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Response to Early Drought for Traits Related to Nitrogen Fixation and Their Correlation to Yield and Drought Tolerance Traits in Peanut (*Arachis hypogaea* L.)

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Abstract: This study was aimed to examine the response and contribution of early drought to traits related to N_2-fixation and pod yield and their correlation to drought tolerance. The experiment was conducted at the Field Crop Research Station of Khon Kaen University, Khon Kaen Province, Thailand in the dry season of 2007/08. Eleven peanut genotypes (ICGV 98300, ICGV 98303, ICGV 98305, ICGV 98308, ICGV 98324, KK 60-3, Tainan 9, KKU 72-1, KKU 60, KK 4 and KKU 1) and two soil moisture levels [field capacity (FC) and 1/3 available water (1/3 AW)] were laid out in a split-plot design with four replications. Early drought treatment was given by maintaining 1/3 AW from emergence to 40 days after emergence followed by adequate water supply. The data were recorded for nodule dry weight (NDW) and biomass production (BM) as traits related to N_2-fixation (TNf) at harvest. In addition to, the data on pod yield, number of pod plant^{-1}, number of seed pod^{-1} and seed size (SZ) were also collected at harvest. Specific leaf area (SLA) and SPAD chlorophyll meter reading (SCMR) were measured on 20, 40, 50 and 60 days after emergence (DAE) as drought tolerance traits and harvest index (HI) was calculated after harvest. Early drought did not affect NDW and BM. Major variation was found among peanut genotypes and ICGV 98305 showed higher NDW and pod yield under drought condition. Significant and consistent correlation was found between NDW and BM, (r = 0.82*, $p<0.05$) and (r = 80*, $p<0.05$) under FC and 1/3 AW, respectively. The correlation between TNf and pod yield and yield component parameters varied under the two water regimes. Under 1/3 AW, the only positive correlation observed was between SZ and BM and it might be the only reason for increase in pod yield in some genotypes. SCMR at 60 DAE was strongly related with TNf under both water regimes. There was not any correlation between SLA and HI with NDW and BM. SCMR at 60 DAE is useful to detect chlorophyll density and N_2-fixation under both water regimes because of its high and constant correlation with TNf.

Key words: Peanut, biological nitrogen fixation, SCMR, SLA, water stress, yield components

INTRODUCTION

Peanut is largely grown under rain-fed conditions and its production depends on rainfall and rain distribution that are usually unpredictable (Reddy *et al*., 2003). Droughts occur at any stage of crop development and peanut usually is at the risk of water stress even under irrigated conditions because of limited availability of water and the high cost of energy.

Drought stress, in general, reduces pod yield and other growth parameters of peanut (Pimratch *et al*., 2008b, Songsri *et al*., 2008a). Drought stress during late reproductive phases from pegging to pod filling can greatly reduce pod yield but during pre-flowering growth it has less effect on pod yield or even increases pod yield (Nageswara *et al*., 1985). The mechanisms underlying the ability of peanut to recover from early season drought has not been well researched, especially, in relation to symbiotic N_2-fixation.

Biological N_2-fixation which is crucially beneficial for the development of peanut plants and can support the succeeding crop with the residual fixed nitrogen in the soil is particularly sensitive to adverse environmental conditions such as water stress or drought. Drought affects nodulation, nodule growth and weight as well as nitrogen fixing activity in legumes including peanut (Hungria and Vargas, 2000; Giller, 2001; Pimratch *et al*., 2008a, b). Several traits such as nodule dry weight, biomass production, shoot dry weight, harvest index and leaf color score have been identified and used as selection criteria for high N_2-fixation because the direct ways to measure the fixed nitrogen were too

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costly and laborious (Pimratch *et al*., 2004; Pimratch *et al*., 2008b). Pimratch *et al*. (2004) reported that, the leaf color score, nodule dry weight, pod yield and nitrogenase activity were useful indicators for nitrogen fixing ability of peanuts. In general, the effects of drought stress on N_2-fixation and its related traits have been well documented. However, little is known about response of N_2-fixation and its related traits that enhance yield performance when peanut is subjected to early drought stress and further investigations are required.

Earlier investigations demonstrated that several physiological traits could be used for the screening of peanut genotypes for drought resistance. Cruickshank *et al*. (2004) reported three functional components i.e., transpiration (T), transpiration efficiency (TE) and harvest index (HI) as drought tolerance traits. However, specific leaf area (SLA) (leaf area per unit leaf dry weight) has been widely perceived as a trait of drought resistance because it is strongly correlated with TE (Nageswara and Wright, 1994). Further experiments revealed that in peanut, there was significant genetic variability for TE (Wright *et al*., 1988; Nageswara Rao *et al*., 1993).

Drought is known to affect chlorophyll content and inhibit the photosynthetic capacity thereafter (Epron and Dreyer, 1993). Samdur *et al*. (2000) and Arunyanark *et al*. (2008) reported that, the leaf chlorophyll content can be rapidly assessed using the SPAD chlorophyll meter reading and it could be used as a rapid and cost effective tool for assessment of relative chlorophyll status in peanut leaves. Moreover, SCMR could be applied for indirect selection of drought tolerance traits in peanut because it is strongly related with SLA (Nageswara Rao *et al*., 2001) and TE (Sheshshayee *et al*., 2006).

The improvement of peanut for drought resistance and high N_2-fixation is the main objective of the ongoing peanut breeding program at Khon Kaen University. Pimratch *et al*. (2008a) suggested that maintaining high N_2-fixation under drought stress could be a means for the peanut genotypes to achieve high yield under water limited conditions. Therefore, improvement of N_2-fixation is an alternative strategy to improve pod yield under drought conditions. The information on the responses of peanut genotypes to early drought for N_2-fixation is still lacking and its relationships with pod yield and drought resistance traits are still not well understood. Therefore, the objectives of this study are to observe (1) the response of biological N_2-fixation related traits to early drought and (2) the correlation of the traits related to N_2-fixation to yield and drought tolerance traits in peanut.

MATERIALS AND METHODS

Plant materials: Field experiment was conducted at Khon Kaen University's Field Crop Research Station during December 2007 to April 2008. Eleven peanut genotypes, ICGV 98300, ICGV 98303, ICGV 98305, ICGV 98308, ICGV 98324, KK 60-3, Tainan 9, KKU 72-1, KKU 60, KK 4 and KKU 1 were used in this study. KK 60-3 is a released cultivar commonly grown in Thailand and it is a Virginia-type peanut cultivar with high N_2-fixation (Toomsan *et al*., 1995) but sensitive to drought for pod yield. Also, KK 72-1 is a Virginia-type peanut cultivar whereas, KK 4 is the only one Valencia-type cultivar. ICGV 98300, ICGV 98303, ICGV 98305, ICGV 98308 and ICGV 98324 are produced from ICRISAT and they are drought resistant Spanish cultivars because they gave high total biomass and pod yield in screening tests under drought stress conditions (Nigam *et al*., 2005). Tainan 9 is also a Spanish-type peanut cultivar having high SLA, low SCMR under both stressed and nonstressed condition (Songsri *et al*., 2008a), low dry matter production (Pimratch *et al*., 2008b) and low N_2-fixation (McDonagh *et al*., 1993). Also, KKU 1 is a Spanish-type cultivar and a non-nodulating line was used as a reference plant for traits related to N_2-fixation.

Experimental design and treatments: The experiment was arranged in a split-plot design with 4 replications. Where, the main-plot treatments were 2 moisture levels [field capacity (FC) and 1/3 available soil water (1/3 AW)] and sub-plot treatments were 11 genotypes. Plot size was a five rows plot with 3 m long with spacing of 20 cm between plants within row and 40 cm between rows.

Crop management: The land was plowed three times before planting. Lime at the rate of 625 kg ha^{-1} was incorporated into the soil during soil preparation. Phosphorous fertilizer as triple superphosphate at the rate of 24.7 kg P ha^{-1} and potassium fertilizer as muriate of potash (KCl) at the rate of 31.1 kg K ha^{-1} were applied as basal dose before planting. Seeds were treated with a fungicide (Captan) at the rate of 5 g kg^{-1} of seed before planting. Three seeds were planted per hill and thinning was done to obtain one plant per hill at 21 days after planting (DAP). Pre-emergence weed control was carried out by spraying alachlor at the rate of 3 L ha^{-1} after planting and hand weeding was followed at 15 and 35 DAP.

Rhizobium inoculation was done by applying a water-diluted commercial peat-based inoculums 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. Gypsum ($CaSO_4$) was applied at the rate of 312 kg ha^{-1} at the pod filling stage. Pest and disease were controlled by weekly applications of carbosulfan at 2.5 L ha^{-1}, methomyl at 1.0 kg ha^{-1} and carboxin at 1.68 kg ha^{-1}. Carbofuran 3% granular was applied at the pod setting stage by side dressing.

Irrigation: Subsurface drip irrigation system was installed to supply water to the peanut plants and soil water level was maintained uniformly at field capacity from planting to 7 DAP in both FC and water stress plots. The soil moisture of water stress plot decreased gradually and from then on it was maintained at the level of 1/3 AW constantly and at ±1% of the pre-determined level until flowering (40 DAE). Water was added to the respective plots by subsurface drip irrigation based on the crop water requirement and surface evaporation which were calculated following the methods described by Songsri *et al.* (2008a).

The calculation of total crop water use for each water treatment was done as the sum of transpiration and soil evaporation. Transpiration (T) was calculated using the methods described by Doorenbos and Pruitt (1992) as follows:

$$\text{ET crop} = \text{ETo} \times \text{Kc}$$

where, ET crop is crop water requirement (mm day^{-1}), Eto is the evapotranspiration of a reference under specified conditions calculated by pan evaporation method and Kc is the crop water requirement coefficient for peanut, which varies with genotypes and growth stage. In addition to, surface evaporation (Es) was calculated with the following formula described by Songsri *et al.* (2008a):

$$\text{Es} = \beta \times (\text{Eo}/\text{t})$$

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

Data collection

Weather parameters: The experiment was conducted during the dry season, December 2007 to April 2008. There was maximum rainfall (23.4 mm) at 110 DAE in the dry season (data not shown). The maximum and minimum of seasonal air temperature were 31.7 and 19.7°C, respectively. Daily pan evaporation ranged from 1.78 to 12.68 mm and a seasonal mean solar radiation, 18.0 MJ m^{-2} days^{-1} was observed.

Soil moisture status: Soil moisture in the individual plots was measured by gravimetric soil analysis at planting and harvest at the depths of 0-5, 25-30 and 55-60 cm at 0, 10, 25, 40 and 50 DAP. It could help to calculate the required amount of water to apply. The soil water status was also weekly monitored with a neutron moisture meter (Type I.H. II SER. N° N0152, Ambe Diccot Instruments Co. Ltd., England) at a depth of 0.3 m to 0.6 m at 0.3 m intervals.

Traits related to biological N_2 fixation, yield and yield components: Data were recorded for traits related to N_2-fixation parameters, nodule dry weight and shoot dry weigh at harvest only. Direct N_2-fixation was not determined, because, the earlier investigations have already indicated that, these traits are closely related with N_2-fixation (Pimratch *et al.*, 2004). Plants at the two ends of each row were discarded and only competitive plants were taken as samples. Samples in each plot were dug and separated into parts. Nodules were taken off from the roots and kept separately. Nodules, stems and leaves were oven-dried at 80°C for 48 h and nodule dry weight, shoot dry weight and total dry weight were determined. Pods were air-dried to obtain approximately 8% moisture content and shelled. Then, pod number per plant, seed number per pod, pod yield, seed size and harvest index were determined. To measure the biomass production, bordered plants in an area of 3.36 m^2 were harvested from each plot, then, they were deposed and weighted in the field. A random shoot sample of 2 kg was taken, weighed, then, oven-dried at 75°C for 48 h and dry weight was measured. Shoot dry matter content was calculated and used for determining shoot dry weight for a plot.

Drought tolerance traits: Specific leaf area (SLA) and SPAD chlorophyll meter reading (SCMR) were measured at 20, 40, 50 and 60 days after emergence. The third fully-expanded leaves from their respective terminal bud were detached from 5 chosen plants which were randomly selected from each plot between 8:30 and 9:00 am. SPAD chlorophyll reading was recorded twice on each leaflet of the tetra foliate leaf along the mid-rib. The model of this SPAD chlorophyll meter reading device was Minolta SPAD-502 meter, Tokyo, Japan. Nageswara Rao *et al.* (2001) suggested to fully covering the SPAD meter sensor upon the leaf lamina to avoid the interference from veins and midribs. SLA was measured on these leaves after recording SCMR at the same day. Measuring the leaf area with a leaf area meter (LI 3100C Area Meter, LI-COR Inc., USA) was followed by drying the leaves in an oven at 80°C for at least 48 h and weighted. SLA was calculated using the following formula:

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

Harvest index was computed as the ratio of total pod weight at the final harvest to total biomass at the final harvest. Drought tolerance indexes (DTI) of pod yield (PY) and yield components were calculated using Songsri *et al*. (2008b) formula as follow:

DTI (PY) = Pod yield under stressed treatment/
Pod yield under well-watered condition

Data analysis

Traits related to N_2-fixation and drought tolerance traits: The data were subjected to analysis of variance according to a split plot design. In case of significant difference, mean comparison was done based on Duncan's multiple range test (Gomez and Gomez, 1984). To reveal the comparison between two means of each genotype under two water regimes for nodule dry weight, biomass production and pod yield, the data were separately analyzed with randomized complete block design and least significant difference (LSD) test was used for mean comparison (Gomez and Gomez, 1984). Simple correlations among variables were calculated to determine the relationships among traits (Gomez and Gomez, 1984). Despite collecting SLA and SCMR data on 20, 40, 50 and 60 DAE, the data with the lowest CV and the highest F ratio were considered in data interpretation for precision. SLA data at 50 DAE and SCMR data at 60 DAE were focused to analysis of the variances.

RESULTS AND DISCUSSION

Soil moisture content: Soil moisture was weekly measured using a neutron moisture meter until harvest to directly check whether the water treatments were correct enough or not because water supply was calculated based on weather data. A clear distinction between two soil moisture levels noted at 30 cm of soil depth showed that soil moisture could be controlled along crop development to treat with the desired moisture levels (Fig. 1 a-b). The soil moisture difference due to 2 treatments was smaller at 60 cm depth. Since, there was not any significant change in weather data and no interference of rain during drought treatment, water-regime treatment was carried out correctly until harvest.

Effect of early drought on N_2-fixation related traits: Analysis of variance showed that variety differences were observed for all N_2-fixation traits, nodule dry weight and biomass production but the interaction of variety x water regime (G×W) were not significant for these traits (Table 1). The results indicated that varieties were the most important sources of variation for above traits. Moreover, the differences between two water regimes were not significant for all nitrogen fixing related traits.

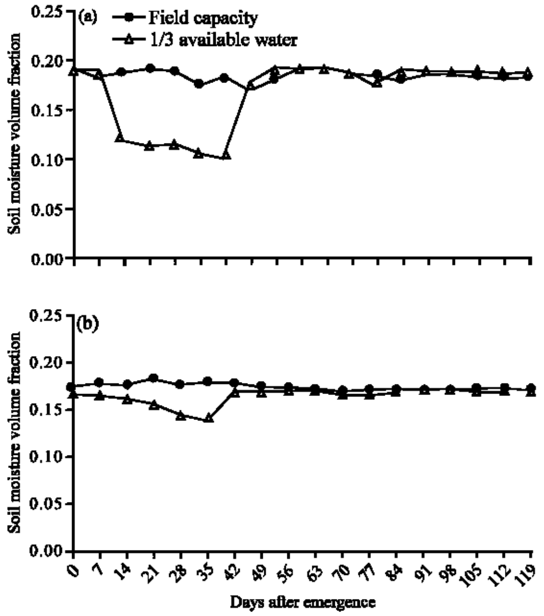

Fig. 1: Soil moisture volume fraction in two available soil water regimes [field capacity (FC) and 1/3 available water (AW)] at 30 cm (a) and 60 cm (b) of the soil level during 2007/08 dry seasons

Perhaps, stressed plants completely recovered from early season drought for N_2-fixation related traits although N_2-fixation decreased under 1/3 AW. On the other hand, since the data of these traits were collected at harvest only, the immediate response of them could not be seen as much as they did. N_2-fixation was affected by early drought because N_2-fixation under irrigated treatment average 350.5 mg N plant^{-1} while the N_2-fixation during recovery period from early drought (40 DAE-final harvest) increased to an averaged of 487.6 mg N plant^{-1} (unpublished data). The analysis also showed that there was no differential responses of genotypes in different moisture regimes (G×W, $p>0.05$) as shown in Table 1. Peanut genotypes showed the different performance in N_2-fixation related traits but they showed uniformly to both water regimes. Stressed plants might response to drought at the end of drought period but each genotype recovered from drought at the harvest time. Since, G×W interaction effects were small, screening and selection of peanut genotypes for high nitrogen fixing ability can be done under all water regimes.

There were differences among the tested genotypes in nodule dry weight at all water regimes ($p<0.01$), ranging from 0.24-0.64 and 0.20-0.68 g plant^{-1} for FC and 1/3 AW, respectively (Table 2). Furthermore, significant differences among tested genotypes were observed in biomass production and it ranged from 5.80-11.05 and

Table 1: Mean square for nodule dry weight, biomass production (BM), pod yield, harvest index (HI), number of pod per plant, number of seed per pod, seed size, specific leaf area (SLA) 50 DAE and SPAD chlorophyll meter reading (SCMR) 60 DAE of 11 peanut genotypes evaluated under two water regimes

SOV	df	Nodule dry wt. (g plant^{-1})	BM (t ha^{-1})	Pod yield (t ha^{-1})	No. of pod plant^{-1}	No. of seed pod^{-1}	Seed size (mm)	SLA 50 DAE (cm^2 g^{-1})	SCMR 60 DAE	HI
Rep.	3	0.006	9.59	0.75	38.35	0.073	109.48	1943.38	9.03	0.001
Water Regime (W)	1	0.003^{ns}	0.09^{ns}	6.66^{ns}	661.12*	0.155**	0.15^{ns}	2425.50^{ns}	71.46*	0.045^{ns}
Error (a)	3	0.022	8.30	2.30	32.65	0.003	28.27	1587.77	6.95	0.02
Genotype (G)	10	0.173**	17.39**	3.73**	98.18**	0.014**	712.27**	2366.00**	56.83**	0.019**
G x W	10	0.014^{ns}	2.23^{ns}	0.75^{ns}	33.06^{ns}	0.015^{ns}	22.32^{ns}	622.74^{ns}	4.28^{ns}	0.012*
Error (b)	60	0.011	2.62	0.48	34.26	0.021	55.57	450.51	5.78	0.006
CV (a)%		31.900	33.69	52.22	25.08	3.120	9.69	19.88	6.01	40.67
CV (b)%		22.600	18.93	23.81	25.69	7.770	13.59	10.59	5.48	21.65

ns: Non significant, *,**Significant at $p<0.05$ and $p<0.01$ levels, respectively. CV: Coefficient of variation, DAE: Day after emergence

Table 2: Nodule dry weight and biomass production of 11 peanut genotypes under different water regimes

	Nodule dry weight (g plant^{-1})				Biomass production (t ha^{-1})			
Genotypes	FC	Significance	1/3 AW	Significance	FC	Significance	1/3 AW	Significance
ICGV 98300	0.59ab	A	0.63a	A	10.40ab	A	9.72abc	A
ICGV 98303	0.59ab	A	0.48ab	A	8.62abc	A	7.40cd	A
ICGV 98305	0.48bc	B	0.58ab	A	8.15bcd	A	8.42bcd	A
ICGV 98308	0.56ab	A	0.40bc	B	7.75bcd	A	8.52bcd	A
ICGV 98324	0.47bc	A	0.56ab	A	10.00ab	A	8.32bcd	A
KK 60-3	0.62a	A	0.66a	A	10.43ab	A	10.52ab	A
Tainan-9	0.36cde	A	0.28c	A	6.47cd	A	6.52d	A
KKU 72-1	0.64a	A	0.68a	A	11.05a	A	11.03a	A
KKU 60	0.39cd	A	0.39bc	A	7.05cd	A	8.57bcd	A
KK 4	0.33de	A	0.26c	A	7.95bcd	A	7.70cd	A
KKU 1	0.24e	A	0.20c	A	5.80d	B	7.62cd	A
Mean	0.48		0.47		8.52		8.57	

Different small letters in each column show significant at $p<0.05$ by Duncan's multiple range test and different capital letters in each row of each parameters show significant at $p<0.05$ by least significant difference test. FC: Field capacity, AW: Available soil water

6.52-11.03 t ha^{-1} for FC and 1/3 AW, respectively (Table 2). The mean performances showed that, KK 60-3 and KKU 72-1 were higher for nodule dry weight and biomass production than other genotypes under both water regimes, whereas, KKU 1 and KK 4 showed the low means for all N_2-fixation parameters under all water regimes (Table 2). These former genotypes can be supposed to be high nitrogen fixing lines because Pimratch *et al*. (2004) reported that high nitrogen fixing lines generally gave high values for weight and number of nodules and shoot dry weight when low nitrogen fixing lines gave low values for these traits.

In addition, the high nitrogen fixing genotypes; KK 60-3 and KKU 72-1 showed the high performance in term of nodule dry weight and biomass production under both water regimes. These consistent genotypes can be effectively evaluated under all water regimes with high N_2-fixation. Another statistical analysis using randomized complete block design and least significant difference (LSD) test revealed that ICGV 98305 showed higher nodule dry weight and pod yield at 1/3 AW, whereas, ICGV 98308 showed lower nodule weight under drought (Table 2).

Effect of early drought on yield and yield components: Statistically, there was a significant variance between two water regimes for number of pod per plant and a highly significant difference in number of seed per pod but the same result was observed for pod yield and seed size (Table 1). Drought tolerance index (DTI) % of all yield and yield components were above one or almost one in most genotypes and it showed that early drought favored the yield of peanut because yield advantages were evident in most genotypes (data not shown). The result agreed with Negeswara Rao *et al*. (1985) who reported that the early drought resulted in a more favorable distribution of dry matter into reproductive components. This increase in yield resulting from decreased irrigation in the early stages of a crop's life may be exploited in crop management when irrigation is available (Negeswara Rao *et al*., 1985). Analysis of variance showed that there was no interaction of genotypes and water regimes (G×W) in pod yield and yield components (Table 1).

Peanut genotypes did differ for pod yield under both water regimes ($p<0.01$) and they ranged from 1.47-4.37 and 2.12-4.15 t ha^{-1} for FC and 1/3 AW, respectively. Analysis of variance by RCBD and mean comparison with LSD test showed that ICGV 98305 had higher yield (3.00 t ha^{-1})

under water stress than FC (1.90 t ha^{-1}) (Table 3). It seemed to take the advantage of early drought effect because Songsri *et al.* (2008a) reported that percentage of root length density (RLD%) was increased by drought and it was associated with pod yield. Such genotype, ICGV 98305 would be suggested as a parental line for peanut breeding program under drought condition. Higher seed number per pod was observed in KKU 1 under water stress compared to FC (data not shown). Although there was no effect of early drought on pod yield statistically, it affected on other yield components such as number of pod per plant and number of seed per pod and they were increased due to early drought (Table 1).

Effect of early drought on drought tolerance traits: Analysis of variance showed that there was a significant variance in SCMR 60DAE ($p<0.05$) under different water regimes but no effect on HI and SLA 50 DAE (Table 1). This result confirmed the assumption that drought stress reduced chlorophyll content and increased chlorophyll density which causes higher chlorophyll per unit area (Nageswara Rao and Wright, 1994). The differences among genotypes under all water regimes suggested that peanut genotypes were the sources of variation in HI, SCMR and SLA. Five ICGV lines noted as drought resistant lines showed high SCMR values under both water regimes followed by KKU 72-1 (data not shown). Since, DTI of SCMR 60 DAE for all genotypes were more than one except KKU 60 (0.97), it can be clearly seen that early drought increased the chlorophyll density which is vitally important for photosynthesis. For SLA and HI, they were not different under both water regimes but highly significant differences were observed among genotypes. The highest SLA value was found in KK 4 and KKU 1 genotypes under both water regimes. The variation was not observed for drought tolerance traits at the interaction of G x W except for HI. The higher HI was observed in ICGV 98305 under water stress (Table 3). This result totally resembled the data of nodule dry weight and pod yield that also showed better result of this genotype under 1/3 AW (Table 2). It clearly pointed out that all genotypes tried to promote their adaptive ability to early drought as much as they could but ICGV 98305 was significantly resistant to drought and performed so well for most parameters.

Relationship between traits related to N$_2$-fixation and drought tolerance traits: There was a significant correlation between nodule dry weight and biomass production (r = 0.82*, $p<0.05$) and (r = 80*, $p<0.05$) under FC and 1/3 AW, respectively (Table 4). The result indicated that fixed nitrogen greatly contributed to biomass production rather than pod yield and yield components and the latter parameter can be used as

Table 3: Pod yield and harvest index of 11 peanut genotypes under different water regimes

	Pod yield (t ha^{-1})				HI			
Genotypes	FC	Significance	1/3 AW	Significance	FC	Significance	1/3 AW	Significance
ICGV 98300	2.22def	A	2.85bc	A	0.45a	A	0.30b	A
ICGV 98303	2.40cdef	A	2.95abc	A	0.30bcd	A	0.40ab	A
ICGV 98305	1.90def	B	3.00ab	A	0.22d	B	0.35ab	A
ICGV 98308	2.72cd	A	3.60ab	A	0.37abc	A	0.42ab	A
ICGV 98324	4.37a	A	3.50ab	A	0.32bcd	A	0.42ab	A
KK 60-3	3.20bc	A	3.62ab	A	0.32bcd	A	0.35ab	A
Tainan-9	1.47f	A	2.12c	A	0.22d	A	0.32b	A
KKU 72-1	3.75ab	A	3.57ab	A	0.35bc	A	0.32b	A
KKU 60	2.85bcd	A	4.15a	A	0.40ab	A	0.47a	A
KK 4	2.45cde	A	3.05abc	A	0.32bcd	A	0.37ab	A
KKU 1	1.57ef	A	2.55bc	A	0.27cd	A	0.32b	A
Mean	2.63		3.18		0.33		0.37	

Different small letters in each column show significant at $p<0.05$ by Duncan's multiple range test and different capital letters in each row of each parameters show significant at $p<0.05$ by least significant difference test. FC: Field capacity, AW: Available soil water

Table 4: Correlation coefficients between traits related to N$_2$- fixation, yield and yield components and drought tolerance traits

Parameter	NDW	BM	PY	No. of pod plant^{-1}	No. of seed pod^{-1}	SZ	SLA 50 DAE	SCMR 60 DAE	HI
NDW		0.82*	0.49	0.72*	0.58	0.33	-0.66*	0.63*	0.37
BM	0.80**		0.70*	0.76**	0.65*	0.35	-0.52	0.63*	0.37
PY	0.43	0.58		0.79**	0.65*	0.58	-0.59	0.71*	0.41
No. of pod plant^{-1}	0.31	-0.04	-0.01		0.65*	0.58	-0.69*	0.66*	0.53
No. of seed pod^{-1}	-0.09	0.28	0.04	-0.26		0.07	-0.67*	0.36	0.32
SZ	0.44	0.70*	0.78**	-0.42	-0.00		-0.27	0.60*	0.22
SLA 50DAE	-0.53	-0.22	-0.55	-0.41	0.41	-0.23		-0.71*	-0.43
SCMR 60DAE	0.94**	0.71*	0.59	0.26	-0.09	0.49	-0.66*		0.36
HI	-0.15	-0.20	0.67*	0.13	-0.27	0.27	-0.50	0.13	

*,**: Significant at $p<0.05$ and $p<0.01$ levels, respectively. Upper diagonal: Field capacity data and lower diagonal: 1/3 available water data. NDW: Nodule dry weight, BM: Biomass production, PY: Pod yield, HI: Harvest index, SZ: Seed size, SLA: Specific leaf area, SCMR: SPAD chlorophyll meter reading

N_2-fixation related trait in both water regimes because their correlation was consistent. This assumption was more approved because the correlation coefficient between two N_2-fixation related traits, nodule dry weight and BM production and harvest index (HI) was not significant under both water regimes (Table 4).

In contrast, the correlation coefficient between nodule dry weight, BM production and specific leaf area was not significant at 50 DAE under both water regimes. The results might imply that the fixed nitrogen had more partitioning into other vegetative growth than SLA and this is a reason why biomass production is highly correlated with N_2-fixation. The correlation coefficient between nodule dry weight and SCMR 60 DAE was significant (0.63* and 0.94**) at SCMR 60 DAE readings under FC and 1/3 AW, respectively (Table 4). BM production was also highly correlated with SCMR 60 DAE under both water regimes. This result was doubtless because Pimratch *et al.* (2008a) mentioned that N_2-fixation by root nodules depends on the reserve energy supply in the nodules and/or on the photosynthate supply from the shoot. In general, SCMR which is an indirect measurement of chlorophyll density is significantly correlated with biomass production because chlorophyll loss is always associated with reductions in photosynthesis and the large reductions in chlorophyll content might in large part be responsible for the observed reduction in total dry matter.

Relationship between N_2-fixation traits and yield and yield components: Among pod yield and yield components, only number of pod per plant was highly correlated with nodule dry weight (0.72*) under FC (Table 4). Another N_2-fixation related trait, biomass production was highly correlated with pod yield, number of pod per plant and number of seed per pod under FC and it only highly correlated with seed size under 1/3 AW (Table 4). Higher biomass due to fixed nitrogen during water stress could support in pod filling stage after drought treatment. This implies that under drought fixed nitrogen partly supported to vegetative growth rather than to yield. But during the seed filling stage, plant mechanism and N_2-fixation process have already overcame the drought and they restored their ability of contribution to sink thus biomass production was highly correlated with seed size under water stress. It in turn led to higher yield because the correlation between pod yield and seed size was highly significant (0.78**) under water stress (Table 4) and drought tolerance index (DTI) of each genotypes for pod yield was more than one (data not shown).

Relationship between drought tolerance traits and yield and yield components: Correlation coefficient between pod yield and HI was not significant under FC but significant under 1/3 AW (Table 4). The result was beyond question because pod yield is one portion in calculating of HI and HI was sensitive to an interaction effect of G x W (Table 1). Pod yield showed a significant correlation ($p<0.05$) with SCMR 60DAE under FC only (Table 4). The phothosynthate in general provided in pod yield which is one of the sinks but under drought condition they might partially contribute to other growth as fixed nitrogen did. Thus, SCMR 60 DAE was correlated with pod yield under FC only. Number of pod per plant and seed size was significantly correlated with SCMR 60 DAE under FC (Table 4). As a matter of fact, there was a significant effect of early drought on SCMR 60 DAE (Table 1) and higher photosynthesis due to denser chlorophyll might more support to biomass production or nitrogen fixing process than pod yield under early drought. Therefore, there was no correlation between SLA and SCMR and yield and yield components under early drought (Table 4). It can be said that chlorophyll density (SCMR) more determined the photosynthesis to boost the yield compared to the specific leaf area which is one component of chlorophyll content in leaf.

CONCLUSION

The ability of N_2-fixation related traits, nodule dry weight and biomass production were not affected by early drought because peanut plant could recover and undergo in above traits after stress condition. More partition from fixed nitrogen to vegetative growth such as biomass production rather than some yield components might favor bigger seed size with higher yield under water stress.

Water stress did not alter the relationships between N_2-fixation related traits and drought tolerance trait, SCMR. SCMR can be indirectly used as a tool for evaluation of N_2-fixation traits in peanut.

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