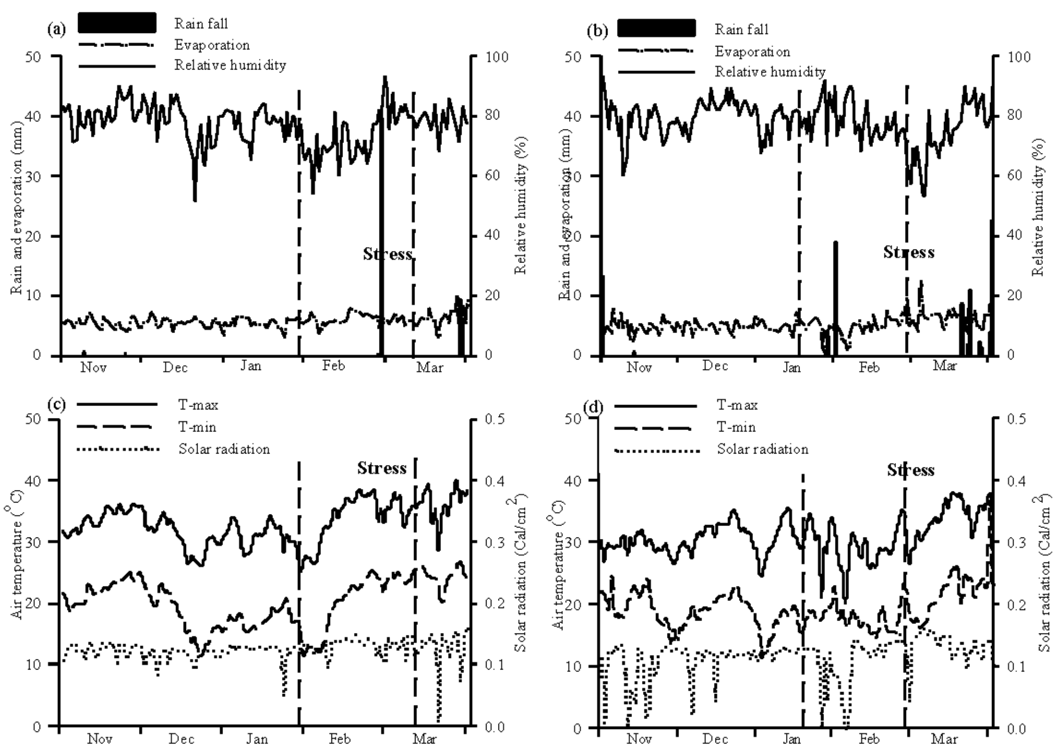

Fig. 1: Relative humidity (%) (a and b), pan evaporation (mm) (a and b), rainfall (mm) (a and b), maximum and minimum air temperature (°C) (c and d) and solar radiation (Cal cm^{-1}) (c and d) during the crop growth period in 2006/07 (a and c) and in 2007/08 (c and d)

daily from sowing until final harvest by a meteorological station located 600 m away from the experimental field. Forty mm of the total amount of rainfall was recorded during 80-100 DAP in 2006/07 and 22.7 mm was recorded during this period in 2007/08 (Fig. 1a-d). Air temperature, relative humidity and evaporation in 2006/07 were higher than in the 2007/08, especially during the water stress period. During stress period (80 DAP to final harvest), mean evaporation was 6.0 and 5.0 mm in 2006/07 and 2007/08, respectively. The maximum and minimum air temperature ranged from 11.8 to 38.5°C in 2006/07 and 14.5 to 35.2°C in 2007/08, being lower during 80-110 DAP in 2007/08. Relative humidity ranged from 54 to 93% in 2006/07 and from 57 to 92% in 2007/08. The seasonal mean solar radiation was 0.13 and 0.11 Cal cm^{-2} in 2006/07 and 2007/08, respectively.

Soil moisture status: Soil moisture in each main plot was monitored using the gravimetric method before planting, at planting and three times after planting (60 DAP, 80 DAP and at final harvest) at the depth of 0-5, 25-30 and 55-60 cm. Readings were taken from two positions in each main plot. The measurement before planting was used for calculating the correct amount of water to be applied for the crop. Soil moisture volume fraction was also monitored at 10 day intervals from planting to final harvest using a neutron moisture meter (Type I.H. II SER, No. N0152, Ambe Didcot Instruments Co. Ltd., Abingdon, UK). Five aluminium access tubes were installed in each main plot. Readings were taken in access tubes from the depth of 30-90 cm at 30 cm intervals.

SPAD chlorophyll meter reading and specific leaf weight: Data were recorded for SCMR and SLW at 80, 90 and 100 DAP. Five plants were randomly selected in each plot to record SCMR and SLW. Second fully-expanded leaves from the top of the main stems were observed during the morning period (0830-0930 h). The readings were recorded twice at the left and right sides for each leaflet using the SPAD Chlorophyll meter (Minolta SPAD-502 meter, Tokyo, Japan). Care was taken to ensure that the SPAD meter sensor fully covered the leaf lamina and to avoid the measurement of vein and midrib areas. The leaf samples were further taken to the laboratory for measurement of leaf area using a leaf area meter (LI 3100C Area Meter, LI-COR Inc., USA). The leaf samples were then dried at 80°C for 48 h to constant weight and dry weight was determined. SLW, the ratio of leaf dry weight to fresh leaf area (g m^{-2}) was calculated as:

$$\text{SLW} = \frac{\text{Leaf dry weight (g)}}{\text{Leaf area (m}^2\text{)}}$$

Agronomic traits: For each plot excluding boarder plants, three rows with 2.6 m in length (3.12 m^{-2}) were harvested at maturity (R8) (Boote, 1982) and their pods and roots were removed before taking fresh shoot weight in the field. Five plants were randomly selected for measuring shoot fresh weight and then oven dried at 80°C for 48 h and dry weight was measured. Shoot dry matter was then calculated and used in determining shoot dry weight for a plot. Pod yields were weighed after air drying to approximately 7-8% moisture content. Mature pods per plant were separated from immature pods and number of seeds per pod and 100 seed weight were also recorded at final harvest. HI was computed by the following formula:

$$\text{HI} = \frac{\text{Pod weight}}{\text{Total biomass}}$$

Statistical analysis: Homogeneity of variance was test and combined analysis of variance over two-year data was performed using general AOV statement function on Statistix 8 software. Because water regime x genotype interaction was significant, each water regime was analyzed separately according to a randomized complete block design (RCBD) (Gomez and Gomez, 1984). Least Square Difference (LSD) at p = 0.05 was used to compare means. A simple correlation was used to determine the relationship between SCMR, SLW, biomass and pod yield under drought conditions.

RESULTS

Soil moisture data: Soil moisture data between water treatments were different in both years. Soil moisture volume fraction measured by Neutron probe agreed well with those measured by gravimetric method. Average soil moisture contents under the drought conditions at 80 DAP (5.7% in both years) were lower than those of the non-stressed treatment (11.5% in 2006/07 and 10.2% in 2007/08, respectively) (Fig. 2 a and b). Soil moisture contents for drought treatment during the growing seasons were 8.2 and 8.1% in 2004/05 and 2005/06, respectively. Soil moisture contents under drought conditions gradually decreased from 60 DAP to 80 DAP. Soil moisture contents for drought treatment during the end of the season (80-120 DAP) were 5.7 to 5.9 and 5.7 to 5.2 in 2006/07 and 2007/08, respectively. After 80 DAP, the soil moisture contents for drought treatment and well-watered treatment were rather constant until harvest. The results confirmed that the water treatments were reasonably controlled at the predetermined levels.

Physiological traits: Drought generally increased SCMR and SLW at 80, 90 and 100 DAP (Table 2). The averaged

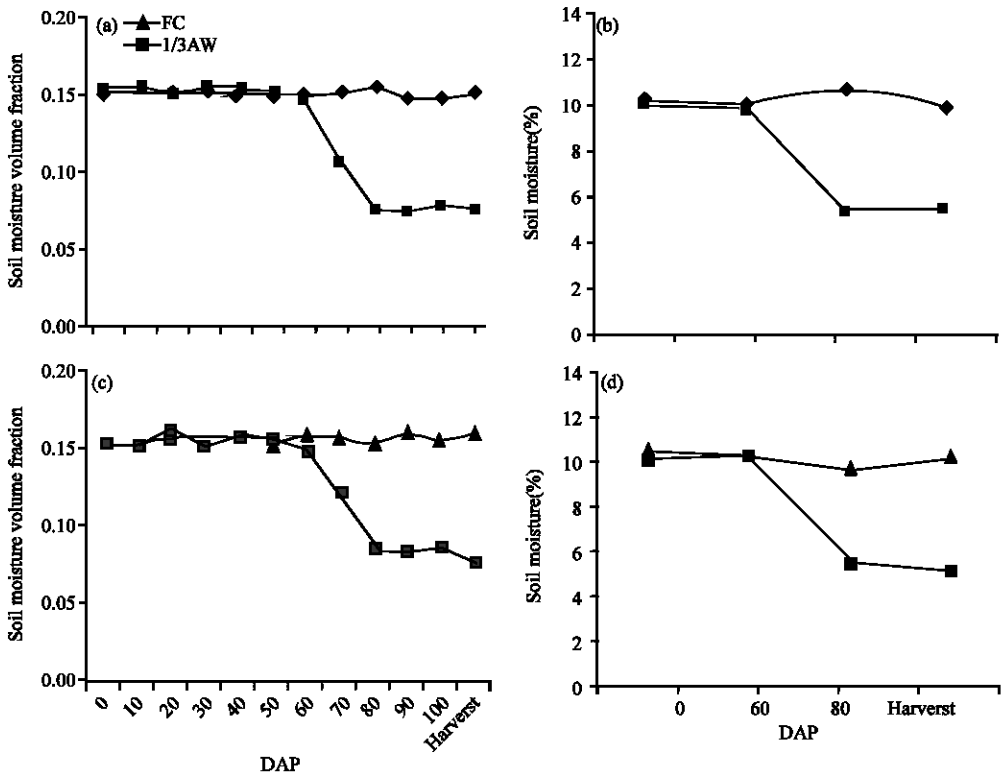

Fig. 2: Soil moisture volume fraction (a and c) at planting, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 days after planting (DAP) and at final harvest and gravimetric soil moisture content (b and d) at planting, 60, 80 DAP and at final harvest under difference water regimes [field capacity (FC) and 1/3 available water (1/3 AW)] averaged from 0-60 cm depth in (a and b) 2006-2007 and (c and d) 2007/2008

Table 2: SPAD chlorophyll meter reading (SCMR) and specific leaf weight of 10 peanut genotype under two water regimes, field capacity (FC) and 1/3 available water (1/3 AW)

	SCMR80		SCMR90		SCMR100		SLW80		SLW90		SLW100	
Genotypes	FC	1/3AW	FC	1/3AW	FC	1/3AW	FC	1/3AW	FC	1/3AW	FC	1/3AW
ICGV 98308	40.6b	42.2c	42.8c	45.4d	44.1c	47.0c	70.4ab	66.7ab	64.9bc	76.0ab	69.1cd	77.3ab
ICGV 98324	43.7a	45.9ab	46.0ab	50.7a	49.3a	50.5ab	68.0bc	69.9ab	67.3bc	78.8ab	70.2bc	78.6ab
ICGV 98348	40.5b	44.1bc	42.1c	47.7bcd	44.5bc	50.6ab	64.8cd	66.5ab	72.1ab	80.3a	71.5bc	80.7a
ICGV 98353	41.9ab	45.1b	42.0c	46.5cd	43.7c	48.6bc	71.7ab	70.9a	79.8a	76.3ab	70.2bc	78.9ab
Tainan 9	34.4c	36.3e	35.8d	37.1f	39.8d	40.9d	61.8d	53.8d	51.0d	63.1d	63.0de	65.2c
KK 60-3	43.7a	48.0a	44.5abc	48.7abc	47.2a	50.4ab	70.8ab	64.2bc	67.8bc	73.5bc	72.2bc	77.9ab
KKU 72-1	42.9ab	46.5ab	45.7ab	49.2ab	49.6a	51.8a	69.8ab	66.7ab	63.1c	79.9a	68.5cd	74.4b
KKU 1	36.4c	39.2d	38.3d	42.3e	39.5d	41.4d	60.0d	58.1cd	51.1d	68.7c	60.0e	68.4c
KKU 60	43.7a	48.2a	47.1a	49.5ab	47.0ab	51.2ab	74.5a	69.3ab	73.2ab	80.3a	84.4a	81.6a
Tifton 8	42.7ab	44.4bc	43.7bc	48.8abc	47.2a	47.7c	68.9bc	68.3ab	66.8bc	74.3b	76.4b	77.1ab
Average	41.1	44.0	42.8	46.6	45.2	48.0	68.1	65.4	65.7	75.1	70.6	76.0
CV	6.3	6.01	6.2	5.44	5.71	5.62	7.18	10.1	13.2	7.05	8.9	6.61
LSD	2.59	2.65	2.66	2.54	2.58	2.71	4.90	6.63	8.70	5.31	6.30	5.04
F-test	**	**	**	**	**	**	**	**	**	**	**	**
Genotype x year	ns	ns	ns	ns	ns	ns	ns	ns	ns	**	ns	*

ns, * and ** non significant, significant at p = 0.05 and significant at p = 0.01, respectively. Mean in the same column with the same letters are not significantly different by LSD at p = 0.05.

SCMR values for well-watered treatment were 44.1, 42.8 and 45.2 at 80, 90 and 100 DAP, respectively, whereas the SCMR values for drought treatment were 44.0, 46.6 and 48.0. The averaged SLW values for well-watered treatment were 68.1, 65.7 and 70.6 g m^{-2} at 80, 90 and 100 DAP, respectively and the values became 65.4, 75.1 and 76.0 g m^{-2} for drought treatment.

The responses to drought among peanut genotypes for SCMR and SLW at 80, 90 and 100 DAP were rather similar in patterns but somewhat different in the extents.

Therefore, the ranks of peanut genotypes were somewhat different among sampling dates. However, peanut genotypes showing consistently high SCMR across water regimes and sampling dates were ICGV 98324, KK 60-3, KKU 72-1 and KKU 60.

The peanut genotypes with high SLW across water regimes and sampling dates were ICGV 98308, ICGV 98324, ICGV 98348, ICGV 98353 and KKU 60.

It is interesting to note here that ICGV 98324 was the only one peanut genotype previously identified as drought tolerant having high SCMR, whereas all genotypes previously identified as drought tolerant had high SLW especially under drought. It is also interesting that KKU 60 showed high performance for SCMR and SLW.

Agronomic traits: Drought significantly reduced biomass production, pod yield and 100-seed weight, but it did not significantly affected harvest index and number of mature pods (Table 3). The reductions in biomass production and pod yield were rather severe, accounting for about 20% of those under well-watered conditions. The reduction 100-seed weight was rather low.

Biomass production ranged from 12,173 to 6,796 kg ha^{-1} in FC and 8,688 to 4,874 kg ha^{-1} in 1/3 AW (Table 3). Most cultivars reduced biomass production as affected by drought except for ICGV 98324. The most severe reduction in biomass production was observed in ICVG 98353. The cultivars with high biomass production under drought were KKU 72-1, KK 60-3, ICGV 98324, Tifton-8 and ICGV 98348. KKU 72-1 and KK 60-3 had high biomass production under drought primarily due to high biomass production under well-watered conditions, whereas ICGV 98324, Tifton-8 and ICGV 98348 had high biomass production under drought primarily due to low reduction.

Harvest index were varied from 0.22 to 0.39 in well-watered and 0.22 to 0.41 in water limited conditions. Although drought did not significantly affected harvest index, there were variations in harves t index under well-watered and drought conditions and the responses of individuals were also different. High harvest index was observed in all drought resistant lines under well-watered conditions (ICGV 98308, ICGV 98348, ICGV 98324 and ICGV 98353) from ICRISAT and also found in few released cultivars (KKU 60 and KKU 1). The results revealed that high potential of harvest index was important in maintaining high harvest index under drought and low reduction in harvest index was also important for maintaining high harvest index under drought.

Number of matured pod was slightly decreased from 23.7 to 22.1 pods plant^{-1} and pod yield was severely decreased from 3011.3 to 2289.8 kg ha^{-1} (Table 3). The findings revealed that peanut is somewhat tolerant to the reduction in mature pods but quite sensitive for pod yield. Because of reduction in mature pods was not significant, high number of mature pods under well-watered conditions should give more contribution to high number of mature pods under drought. High potential was also important for pod yield although, the reduction in pod yield was more severe.

The cultivars showing the consistently high number of pods across water regimes were KKU 60, ICGV 98308 and ICGV 98348 and the cultivars showing the consistently high pod yield across water regimes was KKU 60 only, although there were some cultivars showing high pod yield either under drought or well-watered conditions similar to those of KKU 60. The results suggested that KKU 60 was more drought tolerant than the lines previously identified as drought tolerant in term of pod yield.

Table 3: Biomass, harvest index (HI), pod yield, number of matured pod and 100-seed weight of 10 peanut genotypes under two water regimes, field capacity (FC) and 1/3 available water (1/3 AW)

	Biomass (kg ha^{-1})			HI			Pod yield (kg ha^{-1})			No. matured pod plant^{-1}			Seed weight (g 100-seed^{-1})		
Genotypes	FC	1/3AW	DTI	FC	1/3AW	DTI	FC	1/3AW	DTI	FC	1/3AW	DTI	FC	1/3AW	DTI
ICGV 98308	8748bc	7140bc	0.82abc	0.37a	0.37ab	1.00abc	3295.0bc	2581.9bc	0.78	27.2a	26.8a	0.99	56.0bcd	52.0c	0.93abc
ICGV 98324	8566bc	8459ab	0.99a	0.35a	0.29cd	0.83c	3112.3bc	2153.6cd	0.69	26.3ab	21.6b	0.82	51.4ef	46.5de	0.90bc
ICGV 98348	8408cd	7344abc	0.87ab	0.37a	0.39ab	1.05abc	2829.3c	2873.3ab	1.02	27.5a	26.8a	0.97	47.9f	48.7cd	1.02a
ICGV 98353	10108b	6340cd	0.63c	0.35a	0.31c	0.89bc	3482.3ab	2213.5cd	0.64	27.1a	21.3b	0.79	57.5bc	42.9e	0.75d
Tainan 9	6918de	5265de	0.76bc	0.26bc	0.23e	0.88c	1691.0d	1127.7f	0.67	19.9cd	16.4d	0.82	53.9cde	48.4cd	0.90bc
KK 60-3	12173a	8489ab	0.70bc	0.22c	0.22e	1.00abc	3031.8bc	2079.5de	0.69	19.1d	19.2bc	1.01	66.3a	58.1b	0.88c
KKU 72-1	12078a	8688a	0.72bc	0.28b	0.34bc	1.21a	3318.3bc	2816.6ab	0.85	22.8bcd	25.3a	1.11	67.5a	62.4a	0.92bc
KKU 1	6796e	4874e	0.72bc	0.37a	0.39ab	1.05abc	2202.1d	1635.8e	0.74	23.3abc	19.9bc	0.85	52.8de	50.4cd	0.95abc
KKU 60	8255cde	6472cd	0.78bc	0.39a	0.41a	1.05ab	4031.6a	3237.3a	0.80	24.1ab	25.5a	1.06	66.7a	60.7ab	0.91bc
Tifton 8	9616bc	8121ab	0.84ab	0.26bc	0.24de	0.92bc	3119.1bc	2178.8cd	0.70	19.4cd	18.3cd	0.94	59.4b	58.7ab	0.99ab
Average	9166.6	7119.2	0.78	0.32	0.32	0.99	3011.3	2289.8	0.76	23.7	22.1	0.94	57.9	52.9	0.91
CV	17.16	19.79	25.86	13.56	16.7	23.24	19.99	19.67	33.86	17.53	11.37	25.02	7.37	7.61	10.79
LSD	1576.5	1412.6	0.21	0.04	0.05	0.23	603.42	451.42	0.27	4.16	2.52	0.25	4.28	4.03	0.23
F-test	**	**	*	**	**	*	**	**	ns	**	**	ns	**	**	**
Genotype x year	*	ns	ns	**	ns	*	ns	ns	ns	**	ns	*	*	*	**

ns, * and ** non significant, significant at p = 0.05 and significant at p = 0.01, respectively. Mean in the same column with the same letters are not significantly different by LSD at p = 0.05.DTI were calculated by the ratio of stressed (1/3 available water (AW)) / non-stressed (field capacity (FC)) conditions

Table 4: Correlation between SPAD chlorophyll meter reading (SCMR), SLW, biomass and pod yield under 1/3 available water (1/3 AW)

Traits	Biomass	Pod yield	SCMR80	SCMR90	SCMR100	SLW80	SLW90
Pod yield	0.45						
SCMR80	0.72*	0.74**					
SCMR90	0.80**	0.74**	0.93**				
SCMR100	0.80**	0.82**	0.94**	0.92**			
SLW80	0.61	0.74**	0.82**	0.88**	0.83**		
SLW90	0.63*	0.92**	0.82**	0.89**	0.92**	0.88**	
SLW100	0.57	0.81**	0.85**	0.86**	0.87**	0.91**	0.88**

* and ** significant at p = 0.05 and significant at p = 0.01, respectively

The reduction in 100-seed weight though significant was not too severe, ranging from 57.9 to 52.9 g on average. The reductions in seed size were also significantly different among cultivars. The best cultivars for large seeds in both well-watered and drought conditions were given to KKU 72-1followed by KKU 60. Tifton-8 and KK 60-3 had smaller seeds than did KKU 72-1 and KKU 60 but they had larger seeds than other cultivars. Tifton-8 had larger seeds than did KK 60-3 under drought and *vice versa*. Similar to biomass production and pod yield, high potential was important in determining large seeds under drought. However, low reduction was also important in maintaining large seeds under drought.

Correlations between physiological traits and yields: The correlation coefficients between SCMR and biomass were positively significant under drought conditions and the correlation coefficients were 0.72**, 0.80** and 0.80** at 80, 90 and 100 DAP, respectively. The correlation coefficient between SLW and biomass production was significant at 90 DAP only with the correlation coefficient of 0.63* (Table 4). The correlation coefficients between SCMR and pod yield were significant with the correlation coefficient of 0.74**, 0.74** and 0.82** at 80, 90 and 100DAP, respectively. The correlation coefficients between SLW and pod yield were also significant and the correlation coefficient were 0.74**, 0.92** and 0.81** at 80, 90 and 100DAP, respectively.

Strong and positive correlation between SCMR and SLW were observed at all dates, whereas the SCMR and SLW were not related to HI, number of pods per plant, 100-seed weight and number of seed per pod (data not presented)

DISCUSSION

Physiological traits: The released cultivars have long been cultivated under diverse conditions where drought is a problem especially in the end of season. However, the released cultivars have not been tested for terminal drought tolerance. In this study, some released cultivars commonly grown in Thailand were tested for terminal drought tolerance compared to the tolerant lines previously identified by ICRISAT and USDA.

Drought generally increased SCMR and SLW. The increase in both characters would be primarily due to the increase in leaf thickness as a result of smaller leaves. Strongly correlation between SCMR and chlorophyll density under drought was observed (Arunyanark *et al*., 2009). This might indicate that drought did not impair chlorophyll in peanut and peanut has been reported to be drought tolerant species (Holbrook and Stalker, 2003). The maintenance of high chlorophyll under drought stress would be benefit to peanut.

The interactions between peanut cultivar and water regime for SCMR were not significant and SCMR was more stable than SLW (data not presented). Therefore, SCMR can be used for screening peanut genotypes for terminal drought tolerance. Similar to previous study, Arunyanark *et al*. (2009) found that SCMR was stable across water regimes and flexibility to application of SCMR for screening drought tolerance in peanut breeding programs. Measurement of SCMR is much easy than SLW and it is non-destructive and inexpensive. Thus, it should be useful for screening in a large scale of breeding materials (Madhava *et al*., 2003; Nigam and Aruna, 2008; Vasanthi *et al*., 2006).

The released cultivars KK 60-3, KKU 72-1 and KKU 60 had high SCMR similar to that of the tolerant line ICGV 98324, whereas the released cultivar KKU 60 had high SLW similar to all drought tolerant lines from ICRISAT. The results indicated that the released cultivars had degrees of drought tolerance as identified by SLW and SCMR especially for KKU 60 which was the best for both SCMR and SLW.

Agronomics traits and correlations: The goal of breeding for drought tolerance was to develop the new cultivars with high pod yield and good agronomic traits under drought. Peanut genotypes identified as drought tolerant by SCMR and SLW should be productive under drought conditions.

Drought severely reduced biomass production and pod yield. The reductions in the same patterns might be the reason for non-responsive harvest index. Drought also significant reduced seed size, but the reduction was less severe than biomass production and pod yield.

The reductions in biomass and pod yield as affected by drought are conclusive in peanut and the results also support previous finding. (Pimratch *et al*., 2008; Jongrungklang *et al*., 2008) also found that drought could reduce biomass production and pod yield in peanut.

The results were rather different from previous finding for harvest index (Nautiyal *et al*., 2002). In this study, average harvest index was not affected by drought. All drought tolerant lines from ICRISAT had high harvest index and the released cultivars with high harvest index were KKU 60 and KKU 1.

Number of pods per plant was slightly reduced by drought, but the reductions were not different among peanut cultivars. This similar to previous results from (Nageswara Rao *et al*., 1989) who found that the pod yield was reduced when peanut imposed with drought during the end of season. Similar to biomass, pod yield and harvest index, this character was strongly dependent on potential under well-watered conditions. All tolerant lines from ICRISAT had high number of pods and this could partially explain the tolerant of these lines. The released cultivar with high number of pods was KKU 60.

Although, the reduction in seed weight was not severe compared to those of pod yield and biomass productions, differential responses among peanut genotypes were observed. The results indicated that the reductions of individuals were different. Therefore, large seed under drought conditions was dependent on both high potential and low reduction.

The drought tolerant lines from ICRISAT generally had smaller seeds than did large-seeded peanuts (KKU 72-1, KK 60-3 and Tifton-8). The line ICGV 98348 and Tifton-8 had the lowest reduction in seed weight which might contribute to high pod yield under drought. In contrast KKU 60 and KKU 72-1 had high potential. Although the reductions were rather high, seeds of these cultivars were still larger than others.

SCMR and SLW were well associated. This similar to previous result from Nageswara Rao *et al*. (2001), who found that the SCMR was significantly correlated with SLW. SCMR had similarly high correlations with pod yield and biomass production, whereas SLW seemed to be better associated with pod yield than biomass production. This finding indicated that peanut genotypes with high SCMR under drought could maintain higher biomass production.

The high association of the physiological characters with pod yield indicated that both of physiological traits had high contribution to pod yield. Songsri *et al*.(2008) also found that SCMR was positively correlated with pod yield under water limiting conditions. This may due to peanut genotypes with high SCMR and SLW could maintain higher photosynthetic capacity, because of thicker leaves has more leaf Carbon Exchange Rate (CER) and chlorophyll contents (Arunyanark *et al*., 2009; Nautiyal *et al*., 2002). SCMR values were more strongly correlated with pod yield and other economic traits such as 100-seed weight at both 60 and 80 DAS than SLA. SCMR appeared to be more stable than SLA.

Present results supported previous finding and demonstrated that SCMR and SLW were useful in identifying peanut genotypes for tolerance to end of season drought. In this study KKU 60 was identified as drought tolerant based on SCMR and SLW and it was also identified by pod yield.

CONCLUSION

End of season drought reduced biomass production, pod yield and seed size. It did not significantly affect harvest index and number of pods per plant. However drought did increase SCMR and SLW. Peanut genotypes had similar responses for pod yield and number of seeds per pod. For these characters, high potential under well-watered conditions alone gave significant contribution to maintaining high pod yield and number of seeds per pod under drought. However, differential responses were observed for biomass production, harvest index and seed size. For these characters, both high potential and low reduction gave significant contribution to high biomass production, high harvest index and large seed size under drought. In this study, KKU 60 was identified as drought tolerant based on SCMR and SLW and pod yield. The tolerance level was similar to that of the best lines previously identified as drought tolerant by ICRISAT.

ACKNOWLEDGMENTS

The author grateful for the Commission on Higher Education of Thailand, the Basic Research for Supporting Groundnut Varietal Improvement for Drought Tolerance, the Senior Research Scholar Project of Prof. Dr. Aran Patanothai under the Thailand research fund and KKU Senior Research Scholar Project of Associate Prof. Dr. Sanun Jogloy for financial support.

REFERENCES

Arunyanark, A., S. Jogloy, C. Akkasaeng, N. Vorasoot and T. Kesmala *et al*., 2008. Chlorophyll stability is an indicator of drought tolerance in peanut. J. Agron. Crop Sci., 194: 113-125.

Arunyanark, A., S. Jogloy, N. Vorasoot, C. Akkasaeng, T. Kesmala and A. Patanothai, 2009. Stability of relationship between chlorophyll density and soil plant analysis development chlorophyll meter readings in peanut across different drought stress conditions. Asian J. Plant Sci., 8: 102-110.

Boote, K.J., 1982. Growth stage of peanut (*Arachis hypogaea* L.). Peanut Sci., 9: 35-40.

Brown, R.H. and G.T. Byrd, 1996. Transpiration efficiency, specific leaf weight and mineral concentration in peanut and pearl millet. Crop Sci., 36: 475-480.

Dwivedi, S.L., D. J. Bertioli, J.H. Crouch, J. F.Valls and H.D. Upadhyaya *et al*., 2007. Peanut. In: Genome Mapping and Molecular Breeding in Plants, Kole, C., (Eds.). Springer-Verlag, New York.

Girdthai, T., S. Jogloy, N. Vorasoot, C. Akkasaeng, S. Wongkaew, C.C. Holbrook and A. Patanothai, 2010. Associations between physiological traits for drought tolerance and aflatoxin contamination in peanut genotypes under terminal drought. Plant Breed., 10.1111/j.1439-0523.2009.01738.x

Gomez, K.A. and A.A. Gomez, 1994. Statistical Procedures for Agricultural Research. 2nd Edn., John Wiley and Sons, New York, pp: 680.

Holbrook, C.C. and H.T. Stalker, 2003. Peanut breeding and genetic resources. Plant Breed. Rev., 22: 297-356.

Jongrungklang, N., B. Toomsan, N. Vorasoot, S. Jogloy, T. Kesmala and A. Patanothai, 2008. Identification of peanut genotypes with high water use efficiency under drought stress conditions from peanut germplasm of diverse origins. Asian J. Plant Sci., 7: 628-638.

Madhava, H.B., M. S. Sheshshayee, A.G. Shankar, T.G. Prasad and M. Udayakumar, 2003. Use of SPAD chlorophyll meter to assess transpiration efficiency of peanut. Proceedings of Breeding of Drought-Resistance Peanut, Feb. 25-27, ACIAR., pp: 3-9.

Nageswara Rao, R.C., H.S. Talwar and G.C. Wright, 2001. Rapid assessment of specific leaf area and leaf nitrogen in peanut (*Arachis hypogaea* L.) using chlorophyll meter. J. Agron. Crop Sci., 189: 175-182.

Nageswara Rao, R.C., J.H. Williams and M. Singh, 1989. Genotypic sensitivity to drought and yield potential of peanut. Agron. J., 81: 887-893.

Nautiyal, P.C., R.C. Nageswara Rao and Y.C. Joshi, 2002. Moisture-deficit-induced changes in leaf-water content, leaf carbon exchange rate and biomass production in groundnut cultivars differing in specific leaf area. Field Crops Res., 74: 67-79.

Nigam, S.N. and R. Aruna, 2008. Stability of soil plant analytical development (SPAD) chlorophyll meter reading (SCMR) and specific leaf area (SLA) and their association across varying soil moisture stress conditions in groundnut (*Arachis hypogaea* L.). Euphytica, 160: 111-117.

Pimratch, S., S. Jogloy, N. Vorasoot, B. Toomsan, A. Patanothai and C.C. Holbrook, 2008. Relationship between biomass production and nitrogen fixation under drought-stress condition in peanut genotypes with different levels of drought resistance. J. Agron. Crop Sci., 194: 15-25.

Reddy, T.Y., V.R. Reddy and V. Anbumozhi, 2003. Physiological responses of groundnut (*Arachis hypogaea* L.) to drought stress and its amelioration: A critical review. Plant Growth Regul., 41: 75-88.

Sheshshayee, M.S., H. Bindumadhava, N.R. Rachaputi, T.G. Prasad, M. Udayakumar, G.C. Wright and S.N. Nigam, 2006. Leaf chlorophyll concentration relates to transpiration efficiency in peanut. Ann. Applied Biol., 148: 7-15.

Songsri, P., S. Jogloy, C.C. Holbrook, T. Kesmala, N. Vorasoot, C. Akkasaeng and A. Patanothai, 2009. Association of root, specific leaf area and SPAD chlorophyll meter reading to water use efficiency of peanut under different available soil water. Agric. Water Manage., 96: 790-798.

Songsri, P., S. Jogloy, N. Vorasoot, C. Akkasaeng, A. Patanothai and C.C. Holbrook, 2008. Root distribution of drought-resistant peanut genotypes in response to drought. J. Agron. Crop Sci., 194: 92-103.

Sukharomana, S. and B. Dobkuntod, 2003. Peanut in the Thai food system: A macro perspective. Peanut in local and global food systems series report No. 8, Department of Anthropology, University of Georgia, Athens, Georgia, U.S.A.

Upadhyaya, H.D., 2005. Variability for drought resistance related traits in the mini core collection of peanut. Crop Sci., 45: 1432-1440.

Vasanthi, R.P., P.V. Reddy, V. Jayalakshmi, P. Sudhakar and M. Asalatha *et al*., 2006. A high-yielding drought-tolerance groundnut variety Abhaya. Int. Arachis Newlett., 26: 15-16.

Wright, G.C. and R.C. Nageswara Rao, 1994. Groundnut Water Relations. In: The Groundnut Crop, Smartt, J. (Eds.), Chapman and Hall, London. ISBN: 0 412 40820 1, pp:281-325.