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Variability in Yield Responses of Peanut (*Arachis hypogaea* L.) Genotypes under Early Season Drought

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Abstract: The objectives of the present study were to investigate the variability in yield responses of peanut genotypes subjected to Early Season Drought (ESD) and to evaluate characters associated with yield. The field experiment was conducted in the rainy and dry seasons. Eleven genotypes of peanut and two water regimes (field capacity and 1/3 available soil water) were laid out in split plot design with four replications. Where, water regimes were assigned in main plots and 11 peanut genotypes were laid out in subplots. Imposition of ESD following re-watering resulted in an increase of pod yield compared to the irrigated treatment. Significant genotypic differences in yield response in relation to ESD were observed in this study and this could be useful in selecting desired genotypes in peanut breeding program. The highest pod yields were found in ICGV 98303 and Tainan 9 in the rainy season, whereas, in the dry season, ICGV 98303 was still highest for pod yield followed by ICGV 98300. After re-watering, SPAD chlorophyll meter reading, leaf area index and biomass productions were increased. Thus, increase in yield was associated with high biomass production after recovery combined with great green leaf area and concentration of leaf chlorophyll.

Key words: Peanut, recovery, SPAD chlorophyll meter reading, leaf area index, drought stress

INTRODUCTION

Peanut is largely grown under rain-fed conditions in the semi-arid tropics and the yield is usually affected by drought stress at different stages of plant growth (Nageswara Rao *et al*., 1985). Severity of drought stress depends on the stages of crop development, the duration of stress and the magnitude of drought stress (Wright and Nageswara Rao, 1994). Drought stress at reproductive phase, especially, at pod setting, could reduce yield substantially (Nautiyal *et al*., 1999) and the yield loss from 15 to 88% (Nageswara Rao *et al*., 1989; Vorasoot *et al*., 2003). However, drought stress at the vegetative phase or pre-flowering stage had no detrimental effect on pod yield, whilst, in many cases the yield was increased (Nageswara Rao *et al*., 1985, 1988; Nautiyal *et al*., 1999). A considerable increase in pod yield by 13-19% had been reported by Nageswara Rao *et al*. (1985). As peanut has amassing ability to recover form pre-flowering drought, this could be a novel strategy to increase peanut productivity through appropriate irrigation scheduling and it opens up an opportunity for peanut breeding to increase the yield under pre-flowering water stress. Several physio-morphological characters have been reported as associated traits for increasing pod yield under pre-flowering drought stress. Nageswara Rao *et al*. (1985) and Nautiyal *et al*. (1999) found that vegetative growth, Crop Growth Rate (CGR), Pod Growth Rate (PGR) and reproductive development were associated with increased yield under pre-flowering drought stress. Also, Awal and Ikeda (2002) reported, in one peanut genotype, that chlorophyll concentration, stomatal conductance, photosynthesis and Relative Growth Rate (RGR) were increased after re-watering. In addition to, flowering after re-watering, might be, responsible for higher pod yield (Awal and Ikeda, 2002).

The recovery knowledge of physio-morphological traits underlying the increase pod yield of peanut grown under pre-flowering drought are important for both irrigation management and breeding if peanut genotypes are different in yield responses. However, the accumulative knowledge on the recovery of these traits in peanut so far has been limited to a few reports on a variety (Nageswara Rao *et al*., 1985, 1988; Awal and Ikeda, 2002), while the extent of useful genetic variability remains unknown. Degree of yield response and recovery mechanisms for obtaining high pod yield under pre-flowering drought stress might be differed among diverse peanut genotypes. This information has not been well documented, whilst many investigations are required

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to elucidate the recovery mechanisms in peanut genotypes. Therefore, the objectives of this study were to investigate the variability in yield response of peanut genotypes subjected to early season drought and to evaluate physio-morphological characters associated with yield. This information will be useful in breeding of peanut for early season drought.

MATERIALS AND METHODS

Experimental design and treatments: The field experiment was conducted in through two seasons; rainy season during June to October 2005 and dry season during December 2005 to April 2006 at the Field Crop Research Station of Khon Kaen University, Khon Kaen Province, Thailand (latitude 16° 28´ N, longitude 102° 48´ E, 200 m above mean sea level). The experiment was conduced in two seasons instead of two years because the experiment was irrigated and the effect of year variation would be minimized by irrigation, while seasonal variation was still large.

Eleven peanut genotypes were used in this study. They included eight elite drought resistant genotypes (ICGV 98300, ICGV 98303, ICGV 98305, ICGV 98308, ICGV 98324, ICGV 98330, ICGV 98348 and ICGV 98353) kindly provided by ICRISAT, Tifton-8, a Virginia-type drought resistant line from the United State Department of Agriculture (USDA) (Coffelt *et al*., 1985) and two released cultivars (KK 60-3 and Tainan 9) from Thailand. The drought resistant genotypes from ICRISAT had been selected because of high total biomass and pod yield under drought stress conditions (Nageswara Rao *et al*., 1992; Nigam *et al*., 2003, 2005). KK 60-3 is a Virginia-type peanut cultivar sensitive to drought for pod yield, while, Tainan 9 is a Spanish-type peanut cultivar having low dry matter production (Vorasoot *et al*., 2003).

In the rainy season, rainout shelters were available, if necessary, but in the dry season the experiment was carried out under field conditions without rainout shelter. The soil type is Yasothon series (Yt: fine-loamy; siliceous, isohypothermic, Oxic Paleustults). A split-plot in a Randomized Complete Block Design (RCBD) (Gomez and Gomez, 1984) with 4 replications was used in both seasons. Main-plots were two water treatments (Field Capacity (FC) and 1/3 available water (1/3 AW)) and sub-plot treatments were 11 peanut genotypes. Plot size was 2.5×2.1 m in the rainy and 3×3 m in the dry season with a spacing of 30 cm between rows and 10 cm between plants.

Crop management: Soil preparation was done by plowing the field three times. Lime at the rate of 625 kg ha^{-1} was incorporated into the soil during soil preparation. Phosphorus fertilizer as triple superphosphate at the rate of 122.3 kg ha^{-1} and potassium fertilizer as potassium chloride at the rate of 62.5 kg ha^{-1} were applied prior to planting and 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} seed before planting and seeds of the two Virginia-type peanut cultivars (KK 60-3 and Tifton-8) were also treated with Ethel solution at the rate of 2 ml L^{-1} water to break seed dormancy. Seeds were over-planted and the seedlings were thinned to one plant per hill at 7 Days After Emergence (DAE). Rhizobium inoculation was done by applying 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) on the rows of peanut plants. A pre-emergence herbicide; alachlor (2-chloro-2', 6'-diethyl-N-(methoxymethyl) acetanilide 48%, w/v, emulsifiable concentrate) at the rate of 3 L ha^{-1} was applied at planting and hand weeding was done two times prior pegging stage.

Gypsum ($CaSO_4$) at the rate of 312 kg ha^{-1} was incorporated into the soil at 40 DAE. Carbofuran (2, 3-dihydro-2, 2-dimethylbenzofuran-7-yl methylcarbamate 3% granular) was applied at pod setting. Pests and diseases were controlled by weekly application of Carbosulfan (2-3-dihydro-2, 2-dimethylbenzofuran-7-yl (dibutylaminothio) methylcarbamate 20% w/v, water soluble concentrate) at 2.5 L ha^{-1}, methomyl (S-methyl-N-((methylcarbamoyl) oxy) thioacetimidate 40% soluble powder) at 1.0 kg ha^{-1} and carboxin (5, 6-dihydro-2-methyl-1, 4-oxath-ine-3-carboxanilide 75% wettable powder) at 1.68 kg ha^{-1}.

Watering regimes: A subsurface drip-irrigation system (Super Typhoon®, Netafim Irrigation Equipment and Drip Systems, Israel) was installed with a spacing of 30 cm between drip lines and 20 cm between emitters. The drip lines were installed at 10 cm below the soil surface between the rows and a pressure valve and water meter were fitted to ensure controlled supply of water to the treatments. Soil moisture was initially supplied with a water Field Capacity (FC) to a depth of 20 cm and to facilitate uniform emergence. After emergence, early season drought treatment was imposed by holding water until soil moisture reached a level of 1/3 Available Water (AW), after which soil moisture was maintained at 1/3±1% AW level until 40 DAE when re-watering was applied to the crop at FC and maintained at this level until harvest. The irrigated treatment was maintained at FC moisture level until harvest.

Soil moisture contents at FC and Permanent Wilting Point (PWP) were determined at 12.5 and 5.2%, respectively, in the rainy season and 11.3 and 4.9%, respectively, in the dry season, by pressure plate method. Soil moisture contents for 1/3 AW was the values between FC and PWP that were proportional to soil moisture at FC. In maintaining the specified soil moisture levels, water was added to the respective plots 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 treatment was calculated as the sum of transpiration and soil evaporation

Transpiration (T) was calculated using the formula:

$$ET\,crop = ETo \times Kc$$

Where:

Etcrop : Crop water requirement (mm day^{-1})

Eto : Evapotranspiration of a reference plant under specified conditions calculated by pan evaporation method

Kc : The crop water requirement coefficient for peanut. Surface evaporation was calculated as:

$$Es = \beta \times (Eo/t)$$

Where:

Es : Soil evaporation (mm)

β : Light transmission coefficient measured depending on crop cover

Eo : Evaporation from class A pan (mm day^{-1})

t : Days from the last irrigation or rain (day)

Data collection meteorological conditions: The field experiments was established during the rainy season (June to October 2005) and in the dry season (December 2005 to April 2006). Weather data for both seasons were obtained from the nearest Meteorological Station, Khon Kaen University, Khon Kaen, Thailand. In the rainy season, the amount of total rainfall during the crop was 743.7 mm (Fig. 1a). The moisture from rainfall was ignored, because the crop was protected by rainout shelters during drought period. In the dry season, there was a rainfall of 24.4 mm between 66 to 71 Days After Emergence (DAE). However, this rain did not interfere with the experiment during ESD (0-40 DAE) (Fig. 1c). The maximum and minimum seasonal mean air temperatures ranged between 31.5 and 26.1°C in the rainy season and

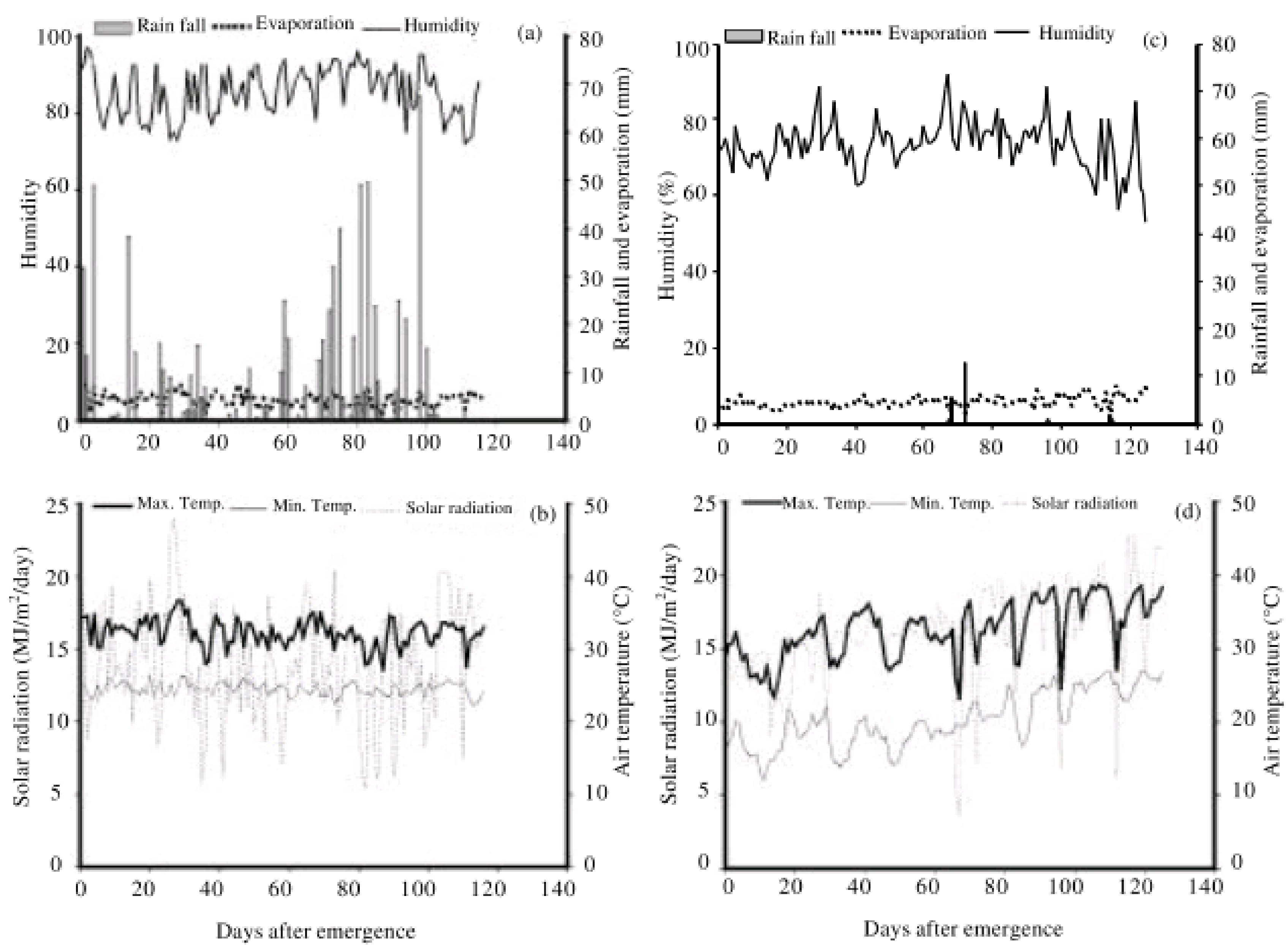

Fig. 1: Rain fall, humidity (RH), evaporation (E_0), maximum and minimum temperature and solar radiation during (a, b) rainy (2005) and (c, d) dry season (2005/06) at the Meteorological Station, Khon Kaen University, Khon Kaen, Thailand

32.6 and 18.8°C in the dry season (Fig. 1b, d). Daily pan evaporation ranged from 1.42 mm to 7.52 mm in the rainy season and 2.78 mm to 9.92 mm in the dry season (Fig. 1a, c). The seasonal mean of solar radiations were 14.3 MJ/m^2/day in the rainy season and 15.9 MJ/m^2/day in the dry season respectively (Fig. 1b, d).

Soil moisture: Soil moisture was measured by gravimetric method at 25, 40, 60 DAE and harvest at depths of 0-5, 25-30 and 55-60 cm.

Relative Water Content (RWC): Relative water content was measured at 40 and 60 DAE to evaluate plant water status using the second fully expanded leaves from the top of the main stem of five plants from each plot. The relative water content was calculated based on the formula suggested by Turner (1986) as follows:

$$RWC (\%) = [(FW-DW)/(TW-DW)]\times 100$$

Where:
FW: Sample fresh weight
TW: Sample turgid weight
DW: Sample dry weight

Leaf Area Index (LAI) and Specific leaf area (SLA): Leaf area was measured at 40 DAE and 60 DAE. At each sampling date, five plants were selected randomly and leaves and stems were separated, leaf area was measured using a LI -3100 area meter (LI-COR, inc. Lincoin Nebraska USA). The LAI was calculated based on the formula suggested by Kiniry *et al.* (2005) as follows:

$$LAI = \text{Leaf area } (cm^2\ plant^{-1})/\text{ground area } (cm^2\ plant^{-1})$$

After, recording the leaf area, leaves were oven dried at 80°C for 48 h and weighted. The SLA was derived as leaf area per unit leaf dry weight (cm^2 g^{-1}) and calculated based on the formula suggested by Nageswara Rao *et al.* (2001) as follows:

$$SLA = \text{Leaf area } (cm^2)/\text{Leaf dry weight (g)}$$

SPAD Chlorophyll Meter Reading (SCMR): A SPAD chlorophyll meter reading was recorded at 40 and 60 DAE. Five plants from each plot were randomly sampled and the second fully expanded leaves from the top of the main stems were used for SCMRs at 8:30-9:30 am. SCMRs were recorded using a Minolta SPAD-502 m (Tokyo, Japan) on the three leaflets from each leaf as described by Nageswara Rao *et al.* (2001).

Biomass production: Five plants in each plot were randomly sampled at 40 DAE and the aerial parts were oven-dried at 80°C for 48 h before recording dry weight. The above ground biomass was harvested from a ground area of 1.8 m^2 in the rainy season and 3.84 m^2 in the dry season. Fresh weights excluding roots were recorded in the field and a one kg was taken from each plot, oven-dried at 80°C for 48 h and weighted using the above-mentioned methods. Total biomass was computed using fresh and dry weight ratio of the sub sample and the total fresh weights.

Pod yield and harvest index: For each plot, bordered plants in an area of 1.8 m^2 in the rainy season and 3.84 m^2 in the dry season were harvested, then, depoded and fresh shoot was weighted in the field. Pod yield (by weight) was observed after air drying to approximately 8% moisture content. Harvest Index (HI) was calculated as pod yield at the final harvest/total biomass at final harvest.

Statistical analysis: Analysis of variance was performed for each season following split plot design (Gomez and Gomez, 1984). Homogeneity of variance was tested for all characters and combined analysis of variance of two seasons data were performed. Calculation procedures were done using MSTAT-C package. Because of, season x genotypes interaction and water regime x genotypes interaction were significant, data of each season and each water regime were analyzed separately according to a Randomized Complete Block Design (RCBD) and Duncan's multiple range test was used to compare the means (Gomez and Gomez, 1984).

RESULTS

Soil moisture and plant water status: Imposition of ESD treatment resulted in rapid depletion of soil moisture which resulted in 1/3 AW level reaching by 14 DAE in rainy season (Fig. 2a) and at 20 DAE in the dry season (Fig. 2b). The desired soil moisture levels in the rainy season (7.6%) and the dry season (7.0%) were maintained at the 1/3 AW level to 40 DAE. ESD was released at 40 DAE in both rainy and dry seasons and the soil moisture contents were maintained at FC until harvest.

Relative Water Content (RWC) for irrigated and ESD treatments following re-watering were similar between rainy season and dry seasons (96%). However, during the ESD, RWC in the dry season were higher (83%) than those in the rainy season (71%) at 40 DAE (Fig. 3) indicating severity of drought stress in the rainy season compared to plants in the dry season.

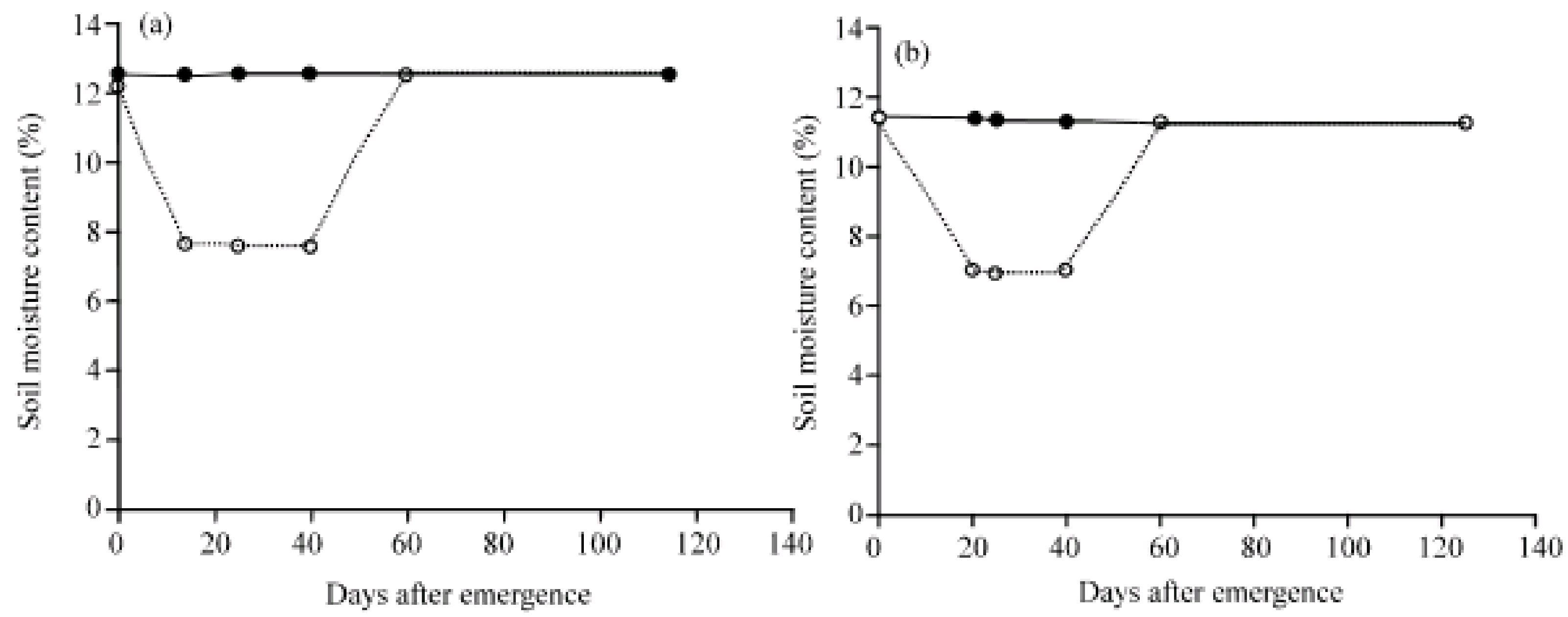

Fig. 2: Seasonal change in soil moisture in irrigated (—●—) and early season drought (ESD) (--○--) treatments (a) in the rainy season (2005) and (b) in the dry season (2005/06)

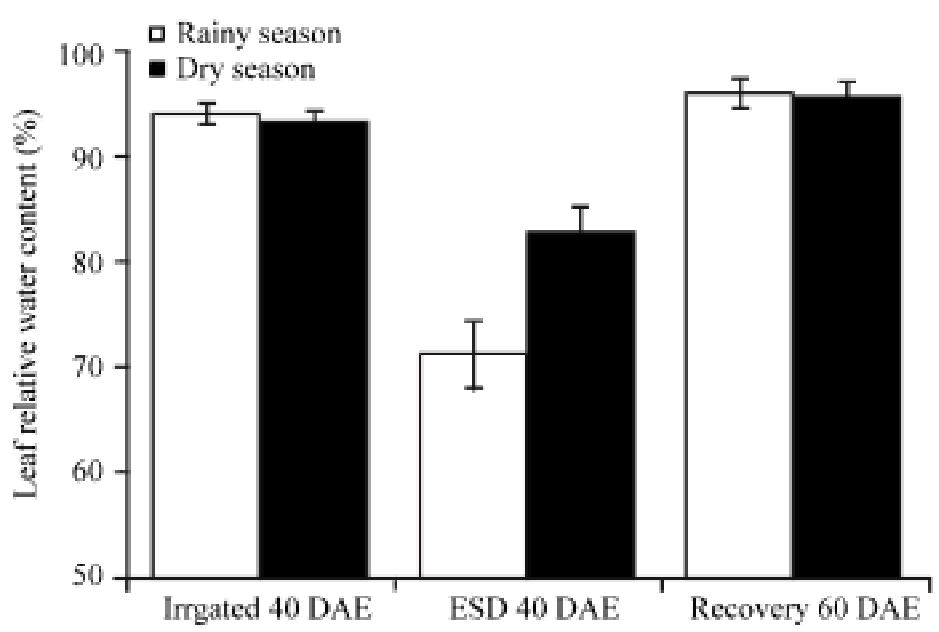

Fig. 3: Leaf relative water content under irrigated, early season drought (ESD) at 40 day after emergence and recovery from ESD (60 DAE) treatments in rainy (2005) and dry season (2005/06)

Pod yield, harvest index and biomass production: In the rainy season, pod yield differed significantly among genotypes and ranged from 2400 to 3600 kg h^{-1} under irrigated conditions (Fig. 4a). However, under ESD conditions, pod yield ranged from 2700 to 3800 kg h^{-1} resulting in an increase of 12% over the irrigated control. The stressed crop could be classified into three groups. ICGV 98303, ICGV 98330 and Tainan 9 were classified as high, ICGV 98300, ICGV 98324, ICGV 98348, KK 60-3 and Tifton-8 were classified as moderate and ICGV 98305, ICGV 98308 and ICGV 98353 were classified as low (Fig. 4a). The most highly responsive genotype was Tainan 9 (41% increase). The genotypes showed reduction in yield were ICGV 98305, ICGV 98308, ICGV 98324 and ICGV 98353.

In the dry season, ESD resulted in 24% increase in pod yield compared to irrigated control (Fig. 4b). Differences among peanut genotypes were significant with pod yield and ranged from 2400 to 3450 kg ha^{-1} under the irrigated treatment and 2370 to 5400 kg ha^{-1} under the ESD conditions. Similar classification could be made for pod yield of the stressed crop in the dry season. Where, ICGV 98303 and ICGV 98300 were classified as high, ICGV 98324, ICGV 98330, Tainan 9, KK 60-3 and Tifton-8 were classified as moderate and ICGV 98305, ICGV 98308, ICGV 98348 and ICGV 98353 were classified as low (Fig. 4b). The genotype having the highest increase percent was ICGV 98303 (57%). Whereas, ICGV 98305 and ICGV 98353 genotypes showed reduction for yield.

In the rainy season, difference among genotypes for harvest index was not significant. However, significant differences among peanut genotypes for harvest index were found in the dry season (Table 1). The responses for harvest index were in both positive and negative directions when compared to their respective potentials, giving similar average performance in both the seasons. Tifton-8 showed increase in harvest index in both seasons (6 and 14% in the rainy and dry seasons, respectively). Peanut genotypes did not show large differences in harvest index between irrigated and ESD treatments, therefore, biomass production might be the cause of differences in pod yield.

In the rainy season, at the end of ESD (40 DAE), biomass production was decreased by 71% when averaged over all genotypes (Table 2). There were significant differences among genotypes for biomass production under the ESD conditions with ICGV 98353 and ICGV 98305 had the highest biomass production (3.5 and 3.3 g $plant^{-1}$, respectively).

At harvest, biomass production was increased by 5% under ESD than irrigated. Most peanut genotypes showed the increase of biomass production except for ICGV 98305, ICGV 98308 and ICGV 98353 (Table 2). It is clear that certain peanut genotypes showed the increase

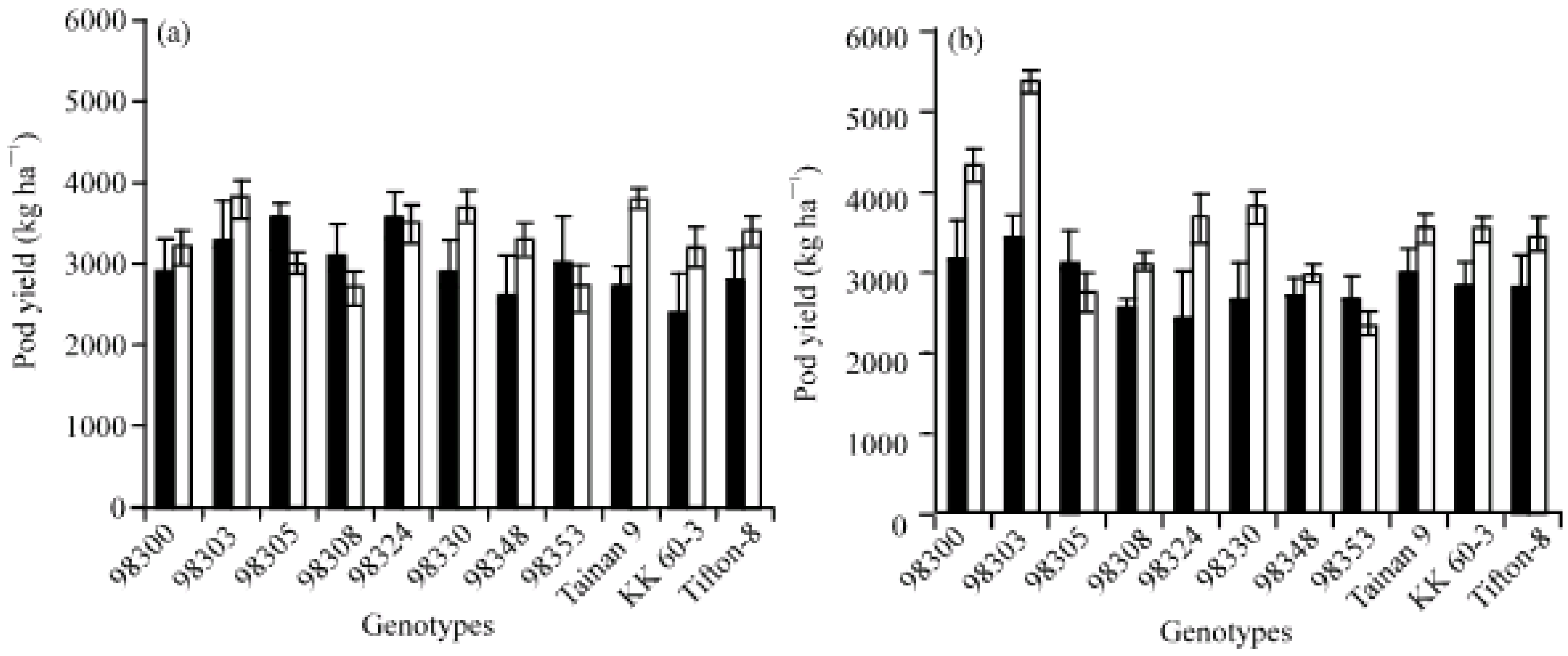

Fig. 4: Pod yield of 11 peanut genotypes under irrigated (■) and early season drought (ESD) (□) treatments (a) in the rainy season (2005) and (b) in the dry season (2005/06), vertical bars shown standard error difference of means

Table 1: Harvest index of peanut genotypes under irrigated and Early Season Drought (ESD) treatments in the rainy season (2005) and dry season (2005/06)

	Harvest index (HI)					
	Rainy season			Dry season		
Genotypes	Irrigated	ESD	Change (%)	Irrigated	ESD	Change (%)
ICGV 98300	0.32a	0.33a	3	0.32b	0.35ab	9
ICGV 98303	0.33a	0.35a	6	0.30b	0.32b	6
ICGV 98305	0.35a	0.34a	-3	0.30bc	0.30bc	0
ICGV 98308	0.32a	0.31a	-3	0.30bc	0.30bc	0
ICGV 98324	0.36a	0.33a	-9	0.30bc	0.30bc	0
ICGV 98330	0.33a	0.35a	6	0.30bc	0.29c	-3
ICGV 98348	0.32a	0.32a	0	0.36a	0.36a	0
ICGV 98353	0.34a	0.31a	-10	0.32b	0.29c	-10
Tainan 9	0.33a	0.33a	0	0.32b	0.35ab	9
KK 60-3	0.33a	0.33a	0	0.30c	0.33b	9
Tifton-8	0.35a	0.37a	6	0.30c	0.35ab	14
Mean	0.33	0.33	0	0.31	0.32	3

Mean in the same column with the same letter(s) are not significantly different by DMRT at $p<0.05$, Change (%) = (HI in ESD- HI in irrigated)/HI in irrigated× 100

Table 2: Biomass production of 11 peanut genotypes under irrigated and early season drought (ESD) treatments in the rainy season (2005)

	Biomass production					
	Drought period (g plant^{-1})			Harvest (kg ha^{-1})		
Genotypes	Irrigated	ESD	Change (%)	Irrigated	ESD	Change (%)
ICGV 98300	10.7b	2.4f	-78	9800ab	10100b	3
ICGV 98303	10.8b	3.1bc	-71	9500ab	11500a	21
ICGV 98305	8.6c	3.3ab	-62	10500a	8700cd	-17
ICGV 98308	7.2d	2.9cd	-60	9800ab	8600cd	-12
ICGV 98324	8.4c	2.9cd	-65	10100a	10100b	0
ICGV 98330	9.2c	2.9cd	-68	8800bc	10600ab	20
ICGV 98348	10.7b	2.9cd	-73	8400cd	10300b	23
ICGV 98353	10.5b	3.5a	-67	8900bc	8800cd	-1
Tainan 9	10.7b	2.7de	-75	10500a	10800ab	3
KK 60-3	12.6a	2.9cd	-77	7400d	9700bc	31
Tifton-8	9.3c	2.5ef	-73	9800ab	9800bc	0
Mean	9.9	2.9	-71	9409	9909	5

Mean in the same column with the same letter(s) are not significantly different by DMRT at $p<0.05$, Change (%) = (biomass production in ESD-biomass production in irrigated)/biomass production in irrigated×100

of biomass production, but certain genotypes did not. Differences among peanut genotypes were significant for biomass production, ranging from 7400 to 10500 kg ha^{-1} for irrigated treatment and 8600 to 11500 kg ha^{-1} for ESD treatment, with ICGV 98303 being the highest.

In the dry season, biomass production was reduced by 16% at the end of drought stress (Table 3). Differences among peanut genotypes were significant, ranging from 3.5 to 5.2 g plant^{-1} under irrigated treatment and 3.2 to 4.5 g plant^{-1} in ESD treatments.

Table 3: Biomass production of 11 peanut genotypes under irrigated and early season drought (ESD) treatments in the dry season (2005/06)

	Biomass production					
	Drought period (g plant^{-1})			Harvest (kg ha^{-1})		
Genotypes	Irrigated	ESD	Change (%)	Irrigated	ESD	Change (%)
ICGV 98300	3.9cd	3.3d	-15	9870ab	10800c	9
ICGV 98303	3.5d	3.3d	-6	10150a	12150a	20
ICGV 98305	4.5abc	3.8bcd	-16	9500abc	9470d	-1
ICGV 98308	4.3bc	3.6cd	-16	8450cd	10270cd	22
ICGV 98324	3.8cd	3.2d	-16	7900d	9400d	19
ICGV 98330	4.5abc	3.3d	-27	8800bcd	10320cd	17
ICGV 98348	4.7ab	3.3d	-30	10600a	11450ab	8
ICGV 98353	5.2a	4.5a	-13	7870d	8700e	10
Tainan 9	5.1a	3.7bcd	-27	8820bcd	11020b	25
KK 60-3	4.2bcd	3.9abc	-7	9650abc	10770c	12
Tifton-8	4.2bcd	4.2ab	0	9920ab	11050b	11
Mean	4.3	3.6	-16	9230	10491	14

Mean in the same column with the same letter(s) are not significantly different by DMRT at p<0.05, Change (%) = (biomass production in ESD-biomass production in irrigated)/biomass production in irrigated×00

Table 4: SPAD chlorophyll meter reading (SCMR) of 11 peanut genotypes under irrigated and early season drought (ESD) treatments during water stress (40 DAE) and after re-watering (60 DAE) in the rainy season (2005)

	SCMR			
	Drought		Recovery	
Genotypes	Irrigated	ESD	Irrigated	ESD
ICGV 98300	41.7bc	43.2c	39.2d	40.2b
ICGV 98303	42.1bc	45.5ab	40.0c	41.2b
ICGV 98305	42.5bc	43.9bc	39.7d	40.2b
ICGV 98308	41.2bc	43.3bc	39.6d	42.3ab
ICGV 98324	44.1a	46.0ab	42.3a	45.0a
ICGV 98330	43.9a	47.3a	40.4c	41.9ab
ICGV 98348	40.7bc	42.7c	40.7c	40.6b
ICGV 98353	38.9c	44.2bc	40.0c	40.4b
Tainan 9	40.6c	43.9bc	39.9d	39.6bc
KK 60-3	43.4ab	43.6bc	40.0c	39.8bc
Tifton-8	42.0bc	45.4ab	40.9bc	42.0ab
Mean	41.9	44.4	40.2	41.2

Mean in the same column with the same letter(s) are not significantly different by DMRT at p<0.05, DAE: Days after emergence

ICGV 98353 and Tifton-8 had the highest biomass production (4.5 and 4.2 g plant^{-1}, respectively) under the ESD conditions.

At harvest, biomass production increased by 14% compared to the irrigated conditions. Differences among genotypes were significant, with biomass production ranging from 7870 to 10150 kg ha^{-1} under the irrigated treatment and 8700 to 12150 kg ha^{-1} under the ESD treatment. ICGV 98303 was found to be the highest genotype for biomass production (12150 kg ha^{-1}), whereas Tainan 9 the genotype having the highest percentage of increase (25%).

Physiological response during water stress and recovery: Physiological characters were investigated to understand its effect on peanut yield. The traits included SPAD Chlorophyll Meter Reading (SCMR) which easy to measure and potentially useful as a selection trait for drought resistance (Nageswara Rao *et al*., 2001; Nigam and Aruna, 2007), Specific Leaf Area (SLA) as a trait for drought resistance and Leaf Area Index (LAI).

In the rainy season, at the end of stress period, drought increased SCMR. After recovery at 60 DAE, SCMR was slightly increased (Table 4). Significant differences in SCMR among peanut genotypes were found in both stress and non-stress conditions. ICGV 98324 and ICGV 98330 had the highest SCMR under both irrigated treatment (44.1 and 43.9) and ESD treatment (46.0 and 47.3) and they also had consistently high SCMR at the end of drought period (40 DAE) and after recovery (60 DAE).

In the dry season, the effect of drought on SCMR was quite similar to that in the rainy season. SCMR was increased at the end of stress period. Difference among the peanut genotypes used was found in both treatments and ICGV 98303, ICGV 98324, ICGV 98330, KK 60-3 and Tifton-8 genotypes were highest (50.5, 50.9, 51.8, 51.0 and 50.6, respectively) as shown in Table 5. After recovery, SCMR of stressed crop was still higher than that of non-stressed crop. ICGV 98330 and Tifton-8 had the highest SCMR (51.5 and 52.4, respectively).

In contrast to SCMR, drought reduced SLA and LAI at the end of drought period (40 DAE) in the rainy season (Table 6, 8). Significant differences in SLA and LAI among peanut genotypes were found in both treatments. ICGV 98324 and ICGV 98330 had the lowest SLA (208 and 204 cm^2 g^{-1}, respectively), while, ICGV 98303 and ICGV 98353 had the highest LAI (1.8) under stress treatment. However, after recovery (60 DAE), SLA was still decreased, whereas, LAI was slightly increased. ICGV 98330 and Tifton-8 had the lowest SLA (199 and 209 cm^2 g^{-1}, respectively), whereas,

Table 5: SPAD chlorophyll meter reading (SCMR) of 11 peanut genotypes under irrigated and early season drought (ESD) treatments during water stress (40 DAE) and after re-watering (60 DAE) in the dry season (2005/06)

	SCMR			
	Drought		Recovery	
Genotypes	Irrigated	ESD	Irrigated	ESD
ICGV 98300	40.2e	48.0b	43.9cd	48.7c
ICGV 98303	41.2cde	50.5a	42.6d	49.0c
ICGV 98305	42.1bcd	46.8c	44.5bc	46.5c
ICGV 98308	40.3e	45.6d	42.7d	45.9d
ICGV 98324	44.7a	50.9a	45.2bc	50.0b
ICGV 98330	44.6a	51.8a	47.9a	51.5ab
ICGV 98348	43.3ab	46.5d	40.3e	44.4de
ICGV 98353	40.9de	45.1d	44.8bc	45.2de
Tainan 9	41.8b-e	45.7d	42.3d	45.1e
KK 60-3	42.7bc	51.0a	47.4a	50.7b
Tifton-8	44.7a	50.6a	45.6b	52.4a
Mean	42.4	48.4	44.3	48.1

Mean in the same column with the same letter(s) are not significantly different by DMRT at $p<0.05$, DAE: Days after emergence

Table 6: Specific leaf area (SLA) of 11 peanut genotypes under irrigated and early season drought (ESD) treatments at (40 DAE) and after re-watering (60 DAE) in the rainy season (2005)

	SLA (cm^2 g^{-1})			
	Drought		Recovery	
Genotypes	Irrigated	ESD	Irrigated	ESD
ICGV 98300	264b	230b	260a	226c
ICGV 98303	243bc	225c	251a	221c
ICGV 98305	251b	238b	248a	233b
ICGV 98308	262b	251a	244a	232a
ICGV 98324	222d	208d	248a	210d
ICGV 98330	222d	204d	232a	199e
ICGV 98348	242bc	224c	243a	219d
ICGV 98353	274a	235b	236a	218d
Tainan 9	267b	240b	258a	213d
KK 60-3	249bc	236b	247a	219c
Tifton-8	243bc	228c	231a	209d
Mean	249	229	245	218

Mean in the same column with the same letter(s) are not significantly different by DMRT at $p<0.05$, DAE: Days after emergence

Tainan 9, KK 60-3 and Tifton-8 had the highest for LAI (8.0, 7.5 and 6.8, respectively).

In the dry season, ESD significantly reduced SLA and LAI (Table 7, 9). Differences among peanut genotypes were significant under well-watered conditions and stress conditions for SLA but LAI was significant, only, at well-watered conditions. ICGV 98324, ICGV 98330 and Tifton-8 had the lowest SLA (154, 149 and 150 cm^2 g^{-1}, respectively). Under well-watered conditions, ICGV 98305 had the highest LAI (2.0). After recovery from early season drought, ICGV 98324, ICGV 98330 and Tifton-8 still had the lowest SLA (127, 129 and 130 cm^2 g^{-1}, respectively). Tainan 9 and Tifton-8 had the highest LAI (4.0 and 4.1, respectively).

Table 7: Specific leaf area (SLA) of 11 peanut genotypes under irrigated and early season drought (ESD) treatments during water stress (40 DAE) and after re-watering (60 DAE) in the dry season (2005/06)

	SLA (cm^2 g^{-1})			
	Drought		Recovery	
Genotypes	Irrigated	ESD	Irrigated	ESD
ICGV 98300	195b	175b	163b	144b
ICGV 98303	193b	171b	165b	132d
ICGV 98305	193b	180a	179d	154a
ICGV 98308	188bc	173b	160c	146b
ICGV 98324	173c	154d	139e	127d
ICGV 98330	179c	149d	145d	129d
ICGV 98348	207a	171b	162b	145b
ICGV 98353	186bc	165c	158c	149b
Tainan 9	195b	174b	165b	140c
KK 60-3	187bc	155d	153c	140c
Tifton-8	174c	150d	145d	130d
Mean	188	165	158	140

Mean in the same column with the same letter(s) are not significantly different by DMRT at $p<0.05$, DAE: Days after emergence

Table 8: Leaf area index (LAI) of 11 peanut genotypes under irrigated and early season drought (ESD) treatments during water stress (40 DAE) and after re-watering (60 DAE) in the rainy season (2005)

	LAI			
	Drought		Recovery	
Genotypes	Irrigated	ESD	Irrigated	ESD
ICGV 98300	4.2ab	1.1cd	6.0b	6.4b
ICGV 98303	3.9bc	1.8a	5.9b	6.3b
ICGV 98305	3.0e	1.6ab	6.1b	4.9de
ICGV 98308	2.9e	1.4bc	4.4d	4.5e
ICGV 98324	2.9e	1.2cd	5.9b	6.1bc
ICGV 98330	3.1de	1.2cd	4.8cd	6.1bc
ICGV 98348	3.2de	1.4bc	5.0c	5.9c
ICGV 98353	3.8c	1.8a	4.6d	4.8de
Tainan 9	3.8c	1.4bc	7.0a	8.0a
KK 60-3	4.6a	1.3bcd	5.7b	7.5a
Tifton-8	3.5cd	1.0d	5.5bc	6.8ab
Mean	3.5	1.4	5.5	6.1

Mean in the same column with the same letter(s) are not significantly different by DMRT at $p<0.05$, DAE: Days after emergence

Table 9: Leaf area index (LAI) of 11 peanut genotypes under irrigated and early season drought (ESD) treatments during water stress (40 DAE) and after re-watering (60 DAE) in the dry season (2005/06)

	LAI			
	Drought		Recovery	
Genotypes	Irrigated	ESD	Irrigated	ESD
ICGV 98300	1.6cd	1.1a	3.1a	3.4b
ICGV 98303	1.4d	1.1a	3.1a	3.1c
ICGV 98305	2.0a	1.3a	2.8b	2.3e
ICGV 98308	1.6bcd	1.1a	2.8b	3.0d
ICGV 98324	1.3d	0.9a	3.0ab	2.9d
ICGV 98330	1.6cd	1.1a	2.7b	3.1c
ICGV 98348	1.8abc	1.1a	3.0a	3.3c
ICGV 98353	1.8abc	1.1a	2.5c	2.0e
Tainan 9	2.0abc	1.1a	3.0ab	4.0a
KK 60-3	1.5cd	1.4a	3.3a	3.8b
Tifton-8	1.4d	1.4a	3.3a	4.1a
Mean	1.6	1.2	3	3.2

Mean in the same column with the same letter(s) are not significantly different by DMRT at $p<0.05$, DAE: Days after emergence

DISCUSSION

Variability of yield response to early season drought followed by recovery: Although, earlier studies found that pre-flowering drought following recovery can increase pod yield of peanut (Nageswara Rao *et al*., 1985, 1988; Nautiyal *et al*., 1999). Variation in yield response of peanut genotypes and the traits associated with pod yield under early season drought have not been well understood as earlier studies have been limited to a few peanut genotypes.

To the best of our knowledge, variation in pod yield of peanut in response to pre-flowering drought stress has not been reported in the literature. Most of the previous studies have focused on only a few peanut genotypes (Nageswara Rao *et al*., 1985, 1988; Nautiyal *et al*., 1999; Awal and Ikeda, 2002). Therefore, there might be the possibility to select peanut genotypes with good response to pre-flowering drought stress, when a wide range of peanut genotypes are screened. This should be worth-exploring for future investigations.

The present study supports the earlier findings that imposition of pre-flowering drought can result in higher yield compared to irrigated conditions (Nageswara Rao *et al*., 1988; Nautiyal *et al*., 1999). However, this study revealed significant genotypic variation in yield response to early season drought followed by recovery of the peanut genotypes with different degrees of drought resistance (Songsri *et al*., 2008). This indicates that the increase of yield during the recovery from early season drought in peanut is a genotypic character associated with physio-morphological traits.

The present study revealed that the imposition of early season drought followed by recovery resulted in an increase in pod yield compared to fully-irrigated control, although, genotypes differed significantly in ability to recover from early season drought. The genotypes ICGV 98300, ICGV 98303, ICGV 98330, Tainan 9, KK 60-3 and Tifton-8 could be identified as genotypes with increase in pod yield. The results indicate that pod yield of peanut genotypes can be increased by appropriately withholding irrigation at pre-flowering growth stage. Selection for positive interaction between peanut genotype and water stress at pre-flowering might be an alternative strategy to improve pod yield and increase water use efficiency.

Dry mater accumulation (biomass production) and partitioning of assimilates (HI) could be the main reasons for the differences in yield performance of stressed and non-stressed plants. The results indicated that difference in harvest index was not likely to be the source of yield variation between stressed and non-stressed plants. Difference in biomass production was solely the source of yield difference. The results were in agreement with those of Nageswara Rao *et al.* (1988), who observed that increased CGR (biomass production) contributed to higher yield. The results indicated that high biomass production was associated with high pod yield and the genotypes with high biomass production could be identified. ICGV 98300, ICGV 98303, ICGV 98324, ICGV 98330, ICGV 98348, Tainan 9, KK 60-3 and Tifton-8 had high increase in biomass production. Six of these genotypes (ICGV 98300, ICGV 98303, ICGV 98330, Tainan 9 and KK 60-3 and Tifton-8) had concomitantly high pod yield.

Response of peanut to water deficit: Drought stress was identified by the differences between water regimes in soil moisture and relative water content of the plant. It is clear that soil moisture content was different at the end of drought period (40 DAE) and relative water content was, also, different. As soil moisture content is site-specific depending on soil properties and cannot be compared directly with other factors, relative water content in contrast allows direct comparison, because, it expresses directly in the crop. In the present study, RWC in stressed plants ranged between 68-83% compared with 90-96% in non-stressed plants. Awal and Ikeda (2002) reported that RWC of non-stressed plants range from 85-90%, whereas RWC in stressed plants could be as low as 30%. RWC in the range of 68-83% in this study was not too severe compared with RWC of 30% in the most severely stressed plants and the stress in the rainy season was slightly more severe than in the dry season. This could be due to higher air temperature during drought period causing the rapid depletion of stored soil moisture. However, peanut genotypes were not statistically different in relative water content for both soil moisture levels in both the seasons. The results indicated that relative water content might be a useful tool for discriminating water status of stressed and non-stressed plants, but, it discriminating power is not enough to distinguish the differences among peanut genotypes.

Advantage of water deficit at early season drought over the continuous and adequate water supply is higher concentration of leaf chlorophyll in stressed plants as indicated by high SCMR (Table 4, 5). High concentration of leaf chlorophyll in stressed plants helps to maintain high photosynthetic capacity after re-watering when resources are not limited by drought.

The reduction in SLA and LAI due to water stress resulted from the reduction of photosynthetic capacity (Reddy *et al*., 2003; Lauriano *et al*., 2004). The decrease in LAI was associated with low leaf area. In addition to, the decrease in photosynthetic capacity was attributed to reduction of total chlorophyll and leaf area. Drought reduced leaf area by slowing leaf expansion and reducing the supply of resulted carbohydrates content to small leaves with smaller and more compact cells and greater specific leaf weight, whereas, leaf area was decreased (Reddy *et al*., 2003).

However, the difference in root characters in response to the drought may, also, help. Root characteristics such as root length density, rooting depth and root distribution have been established as constituting factors of drought resistance (Songsri *et al*., 2008). In addition to, they reported that, the ability of plant to change its root distribution in the deeper soil water is an important mechanism for drought avoidance.

Response of stressed plants after re-watering: RWC completely recovered within 1-3 days of re-watering and some peanut genotypes tended to have higher RWC compared to non-stress treatment. Awal and Ikeda (2002) reported that RWC recovered within 1-2 days of re-watering, suggesting that stomatal conductance of peanut responded very vigorously during recovery following the stress period.

After re-watering, peanut genotypes could maintain higher SCMR. Awal and Ikeda (2002) reported that chlorophyll concentration was increased in the leaves of water deficit plants on 4th day of recovery and it resulted in an increase in photosynthesis also (Lauriano *et al*., 2004). SCMR is an indicator of the photosynthetic light transmittance characteristics of leaves and is positively correlated with chlorophyll content and chlorophyll density (Arunyanark *et al*., 2008). Photosynthesis is closely related to biomass production in most crops and biomass production is a major determinant of yield (Anyia and Herzog, 2004). Increase of SCMR might contribute to photosynthesis capacity and increase of biomass and pod yield. Upadhyaya (2005) found that SCMR was correlated with peanut pod yield.

The decrease in SLA after recovery, may be, due to thicker leaves during leaf development. The thicker and/or denser leaves usually have a higher content of chlorophyll and proteins per leaf area unit and a greater photosynthetic capacity than thinner and/or less dense leaves (Xiao *et al*., 2005).

Rapid increase in LAI is because of high increase in leaf area after recovery (Table 8, 9). Leaf area reflects photosynthesis capacity and biomass production (El Hafid *et al*., 1998). Photosynthesis is closely related to biomass production in most crops (Anyia and Herzog, 2004). The ability to recover from drought for biomass production was independent from the reduction at the end of the stress period in the present experiments. The results are in agreement with those of Anyia and Herzog (2004), who reported that growth after recovery from drought appears to be more important in determining the final biomass than plant responses during drought in cowpea.

Higher green leaf area and high capacity of photosynthesis after re-watering (Luariano *et al*., 2004) might trigger the onset of flash growth, which increases biomass production contributing to more fruit set and resulting in yield increase (Nageswara Rao *et al*., 1988). After stress, recovery may compensate for physiological drought injury that initiates strong reproductive efficiency and ultimately pod yield (Nautiyal *et al*., 1999). The relief of stress triggered flash vegetative growth and a new flush of flowering resulting ultimately increases number of mature pods and pod yield. These suggest that peanut yield can be improved by reduced irrigations during vegetative phase (Nageswara Rao *et al*., 1985; Nautiyal *et al*., 1999).

Based on the results, it is apparent that high pod yield in certain peanut genotypes that were exposed to early season drought stress was associated with high biomass production, high leaf area and high photosynthesis capacity. After recovery, the plants could produce more biomass and partitioned assimilates to developing pods, whereas, vegetative demand of assimilate supply was reduced. Nageswara Rao *et al*. (1988) reported that when stress was released, the plants could set more fruiting sites, since, vegetative sites were reduced.

In conclusion, the results indicated water deficit at early season drought and subsequent recovery could obviously increase pod yield, although genotypes differed significantly in ability to recover from early season drought. However, significant genotypic variation in pod yield response could be useful for improving genotypic performance in breeding program of peanut for early season drought resistance. Peanut genotypes did not show large differences in harvest index under ESD treatments and therefore, biomass production might be the cause of differences in pod yield. Therefore, high yield under early season drought were attributed to maintenance of green leaf area and high capacity of photosynthesis and biomass production.

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