Reproductive efficiency and yield responses of Valencia peanut genotypes under terminal drought conditions

Rita Valentin Manjonda[1], Nimitr Vorasoot[1], Naveen Puppala[3], Amade Milian Muetia[4] and Sanun Jogloy[1, 2*]

ABSTRACT: Drought at different growth stages has different effects on peanut (*Arachis hypogaea* L.). Terminal drought greatly affects reproductive traits and consequently reduce pod yield. The objective of this study was to determine the reproductive efficiency responses and yield of Valencia peanut genotypes under terminal drought conditions. A 2 × 9 factorial experiment consisting of nine peanut genotypes and two water regimes (full irrigation and drought stress) was used, and the treatments were arranged in a randomized complete block design with four replications at the Field Crop Research Station of Khon Kaen University, Thailand during July to October 2016. Based on flower number and number of reproductive parts, the data were recorded for the number of reproductive sink number (hanging pegs + total pods) and number of total pods (immature and mature pods/plant) at harvest. Reproductive efficiency traits (RET), including percentage of flower to peg (RET1), percentage of the peg to the pod (RET2), percentage of the pod to mature pod (RET3) and percentage of flower to mature pod (RET4) were recorded at harvest. All Valencia genotypes had produced flowers under drought stress conditions, but they had lower conversion of flowers to economic yield. Valencia peanut genotypes have different number of reproductive traits and yield. Genotypes (ICG 14127 and ICG 10092) with high reproductive efficiency responses (RET1, RET2 and RET4) also showed high yield. Genotypes ICG 14127 and ICG 10092 with high number of mature pods/plant performed well under drought stress.

Keywords: groundnut, water stress, mature pods, flower number

Introduction

Peanut (*Arachis hypogaea* L.) is one of the important grain legume crop of tropical and semi-arid tropical regions. It has been cultivated as an important source of edible oil, vegetable protein and cash crop for the small-holder farmers (Prasad et al., 2009). However, drought is an important factor limiting peanut yield in the tropics. Drought can occur at any growth stage of peanut and cause yield reduction of more than 70% (Prasad et al., 2009). Previous studies in peanut indicated that water deficit at the early growth stage, or pre-flowering stage did not have a detrimental effect on peanut yield. In some cases, it could increase yield (Nageswara Rao et al., 1985, 1988; Nautiyal et al., 1999). However, drought during flowering can decrease flower number and delay days to flowering (Pallas et al., 1977; Nageswara Rao et al., 1988; Harris et al., 1988). On the other hand, water deficit in the pegging and podding zone have an important

[1] Department of Plant Science and Agricultural Resources, Faculty of Agriculture, Khon Kaen University, Khon Kaen, 40002, Thailand

[2] Peanut and Jerusalem Artichoke Improvement for Functional Food Research Group, Khon Kaen University, Khon Kaen, 40002, Thailand

[3] Plant and Environmental Science, Agricultural Science Center, New Mexico State University, Clovis, NM 88101

[4] Mozambique Agricultural Research Institute, Nampula Research Station, Av. FPLM km 7

* Corresponding author: sjogloy@gmail.com

influence on reproductive growth as peg penetration and conversion of peg into pod are largely influenced by pod zone water content (Boote, 1982). Drought at later growing season during pegging and pod development (Pallas et al., 1977; Boontang et al., 2010) can severely reduce pod yield by decreasing pod growth and development and reducing pod number rather than kernel weight per pod (Pallas et al., 1977), pod size, pod filling and number of mature pods (Nageswara Rao et al., 1988; Nautiyal et al., 1999; Awal and Ikeda, 2002). Girdthai et al. (2010) reported that insufficient water occurring during the pod-forming and seed-filling phase has been observed to cause the largest reduction in peanut pod yield. Drought reduced peanut yields of about 24%-35% (Boontang et al., 2010; Girdthai et al., 2010). Songsri et al. (2009) reported that severe drought has large effect on reproductive traits, conversion of flower to reproductive sink and reproductive sink to pod yield. Most studies so far have been reported in Virginia and Spanish type peanut genotypes. Different peanuts types may respond differently to drought stress, and the information on the response of Valencia type peanut to terminal drought is still lacking. The objectives of this study were to determine the reproductive efficiency and yield responses of Valencia peanut genotypes under terminal drought.

Materials and methods

A pot experiment was conducted during July to October 2016 under high humidity and high temperature conditions at the Field Crop Research Station, Faculty of Agriculture, Khon Kaen University, Khon Kaen province, Thailand (latitude 16º 28´ N, longitude 102º 48´ E, and 200 m above sea level).

Experimental design and plant materials

A 2 × 9 factorial experiment was laid out in the pots under greenhouse conditions. The treatment combinations of 2 water regimes and nine peanut genotypes were arranged in a randomized complete block design with four replications. Two water levels included full irrigation and drought stress starting at 60 days after emergence (DAE) to harvest, and nine peanut genotypes consisted of ICG 10092, ICG 10890, ICG 14127, ICG 6888, PI 536121, KK 4, ICG 14106, PI 365564 and ICGV 98324. ICGV 98324 were kindly provided by the International Crop Research Institute for the Semi-arid Tropics and was used as a drought resistant check (Nigam et al., 2003). In earlier investigations of our project, it was identified as drought resistance because of its high total biomass and high pod yield under drought condition (Koolachart et al., 2013).

Experimental management

Pot and soil preparation

The plants were grown in cylindrical pots with inner diameter of 24 cm and height of 70 cm. Five pots were assigned to each treatment in a replication and, therefore, one replication with 18 treatment combinations had 90 pots. There were 360 pots for the experiment. Prior to planting, soil samples were taken at the field from 2 points at the depths of 0-5 cm, 25-30 cm and 45-50 cm and oven dried at 105 $^{\circ}$C during 72 hours. The oven dry soil samples were weighted and bulk density

was calculated. The soil was taken from the field and air dried. Two dry soil samples were taken for laboratory analysis to determine the physical and chemical properties. Each pot was filled with air dry soil of 42 kg to 10 cm from the top, making a soil volume of 0.029 m^3 for each pot. Soil was separated into four layers with the same volume (10.5 kg of soil) to create uniform 1.55 g/cm^3 bulk density.

Cultural practices

The seed used in this experiment was obtained from a seed multiplication plot. The plot was prior planted at the Field Crop Research Experimental Station, Faculty of Agriculture, Khon Kaen University, Khon Kaen province, Thailand. Four seeds were planted in each pot and the seedlings were then thinned to two plants per pot at 14 DAE. Rhizobium with a water diluted commercial peat-based inoculum of *Bradyrhizobium* (mixture of strains THA 201 and THA 205; Department of Agriculture, Ministry of Agriculture and Cooperatives, Bangkok, Thailand) was applied at the rate of 13 g/l of water just after planting. Potassium fertilizer as muriate of potash (KCl) at 0.34 g/pot was applied to each pot at 7 DAE. Gypsum ($CaSO_4$) at the rate of 1.42 g/pot was applied into the soil at 30 DAE to supply calcium for development of pods and seeds. Carbofuran (2, 3-dihydro-2, 2-dimethylbenofuran-7-ylmethylcarbamate 3% granular) was applied to the soil prior planting and at the pod setting stage to control soil insects. Pests and diseases were controlled by weekly application of carbosulfan [2,3-dihydro-2,2-dimethylbenzofuran-7-yl methylbamate 20% w/v water soluble concentrate] at 2.5 l/ha, methomyl [S-methyl-N (methylcarbomoyl) Oxy thioacetimidate 40% soluble powder] at 1.0 kg/ha and carboxin [5, 6-dihydro-2 methyl-1, 4-oxath-in-3-carboxanilide 75% wet table powder] at 1.68 kg/ha and weeds were controlled by hand.

Water management

Prior to planting, full irrigation was applied in each pot to facilitate uniform emergence. Soil moisture for all pots was maintained at this level from planting to 60 DAE. Full irrigation treatment was resumed at the field capacity (FC) level until harvest. Drought stress treatment was commenced at 60 DAE by withholding irrigation until soil moisture was reduced to 1/3 available water (1/3 AW) water at 80 DAE and the soil moisture was maintained at this level until harvest. Water losses were calculated for full irrigation and drought treatments and the amounts of water losses were replenished daily to the pots on the soil surface. The total crop water use for each treatment was calculated using the methods described by Doorenbos and Pruitt (1992);

$$ETcrop = ETo \times Kc$$

Where ETcrop is the crop water requirement (mm/day), ETo is evapotranspiration of the reference plant under specificed treatment calculated by pan evaporation method and Kc is a crop water requirement coefficient for peanut, which varies depending on growth stage.

Data collection

Weather parameters and soil properties

Weather data, such as relative humidity (RH %), evaporation (mm), rainfall (mm), maximum and minimum air temperature (ºC), were recorded daily from planting until harvest by the nearest meteorological station located 50 m away from the greenhouse. The physical and chemical

properties of the soil were determined before filling the pots. Soil samples were taken from two points at the depths of 0-50 cm and the bulk of all soil samples was analyzed to determine physical properties such as sand, silt, clay (%) and chemical properties such as soil pH, electrical conductivity, cation exchange capacity, organic matter, total nitrogen, available phosphorus, exchangeable potassium and exchangeable calcium. The soil physical and chemical data were presented in (**Table 1**).

Soil moisture content

Soil moisture content in the pot was measured at the depth of 0-60 cm using micro augur at 75, 90 DAE and final harvest for determining the soil moisture in the pots. Soil samples from all factor B treatments (peanut genotypes) were measured. The soil moisture was calculated using the formula below;

Soil moisture = [(fresh weight-dry weight) / (dry weight)] × 100.

Relative water content (RWC)

Relative water content in leaves was measured for leaf water status at 10:00-11:30 am (Thailand standard time). Four leaflets from the second fully expanded leaf from the top of the main stem in each pot were taken at 60, 75 and 90 DAE. The samples were put into sealable plastic bags, stored in an ice box and transported to an air-conditioned room. Leaf fresh weight (LFW) was measured immediately after harvest. The leaflets were soaked in distilled water on plastic plates for eight hours and leaf turgid weight (LTW) was determined. The samples were put in paper bags and oven dried at 80 ºC for 48 hours or until the constant weights and weighted (LDW). RWC was determined using the formula suggested by Turner (1986);

RWC (%) = [(LFW-LDW)/ (LTW-LDW)] × 100

Where: LFW is leaf, fresh weight, LTW is leaf turgid weight (saturated weight) and LDW is leaf dry weight.

Number of reproductive parts

Number of flowers were recorded every day on 2 pots of each experimental unit, and 2 plants from each pot during morning time (6:00-8:00 am Thailand standard time) from the first day of flowering (25 DAE) until harvesting. Number of reproductive parts such as the number of pegs (reproductive sink number = hanging pegs + total pods), number of total pods (immature and mature pods) were recorded at harvest, and number of mature pods per plant (mature pods were separated from immature pods, which was identified by dark internal pericarp color). Four reproductive efficiency traits (RET) were calculated based on the following formulae (Songsri et al., 2009);

RET1 = (reproductive sink number/ flower number) × 100,

RET2 = (total pod number/ reproductive sink number) × 100,

RET3 = (mature pod number/ total pod number) × 100 and

RET4 = (mature pod number/ flower number) × 100.

Yield and yield components

Yield and yield components such as pod yield, seed yield, mature pod number per plant, seed number per pod and seed size were determined at the final harvest. Two plants were harvested from two pots and pods were separated from the plant and air dried to approximately 8%

moisture content and recorded.

Statistical analysis

The data were subjected to analysis of variance (ANOVA) following the method described by Gomez and Gomez (1984). Individual analysis of variance was performed for each character based on a factorial experiment in a RCBD using Statistix8 analytical software (Statistix8, 2003). The least significant difference (LSD) was used to detect significant differences among means. Simple correlation was estimated between pod yield and yield components.

Results

Weather parameters

The experiment was conducted under greenhouse conditions. It was planted in July and harvested in October 2016 in high humidity and high temperature conditions. During the crop season, the maximum and minimum air temperature ranged from 22 to 37 ^{o}C. The mean daily pan evaporation was 3.86 mm and the total rainfall was 815.5 mm (**Figure 1**)

Soil moisture

Soil moisture content of the two water regimes was monitored by the gravimetric method at the depth of 0-60 cm. The amounts of water for drought stress and full irrigation treatment refilled to the containers on the soil surface based on crop water requirement. Water contents for drought stress at 75 and 90 DAE were lower than full irrigation treatment (**Figure 2**).

Relative water contents

Relative water contents for drought stress at 60 and 75 DAE were not significantly different from full irrigation treatment (**Figure 3**). Although it was not significant differences, the reductions in relative water contents for drought stress was observed as early as 75 DAE. At 90 DAE, it was significant difference between two water regimes. The results might indicate that relative water content at 75 DAE was not sensitive enough to detect the difference between drought stress and full irrigation treatment compared to soil moisture content.

Weekly flower distribution

The distribution patterns of peanut genotypes grown under drought stress and full irrigation were similar, except that peanut genotypes grown under drought stress produced fewer flowers than did the genotypes grown under full irrigation (**Figure 4**). All peanut genotypes started their flower production at the 3-4 weeks after emergence. Flower distributions could be classified into three different patterns, including bimodal pattern with high peak at early flowering, bimodal pattern with high peak at late flowering and uni-modal pattern. Generally, all Valencia genotypes had two peaks at 5-6 weeks after emergence and 9-10 weeks after emergence, and they were grouped into bimodal patterns (peak early and peak late). ICGV 98324 (Spanish type peanut) had a peak at 10 weeks after an emergence and it is grouped into uni-modal pattern.

Reproductive traits

As the interactions between genotypes and water regimes were not significant for all traits

(data not shown). Water regimes were significantly different (P<0.05) for RET1, percentage of conversion of flower to reproductive sink (peg and pod), RET2, percentage of conversion of the peg to the pod, and RET4, percentage of conversion of flower to mature pod or economic yield except for RET3, percentage of conversion of the pod to mature pod (**Table 2**). Full-irrigation treatment was significantly higher than drought treatment for RET1, RET2 and RET4. Peanut genotypes were significantly different for RET1, RET2, RET3 and RET4. ICG 14127 had a high percentage of conversion of flower to peg (72.2%), whereas ICG 6888 had the lowest percentage of (36.30%). ICG 10092 performed better for percentage of conversion of the peg to pod (58.73%) and ICG V98324 had the lowest percentage of (29.86%). ICG 10092 and ICG 14127 had a high percentage of conversion of flower to mature pod (16.75% and 13.76%,respectively), whereas ICGV 98324 had the lowest percentage of conversion of the peg to pod (3.86%). KK 4, ICG 14106 and PI 365564 had a high percentage of conversing pod to mature pod (57.23%, 53.38% and 56.98%, respectively), whereas ICGV 98324 had the lowest percentage of conversing pod to mature pod (27.40%).

Yield and yield components

Water regimes were significantly different (P<0.05) for pod yield, seed yield and pod number per plant, and fully-irrigation was significantly higher than drought stress for these traits (**Table 3**). However, they were not significantly different for seed number per pod and seed size. Peanut genotypes were also significantly different (P<0.05) for pod yield, seed yield, and pod number per plant, but they were not significantly different for seed number per pod and seed size. ICG 14127 exhibited high pod and seed yield (6.17 g/plant and 4.48 g/plant, respectively) and PI 536121 had low pod and seed yield per plant (1.44 g/ plant and 0.92 g/ plant, respectively). ICG 14127 exhibited a high number of pods per plant (14.19), whereas PI 536121 had the lowest number of pods per plant (4.69). Pod number per plant was significant (r = 0.90*-0.97*) correlated with pod yield, whereas the seed number per pod and seed size were not significantly correlated with pod yield (**Figure 5**). The results might indicate the importance of pod number per plant for high yield of peanut under drought condition.

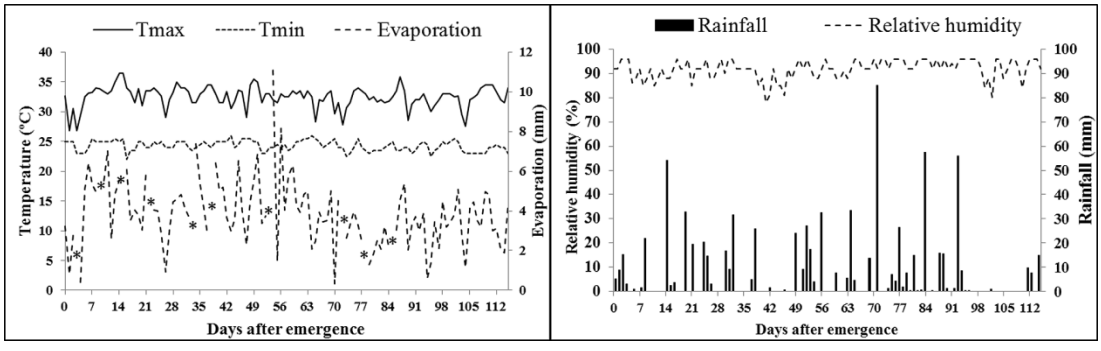


Figure 1 Maximum (T-max) and minimum (T-min) temperature, evaporation (mm), rainfall (mm) and relative humidity (%) during the crop season (July-October 2016) ; *, data not available.

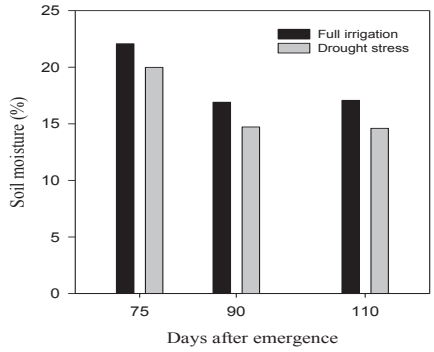


Figure 2 Soil moisture content of full irrigation and drought stress at 75, 90 days after emergence (DAE) and at harvest (110 DAE)

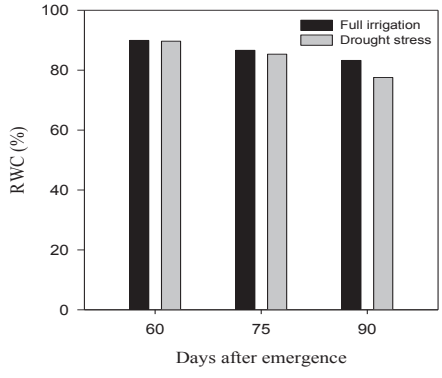


Figure 3 Relative water content (RWC) at 60, 75 and 90 days after emergence under full-irrigation and drought stress

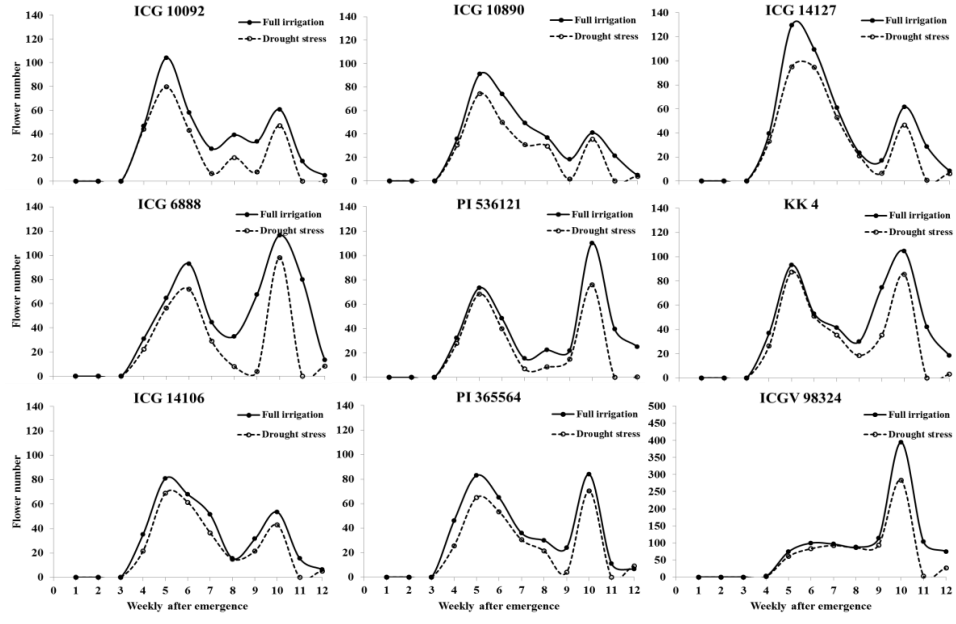


Figure 4 Weekly flower distribution of 9 peanut genotypes under full-irrigation and drought stress

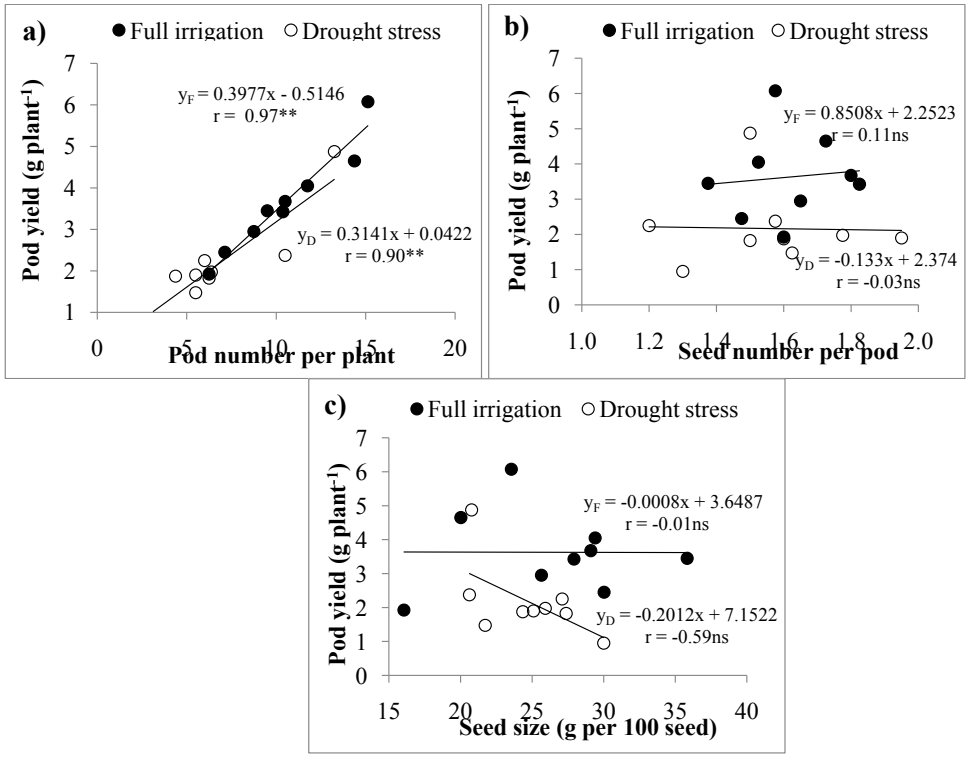


Figure 5 Correlation between pod yield with pod number/plant (a), seed number/ pod (b) and seed size (c) under full irrigation and drought stress

Table 1 Physical and chemical properties of the soil analysis used in the experiment

Soil chemical properties						
pH (1:1 H_2O)	EC (1:5 H_2O) (dS/m) at 25ºC	CEC (c mol/kg)	Organic matter (%)	Total N (%)	Available P (mg/kg)	Exchangeable K (mg/kg)
5.62	0.081	10.27	0.758	0.036	11.85	53.54

Soil physical properties (USDA system)			
% Sand (2.0-0.05 mm)	% Silt (0.05-0.002 mm)	% Clay (<0.002 mm)	Texture Class
69.93	18.07	12.00	Sandy loam

Table 2 Reproductive efficiency traits (RET) of 9 peanuts genotypes grown under full- irrigation and drought stress

Treatments	RET1 (%)[1]	RET2 (%)	RET3 (%)	RET4 (%)
Water Regimes				
Full irrigation	52.54 a[2]	48.41 a	46.13 a	11.75 a
Drought stress	43.70 b	34.40 b	44.40 a	7.06 b
Genotypes				
ICG 10092	60.40 ab	58.73 a	47.96 ab	16.75 a
ICG10890	54.40 bc	38.29 cd	37.53 bc	9.80 b
ICG14127	72.24 a	51.66 ab	35.96 bc	13.76 a
ICG6888	36.30 d	40.80 c	45.91 ab	6.89 bc
PI536121	37.18 d	41.68 bc	45.03 ab	6.95 bc
KK4	43.03 cd	36.61 cd	57.23 a	7.70 bc
ICG 14106	42.01 cd	41.28 c	53.38 a	9.88 b
PI365564	45.38 cd	33.75 cd	56.98 a	9.03 b
ICGV 98324	42.19 cd	29.86 d	27.43 c	3.86 c
CV (%)	28.26	24.78	34.47	40.97

[1] RET1 = (Reproductive sink/ flower number) × 100, RET2 = (Pod number/ reproductive sink) × 100, RET3 = (Mature pod number/ pod number) × 100, RET4 = (Mature pod/flower number) × 100

[2] Means with the same letter(s) in each column of each factor are not significantly

Table 3 Yield and yield components of 9 peanut genotypes grown under full- irrigation and drought stress condition

Treatments	Yield (g/ plant)		Yield components		
	Pod yield	Seed yield	Pod number/ plant	Seed number/ pod	Seed size (g/ 100 seeds)
Water regimes					
Full irrigation	3.81a[1]	2.67a	10.42a	1.62a	29.15a
Drought stress	2.45b	1.74b	7.04b	1.56a	28.37a
Genotype					
ICG 10092	4.32b	2.89b	12.44ab	1.65a	30.17a
ICG 10890	3.01cd	2.20bc	7.86cd	1.71a	30.19a
ICG 14127	6.17a	4.48a	14.19a	1.54a	30.04a
ICG 6888	2.06de	1.53cd	6.31de	1.55a	29.49a
PI 536121	1.44e	0.92d	4.69e	1.45a	25.71a
KK 4	2.74cd	1.94c	8.38cd	1.65a	28.24a
ICG 14106	2.66cd	1.96c	7.50cde	1.66a	30.46a
PI 365564	2.46cde	1.66cd	7.56cd	1.71a	25.76a
ICGV 98324	3.32bc	2.27bc	9.63bc	1.36a	26.16a
CV (%)	32.18	38.07	32.22	24.6	26.3

[1] Means with the same letter(s) in each column of each factor are not significantly different by LSD at $P<0.05$

Conclusion and Discussion

The results from our study demonstrated a decrease in soil moisture on the drought stressed treatments which affected plant water status at 90 DAE. These differences were not clearly visible at 60 DAE, but a slight decrease in RWC started as early as 75 DAE and higher decrease at 90 DAE. Full-irrigated treatment tended to maintain the same level of plant water status from the first day of withholding water until 90 DAE. The drought stress treatment plant water status slightly reduced at 90 DAE this may be due to the high air temperatures (33 oC) and high evaporation (3.86 mm) which caused the depletion of soil moisture and the increase in crop water requirement and irrigation water to be replenished to the crop. According to Prasad et al. (2009) drought stress, either reduces peg and pod development based on the degree of stress and the time of peg initiation and the rate of peg elongation and pod initiation are delayed or inhibited. From our study it was seen that Valencia genotypes had greater percentages of conversion of flowers to reproductive sink (high number of peg and pod) but they had the lowest percentage of conversion of flower to mature pod which caused low yield. This might be because the plant were grown under pot which pot area were not enough for pod development. It was the visible high number of hanging pods were developed out of the pot. From this study the distribution patterns of peanut genotypes grown under drought and full-irrigated conditions were similar, except that peanut genotypes grown under drought stress conditions produced fewer flowers than did the genotypes grown under well-irrigated conditions. Songsri et al. (2009) reported that peanut genotypes producing a lower number of flowers under normal conditions rarely produce high pod yield under drought conditions. From our study peanut genotypes with high peak flower production as early as 4 weeks after emergence (ICG 10092 and ICG 14127) had demonstrated high RET1, RET2 and RET4 and had produced high pod yield under drought conditions. These genotypes might be consider has early mature in this study and the drought effects were not severe as much on RET1, RET2. On the other hand previous studies of Songsri et al. (2009) did not provide clear information on reproductive efficiency trait contributing to high pod yield under drought condition. Terminal drought is a single drought occurring in the pod setting until maturity stage (Nageswara Rao et al., 1989) and was found to decrease pod yield in peanut by affecting pod growth and development, a number of mature pods, and pod size consequently pod yield (Chapman et al., 1993; Nautiyal et al., 1999; Reddy et al., 2003; Bootang et al., 2010). In this study, drought significantly reduced pegs, pods and mature pods leading to a significant yield reduction on Valencia peanut genotypes. Prasad et al. (2009) reported that reproductive development from meiosis to seed set is highly vulnerable to drought stress, which can cause pollen sterility, spikelet death or embryo abortion of newly formed seeds in groundnut. From our study difference between Valencia genotypes were observed in terms of a peg and pod production, but we did not access pollen production. All Valencia genotypes had produced peg and pods, but they differ in terms of number of peg and pod produced which determined pod yield under drought condition. Some genotypes tend to have low seed number

per pod and lower seed size which may be caused by drought. Reproductive parts are important for successful of seeded crop plants and yield (Jin et al., 2013). Therefore, management of soil moisture content at the beginning of reproductive phase is important for further crop yielding. Jin et al. (2013) reported in rice reproductive parts male fertility was dramatically affected, with differing pollen viability in flowers of the same panicle due to aberrant anther development under drought stress conditions. Koti et al. (2005) reported in soybean inhibition on pollen germination and pollen growth under high temperature conditions. Prasad et al. (2003) reported that high temperature above 32 oC reduced pollen viability in peanut, decrease in seed yield and low seed set due to poor pollen viability. In this study different performances under drought conditions were observed among Valencia peanut genotypes. On the other hand, greater flower production was observed in the Spanish type (ICGV 98324) but this genotype demonstrated low in all reproductive efficiency resulting in low yield. The low percentages in reproductive efficiencies (RET3) could be due to the fact that this parameter was evaluated at 110 DAE, which was too early (high percentage of immature pods).

In conclusion number of mature pods was an important character for sustaining pod yield under terminal drought conditions. Valencia peanut genotypes with high number of mature pods had produced high pod yield under drought conditions Therefore, adequate management of moisture content of the pod zone is necessary for pegs to pod development. The results of this study demonstrated positive correlation between pod yield and number of mature pods per plant. Different performances among Valencia genotypes were observed for all reproductive efficiency traits and pod and seed yield. From our study peanut genotypes (ICG 14127 and ICG 10092) with high peak flower production as early as 4 weeks after emergence had demonstrated high RET1, RET2 and RET4 and had produced high pod yield under drought conditions.

Acknowledgements

The authors are grateful and appreciate for the financial support of the Peanut Microtoxin Innovation Lab (PMIL) of the USA and the National Research Institute of Mozambique Groundnut Project of Dr. Amade MilianMuetia. Grateful acknowledgements are also made to the Peanut and Jerusalem Artichoke Improvement for Functional Food Research Group, Plant Breeding Research Center for Sustainable Agriculture and a special thanks is made to the Thailand Research Fund for providing financial supports to this research through the Senior Research Scholar Project of Professor Dr. Sanun Jogloy (Project no. RTA 5880003), the Thailand Research Fund (TRF) (Project no. IRG 5780003) and the Faculty of Agriculture, Khon Kaen University for providing financial support for manuscript preparation activities.

References

Awal, M.A., and T. Ikeda. 2002. Recovery strategy following the imposition of episodic soil moisture deficit in stands of peanut (*Arachis hypogaea* L.). J. Agron. Crop Sci. 188: 185-192.

Boontang, S., T. Girdthai, S. Jogloy, C. Akkasaeng, N. Vorasoot, A. Patanothai, and N. Tantissuwichwong. 2010. Responses of released cultivars of peanut to terminal drought for traits related to drought tolerance. Asian J. Plant Sci. 9: 423-431.

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

Chapman, S.C., M.M. Ludlow, and F.P.C. Blamey. 1993. Effect of drought during early reproductive development on growth of cultivars of groundnut (*Arachis hypogaea* L.). I. Utilization of radiation and water during drought. Field Crops Res. 32: 193-210.

Doorenbos, J., and W.O. Pruitt. 1992. Calculation of crop water requirements. In: Guidelines for predicting crop water requirements, FAO irrigation and Drainage Paper no. 24: 1-65.

Girdthai, T., S. Jogloy, N. Vorassot, C. Akkaseang, 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 Breeding. 129: 693-699.

Gomez, K.A., and A.A. Gomez. 1984. Statistical Procedures for Agricultural Research 2nd Ed. John Wiley & Sons, New York.

Harris, D., R.B. Mathews, R.C. Nageswara Rao, and J.H. Williams. 1988. The physiological basis for yield between four genotypes of groundnut (*Arachis hypogaea* L.) in response to drought. III. Developmental processes. Exp. Agr. 24: 215-226.

Jin, Y., H. Yang, Z. Wei, H. Ma, and X. Ge. 2013. Rice male development under drought stress: phenotypic changes and stage-dependent transcriptomic reprogramming. Mol. Plant. 5: 1630-1645.

Koolachart, R., B. Suriharn, S. Jogloy, N. Vorasoot, S. Wongkaew, C.C. Holbrook, N. Jongrungklang, T. Kesmala, and A. Patanothai. 2013. Relationship between physiological traits and yield components of peanut genotypes with different levels of terminal drought resistance. SABRAO J. Breed. Genet. 45: 442-446.

Koti, S., K.R. Reddy, V.G. Kakani, and D. Zhao. 2005. Interactive effects of carbon dioxide, temperature, and ultraviolet-B radiation on soybean (*Glycine max* L.) flower and pollen morphology, pollen production, germination, and tube lengths. J. Exp. Bot. 412: 725-736.

Nageswara Rao, R.C., S. Singh, M.V.K. Sivakumar, K.L. Srivastava, and J.H. Williams. 1985. Effect of water deficit at the different growth phase of peanut. I Yield responses. Agron. J. 77: 782-786.

Nageswara Rao, .R.C., J.H. Williams, M.V.K. Sivakurumar, and D.R. Wadia. 1988. Effect of water deficit on different growth phase of peanut. II. Response to drought during pre-flowering phase. Agron. J. 80: 431-438.

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.

Nautiayal, C.P., V. Ravinda, P.V. Zala, and Y.C. Joshis. 1999. Enhancement of yield in groundnut following the imposition of transient soil-moisture stress during the vegetative phase. Exp. Agr. 35: 371-385.

Nigam, S.N., M.S. Basu, and A.W. Cruickshank. 2003. Hybridization and description of the trait-based and empirical selection programs. In: Cruickshank A.W., Rachaputi N.C., Wright G.C., and Nigam S.N. (Eds), Breeding of Drought-Resistant Peanuts. pp.15-17. In: Proceedings of a Collaborative Review Meeting Held in ICRISAT Centre, ICRISAT, Hyderabad, AP, India. ACIAR Proceedings No. 112, Canberra.

Pallas, J.E., J.R. Stansell, and R.R. Bruce. 1977. Peanut seed germination as related to the soil, water regime during pod development. Agron. J. 69: 381-383.

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

Songsri, P., S. Jogloy, C.C. Holbrook, N. Vorasoot, T. Kesmala, C. Akkasaeng, and A. Patanothai. 2009. Evaluation of yield and reproductive efficiency in peanut (*Arachis hypogaea* L.) under different available soil water. Asian J. Plant Sci. 8: 465-473.

Statistix8. 2003. Statistix8: analytical software user's manual. Tallahassee, Florida.

Turner, N.C. 1986. Crop water deficits: a decade of progress. Aust. Plant Physiol. 13: 175-190.

Prasad, V., V.G Kakani, and H.D. Upadhyaya. 2009. Growth and production of groundnut, in soil, plant growth and crop production. Verheye W.H. (Ed.), in Encyclopedia of Life Support Systems (EOLSS), Developed under the Auspices of the UNESCO, Eolss Publishers, Oxford, UK.

Prasad,V., K.J. Boote, J.R.L. Hartewell Allen, and J.M.G. Thomas. 2003. Super-optimal temperatures are detrimental to peanut (*Arachis hypogaea* L.) reproductive processes and yield at both ambient and elevated carbon dioxide. Glob. Change Biol. 9: 1775-1787.