



Nutrient uptake of peanut genotypes under different water regimes

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Abstract

Drought is a serious environmental stress limiting growth and productivity in peanut and other crops. Nutrient uptake of peanut is reduced under drought condition, which reduces yield. The objectives of this study were to investigate nutrient uptake of peanut genotypes in response to drought and to estimate the relationship between nutrient uptake and peanut yield under different water regimes. Pot experiment was conducted in a greenhouse in the dry season 2002/03 and the rainy season 2003. Three soil moisture levels [field capacity (FC), 2/3 available soil water (2/3 AW) and 1/3 available soil water (1/3 AW)] were assigned as factor A and 11 peanut genotypes as factor B. Total nutrient uptake was determined at harvest. Season×water regime interactions and differences in seasons, water regimes and genotypes were significant for all nutrient uptakes. The interactions between season and genotype were significant for N and K uptakes. The nutrient uptakes of peanut plants grown under FC were higher than those plants grown under water stress treatments. Tifton 8 was the highest genotype for all nutrient uptakes in both dry and rainy seasons, while ICGV 98303 and KK 60-3 had high nutrient uptake under water stress condition. The nutrient uptake of peanut in the rainy season was higher than the dry season. The relationships between nutrient uptake parameters, biomass and pod dry weight were positive and significant in both seasons. This information is important for peanut breeder interested in developing peanut lines with reasonably high nutrient uptake under drought condition.

Keywords: Biomass; Harvest index; Relationship; Nitrogen uptake; Water stress.

Introduction

Peanut (*Arachis hypogaea* L.) is a major cash crop grown mainly under rainfed conditions in the semi-arid tropics. Prolonged drought has been found to severely reduce yield of peanut (Pimratch et al., 2008; Songsri et al., 2008) and increase aflatoxin contamination (Waliyar et al., 2003; Girdthai et al., 2010). The use of drought resistant peanut varieties and sufficient irrigation can overcome drought problem (Sankar et al., 2008).

Inorganic nutrients such as nitrogen (N), phosphorus (P), potassium (K) and calcium (Ca) ion play multiple essential roles in plant mechanisms (Ashraf et al., 2008). Drought generally reduces nutrient uptake in crop plants and concentrations of mineral nutrients in plant tissues (Fageria et al., 2002). Water stress affects nutrient transportation to the root and root growth. However, crop species and genotypes within a species are known to differ in their ability to take up nutrients under drought stress conditions (Garg, 2003). Generally, nutrient uptake by crop plants grown in soil is greatly influenced by several factors including climate and water stress (Alam, 1999). Drought stress reduced the uptake of N, P and K in peanut (Kulkarni et al., 1988). The reduction in nutrient uptake by plant under drought stress is due to reduced transpiration and impaired active transport and membrane permeability resulting in reduced root absorbing power (Tanguilig et al., 1987). Rewetting experiments have generally indicated that uptake of plant nutrients decreases with increasing water stress and may remain depressed after watering for several days or weeks (Jupp and Newman, 1987; Bassirirad and Caldwell, 1992). Moreover, water stress at flowering, pegging, pod formation and pod development stages reduced pod yields of peanut cv. CG-2 and it also reduced the uptake of N, P, K, Ca, magnesium (Mg) and sulfur (S) (Kolay, 2008). Under drought stress conditions, the available soil N (NO_3^- and NH_4^+) and N_2 fixation is greatly reduced and such reduction leads to low N accumulation and consequently low dry matter production and low crop yield (Pimratch et al., 2008; Pimratch et al., 2013).

The information on the genotypic variation among peanut genotypes for nutrient uptakes across different water regimes is still lacking. Our hypothesis is that drought resistant genotypes will maintain high nutrient uptake under drought conditions and this ability will be a part of the reason for their drought tolerance and improved yield under drought conditions. Variation in drought resistance in peanut is important for selection and

improvement of peanut varieties for drought resistance. The objectives of this study were to investigate the responses of peanut genotypes to drought for nutrient uptake and to estimate the relationship between nutrient uptake and peanut yield parameters.

Materials and Methods

Experimental procedures and plant material

Pot experiment was conducted under greenhouse conditions at the Field Crop Research Station of Khon Kaen University (latitude 16° 28' N, longitude 102° 48' E, 200 m above sea level) during December 2002 to May 2003 and repeated from June to November 2003. The treatments consisting of 3×11 factorial combinations were arranged in a randomized complete block design (RCBD) with 6 replications in both seasons. Three soil moisture levels [field capacity (FC), 2/3 available soil water (2/3 AW) and 1/3 available soil water (1/3 AW)] were assigned as factor A, and 11 peanut genotypes were assigned as factor B. Eight peanut genotypes consisting of ICGV 98300, ICGV 98303, ICGV 98305, ICGV 98308, ICGV 98324, ICGV 98330, ICGV 98348 and ICGV 98353 are elite drought resistant lines with high total biomass and pod yield in screening tests under drought stress conditions (Nigam et al., 2003; Nigam et al., 2005). The ninth genotype, Tifton 8, is a Virginia-type drought resistant line received from the United State Department of Agriculture (USDA). KK 60-3, our 10th genotype, is a Virginia-type peanut cultivar growing in Thailand, with high N₂ fixation (Toomsan et al., 1995), but is sensitive to drought for pod yield (Songsri et al., 2008). Our 11th genotype, Tainan 9, is a Spanish-type peanut cultivar having low N₂ fixation (Mc Donagh et al., 1993) and low dry matter production (Vorasoot et al., 2003).

Each treatment consisted of two pots (diameter 25 cm, height 70 cm) in a replicate. Pots were filled uniformly with dry soil to 10 cm from the top. Seeds were treated with captan (3a,4,7,7a-tetrahydro-2-[(trichloromethyl)thio]-1H-isoindole-1,3(2H)-dione) at the rate of 5 g kg⁻¹ seeds before planting and KK 60-3 and Tifton-8 were treated with ethrel 48% at the rate of 2 ml L⁻¹ water to break seed dormancy. *Bradyrhizobium* (mixture of strains THA 201 and THA 205, from Department of Agriculture, Ministry of Agriculture and Cooperatives, Bangkok, Thailand) was used for seed inoculation at planting. Three seeds were planted per pot and the seedlings were thinned to 2 plants

per pot at 14 days after emergence (DAE). Phosphorus (triple superphosphate) and potassium (KCl) fertilizers were applied at the rates of 24.7 kg P ha⁻¹ and 31.1 kg K ha⁻¹, respectively, at 14 DAE. Gypsum (CaSO₄) was applied at the rate of 312 kg ha⁻¹ at approximately 40 DAE. At pod setting stage, carbofuran (2,3-dihydro-2,2-dimethylbenzofuran-7-ylmethylcarbamate 3% granular) was applied to the crop to control subterranean ants. Pests and diseases were controlled by weekly applications with carbosulfan [2-3-dihydro-2,2-dimethylbenzofuran-7-yl (dibutylaminothio) methylcarbamate 20% w v⁻¹, carboxin [5,6-dihydro-2-methyl-1,4-oxath-ine-3-carboxanilide 75% wettable powder] at 1.68 kg ha⁻¹ and water soluble concentrate] at 2.5 L ha⁻¹, methomyl [*S*-methyl-*N*-((methylcarbamoyl)oxy) thioacetimidate 40% soluble powder] at the rate of 1.0 kg ha⁻¹.

The water supplied to individual pots was equal to the sum of water used by the plants and soil surface evaporation. The calculated amount of water was divided into four fractions. The first fraction was applied on the soil surface and the remaining three fractions were filled in three cones to supply water to the soil columns through plastic tubes at 25, 40 and 55 cm below the top of the pots, respectively. The water content of the soil was maintained at field capacity (FC) and then stress treatments were allowed to gradually reduce until they reached predetermined levels of 2/3 AW (14.14%) and 1/3 AW (10.47%) at 35 and 42 DAE, respectively. Soil moisture was controlled uniformly until harvest. Soil moisture contents at FC and permanent wilting point (PWP) were determined at 17.81% and 6.80%, respectively, by the pressure plate method. Total crop water use for each water treatment described by Doorenbos and Pruitt (1992);

$$ET_{\text{crop}} = ET_o \times K_c,$$

where ET_{crop} = crop water requirement (mm day⁻¹), ET_o = reference evapotranspiration (mm) calculated using pan evaporation data, K_c = crop water requirement coefficient for peanut depending on genotype and growth stage.

Surface evaporation (S.E.) was calculated as followed Singh and Russell (1981);

$$S.E. = \sum [\beta \times (E_o / t)],$$

where S.E. = soil evaporation (mm), β = light transmission coefficient measured depending on crop cover, E_o = evaporation from class A pan

(mm/day), t = days from the last irrigation or rain (day) and \sum is the summation for the soil evaporation from the last irrigation or rainfall to immediately before the next irrigation.

Meteorological conditions and soil moisture

Rainfall, relative humidity (RH), maximum and minimum temperature, evaporation (E_o) and solar radiation were recorded daily from sowing until harvest by a weather station located at 50 m from greenhouse 1 in dry season 2002/03 and 750 m from greenhouse 2 in rainy season 2003. Soil water content was measured by gravimetric method before sowing and at harvest for two seasons. Soil sample was oven-dried at 105 °C for 72 hours to determine soil moisture percentage.

Plant water status

Relative water content (RWC) and leaf water potential (LWP) were measured at 30, 60 and 90 DAE from the first pot. LWP was measured by a pressure bomb (model 1003 S/N 2973) at 10-12 AM using third leaf from the top of the main stem sampled from one plant in each pot. The second leaf from the top of main stem sampled from one plant in each pot was used for determination of RWC. RWC was calculated according to the method suggested by Kramer (1980);

$$\text{RWC} = \frac{(\text{fresh weight} - \text{dry weight})}{(\text{saturated weight} - \text{dry weight})} \times 100,$$

Saturated weight was measured by putting the leaf sample in water for 8 hours; blot drying the outer surface, and then measuring leaf weight.

Biomass, pod dry weight and harvest index

One plant from each pot was harvested at maturity stage. The above ground was clipped at the soil surface. Shoot samples were oven-dried at 80 °C for 48 hours and then weighted. Pod dry weight was determined after air drying to 8% moisture content. Harvest index (HI) was computed as total pod yield plus above ground biomass at final harvest.

Total nitrogen, phosphorus, potassium and calcium content

For each treatment, plants in the pot were uprooted and soil was removed from the root by washing them on a 0.5 mm screen. The nodules, root, shoot and pod were dried at 75 °C for 48 hours or until constant weight and then weighed. Total plant biomass consisted of roots, nodules, shoots and pods. Shoot samples were ground using a hammer mill and total nitrogen was measured using the automated indophenol method by Schuman et al. (1973) and read on a flow injection analyzer (Tecatorinc. model 5012).

Plant nutrients were determined at harvest. Leaf, stem, pod and root samples were ground, oven-dried at 80 °C for 72 hours and weighed. Phosphorus (P) was determined by spectrophotometric methods, the flame photometer was used for potassium (K), Kjeldahl digestion for nitrogen (N) and wet oxidation was used for phosphorus, potassium, calcium and magnesium (P, K, Ca and Mg) (Kaewpradit et al., 2009). Calcium was measured by atomic absorption spectroscopy (Al-Karaki and Al-Raddad, 1997).

Statistical analysis

Individual analysis of variance was performed for each character in each season. Error variances for the two seasons were tested for homogeneity (Gomez and Gomez, 1984). Combined analyses of variance were done for those characters that error variances for the two seasons were homogeneous. Duncan's multiple range test (DMRT) was used to compare means. The analyses of variance at this stage were done using MSTAT-C package (Bricker, 1989).

Simple correlation was used to determine the relationship between biomass production, pod dry weight, harvest index and nutrients uptake under well-watered and drought-stress conditions.

Results

Weather data, plant water status, soil moisture and soil properties

The seasonal means of daily air temperature ranged between 21.8 °C and 33.0 °C in the dry season (2002/03) and between 24.3 °C and 34.5 °C in the rainy season (2003) (Figure 1). Daily evaporation ranged from 2.1-9.4 mm in the dry season 2002/03 and from 0.1-10.1 mm in the rainy season 2003. Daily

means of relative humidity were 81.3% in the dry season 2002/03 and 90.7% in the rainy season 2003. Daily means of solar radiation were 19.2 MJ m⁻² d⁻¹ in the dry season 2002/03 and 15.7 MJ m⁻² d⁻¹ in the rainy season 2003.

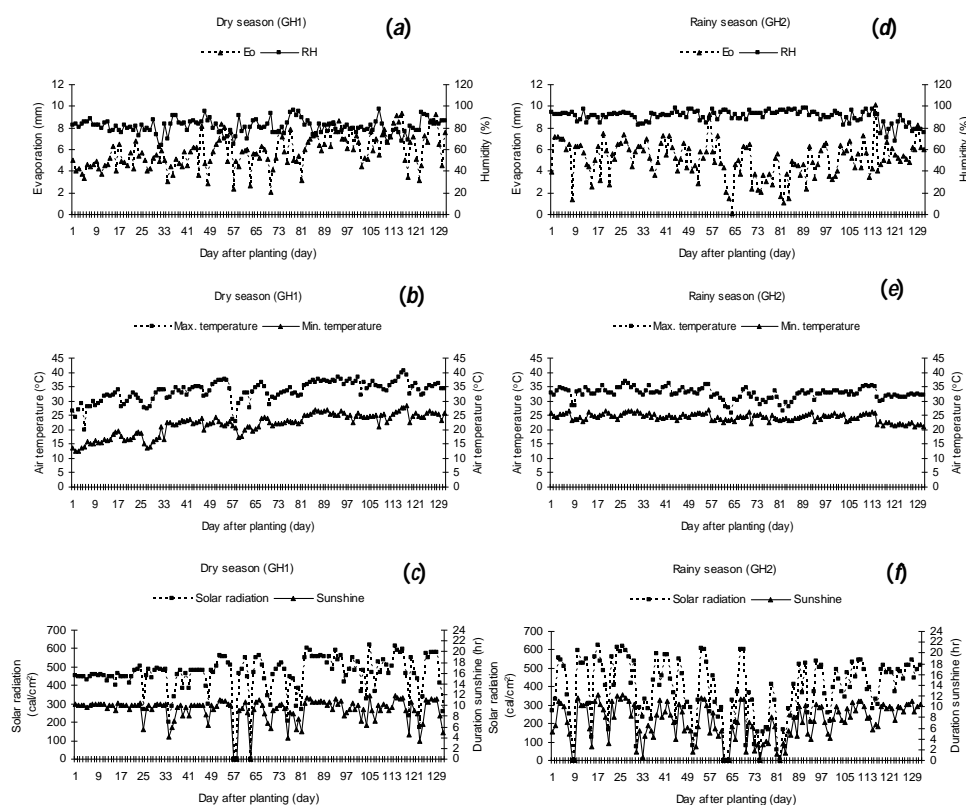


Figure 1. Evaporation (E_0), humidity (RH), maximum temperature, minimum temperature, solar radiation and sunshine in the dry season 2002/03 (a-c for greenhouse 1; GH1) and the rainy season 2003 (d-f for greenhouse 2; GH2).

Soil moisture contents were 16.72, 14.28 and 9.21% for field capacity (FC), 2/3 AW and 1/3 AW treatments, respectively, in the dry season 2002/03 and 16.74, 13.22 and 10.40% for FC, 2/3 AW and 1/3 AW, respectively, in the rainy season 2003 (Table 1). The soil moisture contents for FC, 2/3 AW and 1/3 AW were 17.81%, 14.14% and 10.47%, respectively and close to the predetermined levels, indicating reasonably good management of the experiment.

Table 1. Soil moisture contents at 0-60 cm at the end of stress period during each water regimes in the dry season (2002/03) and the rainy season (2003).

Water regimes	Soil moisture (%)	
	Dry season	Rainy season
FC	16.72	16.74
2/3 AW	14.28	13.22
1/3 AW	9.21	10.40

FC: field capacity is 17.81%; PWP: permanent wilting point is 6.80%.

The values of leaf water potential (LWP) for FC treatment evaluated at 30, 60 and 90 DAE in the dry season and the rainy season were higher than those for 2/3 AW and 1/3 AW treatments (Figure 2). Relative water content (RWC) was lowest for 1/3 AW treatment.

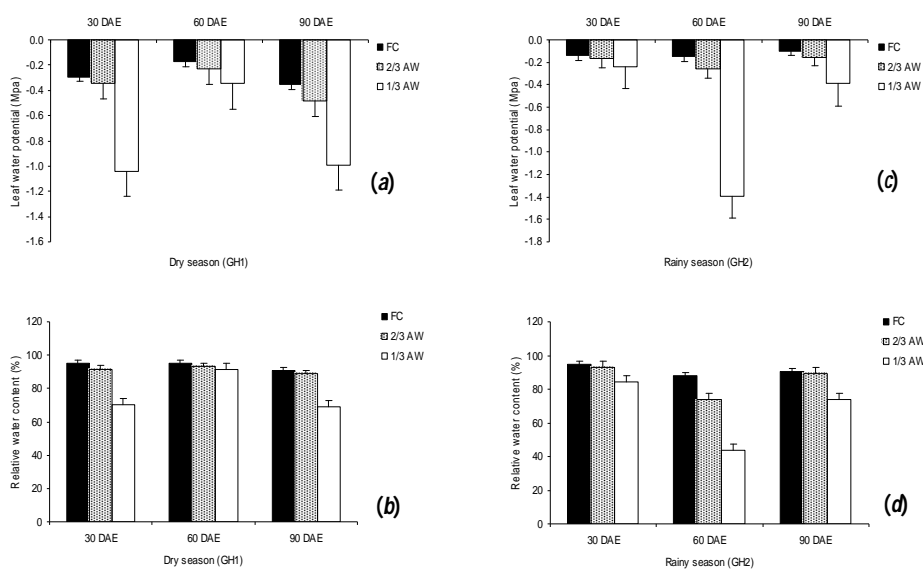


Figure 2. Leaf water potential and relative water content at 30, 60 and 90 day after emergence (DAE) in dry season (a and b) for greenhouse 1; GH1) and rainy season (c and d) for greenhouse 2; GH2) in 2003.

Effect of water stress on total nitrogen, phosphorus, potassium and calcium

Season \times water regime interactions and the differences in seasons, water regimes and genotypes were highly significant for nitrogen (N), phosphorus

(P), potassium (K) and calcium (Ca) (Table 2). The interactions between season and genotype were highly significant only for N and K, whereas the interactions between water regime and genotype and among season, water regime and genotype were not significant for these traits.

Table 2. Mean squares for the combined analyses of variance for N, P, K and Ca under greenhouse conditions in the dry season (2002/03) and the rainy season (2003).

SOV	df	N	P	K	Ca
Season (S)	1	483263**	5460.95**	555859**	490798**
Rep/season	10	4139	176.16	3830	9428
Water (W)	2	269262**	1569.55**	503994**	610331**
Genotype (G)	10	19390**	90.39**	8299**	15183**
S×W	2	28042**	401.41**	27699**	42315**
S×G	10	4762**	18.19	3515**	2148
W×G	20	2511	12.99	1832	1827
S×W×G	20	2307	10.82	1449	2065
Error	320	1632	10.79	1352	1391
C.V (%)		29.03	30.85	22.19	24.09

** significant at $P < 0.01$.

Drought at 1/2 AW and 1/3 AW in the dry season 2002/03 and the rainy season 2003 significantly reduced plant nutrient uptake compared to field capacity (Table 3). Tifton 8 had the highest nutrient uptake for N, P, K and Ca at all water regimes and in both seasons. Tainan 9 had the lowest N ($144 \text{ mg plant}^{-1}$) in the rainy season (2003) and ICGV 98353 had the lowest N ($72.88 \text{ mg plant}^{-1}$) in the dry season (2002/03). However, the means of all nutrients in the rainy season 2003 were higher than in the dry season 2002/03.

Relationship between nutrient uptakes with biomass, pod dry weight and harvest index

Positive and significant correlations were found between BM and total N, P, K, Ca across water regimes in the dry season and the rainy season (Table 4). The correlations between PDW and total nutrient were also positive and significant in the dry season and the rainy season. However, the correlations between N and HI and between P and HI were not significant ($r=0.00$ and $r= -0.11$, respectively) in the dry season 2002/03, but they were significant ($r=0.36$ and $r=0.52$, respectively) in the rainy season 2003.

Table 3. The content of N, P, K and Ca under three water regimes for 11 peanut genotypes in the dry season (2002/03) and the rainy season (2003).

Factor	Dry season				Rainy season			
	N	P	K	Ca	N	P	K	Ca
	mg plant ⁻¹							
Water regime								
FC	139.59 ^a	8.93 ^a	182.62 ^a	176.96 ^a	242.34 ^a	20.33 ^a	290.18 ^a	288.20 ^a
2/3 AW	84.61 ^b	5.63 ^b	105.71 ^b	97.44 ^b	131.78 ^c	11.63 ^b	170.69 ^b	153.11 ^b
1/3 AW	88.41 ^b	6.24 ^b	96.20 ^b	84.41 ^b	148.10 ^b	11.12 ^b	148.45 ^c	128.73 ^c
Genotype								
ICGV 98300	101.45 ^c	6.36 ^{bcd}	116.24 ^{bc}	109.10 ^{cd}	166.00 ^{de}	14.52 ^{bcd}	194.08 ^{cdef}	179.00 ^{cd}
ICGV 98303	85.93 ^{cd}	5.73 ^{cd}	104.66 ^c	95.68 ^d	199.61 ^b	15.93 ^{ab}	220.43 ^{ab}	177.11 ^{cd}
ICGV 98305	83.23 ^{cd}	5.81 ^{cd}	120.55 ^{bc}	96.50 ^d	170.91 ^{cd}	13.81 ^{bcd}	205.93 ^{bcde}	184.77 ^{bc}
ICGV 98308	84.52 ^{cd}	6.18 ^{cd}	129.68 ^b	94.88 ^d	162.13 ^{de}	13.05 ^d	205.48 ^{bcde}	161.34 ^d
ICGV 98324	96.15 ^{cd}	6.17 ^{cd}	124.95 ^{bc}	119.71 ^{bcd}	155.85 ^{de}	12.49 ^d	192.77 ^{def}	186.65 ^{bc}
ICGV 98330	106.27 ^{bc}	7.00 ^{bcd}	139.92 ^b	131.51 ^{bc}	194.88 ^{bc}	15.50 ^{bc}	218.60 ^{abc}	207.97 ^b
ICGV 98348	101.63 ^c	6.34 ^{bcd}	123.91 ^c	114.77 ^{cd}	166.02 ^{de}	13.30 ^{cd}	177.03 ^f	171.96 ^{cd}
ICGV 98353	72.88 ^d	5.20 ^d	117.04 ^{cd}	114.31 ^{cd}	156.13 ^{de}	13.93 ^{bcd}	215.58 ^{abcd}	207.53 ^b
Tainan 9	108.90 ^{bc}	7.16 ^{bc}	128.67 ^b	143.16 ^{ab}	144.06 ^c	13.83 ^{bcd}	179.37 ^f	205.72 ^b
KK 60-3	131.48 ^b	8.18 ^b	130.38 ^b	133.25 ^{bc}	173.52 ^{cd}	13.64 ^{bcd}	188.99 ^{ef}	170.42 ^{cd}
Tifton-8	173.79 ^a	12.12 ^a	173.94 ^a	162.76 ^a	225.66 ^a	17.94 ^a	235.93 ^a	237.66 ^a
Mean	104.20	6.93	128.18	119.60	174.07	14.36	203.11	190.01

Mean in the same column for each factor with the same letters are not significantly different by DMRT (at P<0.05).

Table 4. Correlation coefficients among total N, P, K, Ca, biomass (BM), pod dry weight (PDW) and harvest index (HI) of 11 peanut genotypes across three water regimes grown in the dry season (2002/03) and rainy season (2003).

Nutrient	Dry season			Rainy season		
	BM	PDW	HI	BM	PDW	HI
N	0.74**	0.39*	0.00	0.82**	0.66**	0.36*
P	0.66**	0.38*	-0.11	0.91**	0.78**	0.52**
K	0.91**	0.70**	0.37*	0.93**	0.85**	0.64**
Ca	0.90**	0.71**	0.41*	0.92**	0.84**	0.64**

*, ** significant at $P < 0.05$ and $P < 0.01$, respectively.

Discussion

In this study, nutrient uptake in the rainy season was higher than that in the dry season. Higher temperature in the rainy season (Figure 1) might cause higher transpiration rates, resulting in more nutrient uptakes in peanut plants. In previous investigations, nutrient uptakes were correlated with transpiration rate even under water stress (Reddy et al., 2003; Puangbut et al., 2011).

Mild and severe drought stress significantly reduced nutrient uptake in peanut, and nutrient uptake values were rather similar under both drought stress levels especially in the dry season. The nutrient uptake reduction observed in this study was in agreement with results reported previously in *Dalbergiasisoo* seedlings (Singh and Singh, 2004).

Drought reduces plant growth, yield and nutrient uptake of crop plants (Fageria et al., 1991) and the reduction in nutrient uptake causes low concentrations of mineral nutrients in crop plants (Gunes et al., 2006). A better understanding on nutrient uptake under drought conditions is required for understanding peanut genotypes with different drought resistance levels that can maintain yield under rainfed and drought conditions.

Yield potential is defined as the highest possible yield of a cultivar grown under ideal conditions of nutrient and water availability and it is maintained free of pests and diseases (Evan, 1993). Soil moisture plays an important role in the movement of nutrient to root and consequent absorption and final concentration in the plants. Like Ghanbari et al. (2011), we also noted that yield, plant growth and nutrient uptake were reduced under conditions of drought. Since the reduction in soil water availability affects the rate of diffusion of many plant nutrients, the compositions and concentrations of soil solutions are also affected by drought. Our studies noted that nitrogen,

potassium and calcium were reduced by water stress. The results were similar to those reported in tomato (Nahar and Gretzmacher, 2002).

However, the differences between water regimes and genotypes were significant and the interactions between season and water regime were also significant for all nutrients measure in peanut plants. Although water regimes significantly affected nutrient uptakes of peanut, selection of peanut genotypes for high nutrient uptakes could be done under any water regimes because the interactions between peanut genotype and water regimes were not significant, showing the consistency of the nutrient uptakes across water regimes. Therefore we believe that nutrient uptake from many studies will be useful to identify genetic material for use peanut breeding programs targeting drought.

The responses of peanut genotypes across water regimes were consistent. In general, Tifton 8 performed best for all nutrient uptakes in both seasons although it was not different from other genotypes for some nutrients. Based on our results, Tifton 8 and KK 60-3 were the best genotypes for all nutrient uptakes across water regimes (Table 2). ICGV 98353 had the lowest nitrogen uptake and other nutrient uptakes except for K in the rainy season. Therefore, the uptake of one nutrients is likely to be positively correlated to the uptake of others elements. Interestingly, peanut genotypes with high nitrogen contents, also showed increases in other nutrients.

Correlations between nutrient uptakes and BM were highly significant in both seasons and most correlations between nutrient uptakes and PDW were significant in both seasons except for the correlation between pod dry weight and P in the dry season (Table 4). The correlation coefficients between nutrient uptakes and BM were higher than those between nutrient uptakes and PDW. The results indicated that nutrient uptake contributed to greater BM production than PDW. Gascho et al. (1992) also reported that there was higher proportion of nutrients in the BM compared to roots, seeds and hulls in peanut.

The correlations between HI and nutrient uptakes were significant in the rainy season, where as the correlation coefficients between HI and N, P in the dry season were not significant. In the dry season, N and P uptakes might be allocated to BM rather than PDW. Decreasing water availability under drought generally results in reduced total nutrient uptake and frequently causes reduced concentrations of mineral nutrients in crop plants (Gunes et al., 2006). Water deficit had important effect on the nutrient transport. The uptakes of N, P, K and Ca were much lower than under well-watered conditions.

The low uptake of calcium under stressed conditions noted in our studies and those of others, contributed to a severe yield reduction as calcium is an important element for pod growth and development, yield and percent sound mature seeds (Walker and Csinos, 1980; Hallock and Garren, 1968). Drought conditions have also been documented to decrease Ca uptake in chickpea (Gunes et al., 2006) and pearl millet (Ghanbari et al., 2011). Our results indicated that drought stress reduced pod yield of peanut and caused high pod rot and pod breakage. Moreover, positive and significant relationships between Ca and biomass, PDW and HI indicated that Ca was important for peanut production.

Conclusions

Drought reduced the uptakes of N, P, K and Ca in peanut. High nutrient uptakes across water regimes were observed in Tifton 8 and KK 60-3. Peanut genotypes performed consistently across water regimes for these traits and would be the immense useful peanut lines for further crossing programs. Peanut genotype that showed the high uptake of one nutrient seemed to be high in the uptake of other nutrients. This information also provides insight into how nutrient uptake is partitioned in peanut plants across water regimes. Further studies are required to investigate the responses of peanut plants to the drought for nutrient uptakes at different growth stages and their contribution to peanut yield.

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References

- Alam, S.M., 1999. Nutrient uptake by plants under stress conditions. In: Pessaraki, M. (Ed.), Handbook of plant and crop stress. Marcel Dekker, New York, pp. 285-314.
- Al-Karaki, G.N., Al-Raddad, A., 1997. Effects of arbuscularmycorrhizal fungi and drought stress on growth and nutrient uptake of two wheat genotypes differing in drought resistance. *Mycorrhiza*, 7, 83-88.
- Ashraf, M., Athar, H.R., Harris, P.J.C., Kwon, T.R., 2008. Some prospective strategies for improving crop salt tolerance. *Adv. Agron.* 97, 45-110.
- Bassirirad, H., Caldwell, M.M., 1992. Root growth, osmotic adjustment and NO₃ uptake during and after a period of drought in *Artemisia tridentata*. *Aust. J. Plant Physiol.* 19, 493-500.
- Bricker, A.A., 1989. MSTAT-C user's guide Michigan State University, MSTAT/Crop and Soil Sciences, A87 Plant and Soil Sciences. East Lansing, Michigan.
- Doorenbos, J., Pruitt, W.O., 1992. Calculation of crop water requirements. In: Doorenbos, J., Pruitt, W.O. (Eds.), *Guideline for Predicting Crop Water Requirements: FAO Irrigation and Drainage Paper No. 24*. FAO, Rome, pp. 1-65.
- Evans, L.T., 1993. *Crop Evolution, Adaptation and Yield*. New York, Cambridge.
- Fageria, N.K., Baligar, V.C., Jones, C.A., 1991. Factors Affecting Production of Field Crops. In: Fageria, N.K., Baligar, V.C., Jones, C.A. (Eds.), *Growth and Mineral Nutrition of Field Crops*. Marcel Dekker, Inc., New York, USA, pp. 13-45.
- Fageria, N.K., Baligar, V.C., Clark, R.B., 2002. Micronutrient in crop production. *Adv. Agron.* 77, 185-268.
- Garg, B.K., 2003. Nutrient uptake and management under drought: nutrient-moisture interaction. *Curr. Agric.* 27, 1-8.
- Gascho, G.J., Changzhi, L., Schilling, R., 1992. Groundnut [Peanut] (*Arachishypogaea* L.). In: Wichmann, W. (Ed.), *IFA world fertilizer use manual*. IFA, Paris, France, pp. 201-210.
- Ghanbari, A., Siaharsar, B., Tovassoli, A., Esmaeilian, Y., Babaeian, M., 2011. Effect of uniconazole and cycocel on growth, yield and nutrient uptake of pearl millet under drought stress condition. *Am-Euras J. Agric. Environ. Sci.* 10, 857-862.
- Girdthai, T., Jogloy, S., Vorasoot, N., Akkasaeng, C., Wongkaew, S., Holbrook, C.C., Patanothai, A., 2010. Heritability of and genotypic correlations between, aflatoxin traits and physiological traits for drought tolerance under end of season drought in peanut (*Arachishypogaea* L.). *Field Crops Res.* 118, 169-176.
- Gunes, A., Cicek, N., Inal, A., Alpaslan, M., Eraslan, F., Guneri, E., Guzelordu, T., 2006. Genotypic response of chickpea (*Ciceranrietinum* L.) cultivars to drought stress implemented at pre and post anthesis stage and its relations with nutrient uptake and efficiency. *Plant Soil Environ.* 52, 368-376.
- Gomez, K.A., Gomez, A.A., 1984. *Statistical Procedure for Agricultural Research*, (2nd). John Wiley and Sons Inc., Singapore.
- Hallock, D.L., Garren, K.H., 1968. Pod breakdown, yield, and grade of Virginia type peanuts as affected by Ca, Mg and K sulfates. *Agron. J.* 60 (3), 253-257.
- Jupp, A.P., Newman, E.L., 1987. Phosphorus uptake from soil by *Loliumperenned* during and after severe drought. *J Appl. Ecol.* 24, 979-990.

- Kaewpradit, W., Toomsan, B., Cadisch, G., Vityakorn, P., Limpinuntana, V., Saenjan, P., Jogloy, S., Patanothai, A., 2009. Mixing groundnut residues and rice straw to improve rice yield and N use efficiency. *Field Crops Res.* 110, 130-138.
- Kolay, A.K., 2008. Soil moisture stress and plant growth. In: *Water and crop growth*. Atlantic, Delhi, pp. 45-46.
- Kramer, P.J., 1980. Drought stress and origin of adaptation. In: Turner, N.C., Kramer, P.J. (Eds.), *Adaptation of plants to water and high temperature stress*. John Wiley and Sons, New York, pp. 6-20.
- Kulkarni, J.H., Ravindra, V., Sojitra, V.K., Bhatt, D.M., 1988. Growth, nodulation and N uptake of groundnut (*Arachis hypogaea* L.) as influenced by water deficit stress at different phenophase. *Oleagineus*. 43 (11), 415-419.
- Mc Donagh, J.F., Toomson, B., Limpinuntana, V., Giller, K.E., 1993. Estimates of the residual nitrogen benefit of groundnut to maize in Northeast Thailand. *Plant Soil*. 154, 267-277.
- Nahar, K., Gretzmacher, R., 2002. Effect of water stress on nutrient uptake, yield and quality of tomato (*Lycopersicon esculentum* Mill.) under subtropical conditions. *Die Bodenkultur*. 53 (1), 45-51.
- Nigam, S.N., Basu, M.S., Cruickshank, A.W., 2003. Hybridization and description of the trait-based and empirical selection programs. In: Cruickshank, A.W., Rachaputi, N.C., Wright, G.C., Nigam, S.N. (Eds.), *Report of a Workshop, Breeding for Drought Resistant Peanuts*. ICRISAT Centre Andhra Pradesh, India, ACIAR, Canberra, Australia, pp. 15-17.
- Nigam, S.N., Chandra, S., Rupa Sridevi, K., Manoha Bhukta, A., Reddy, G.S., Nageswara Rao, R.C., Wright, G.C., Reddy, P.V., Deshmukh, M.P., Mathur, R.K., Basu, M.S., Vasundhara, S., Vindhiya Varman, P., Nagda, A.K., 2005. Efficiency of physiological trait-based and empirical selection approaches for drought tolerance in groundnut. *Ann. App. Biol.* 146, 433-439.
- Pimratch, S., Jogloy, S., Vorasoot, N., Toomsan, B., Kesmala, T., Patanothai, A., Holbrook, C.C., 2008. Effect of drought stress on traits related to N₂ fixation in eleven peanut (*Arachis hypogaea* L.) genotypes differing in degrees of resistance to drought. *Asian J. Plant Sci.* 7 (4), 334-342.
- Pimratch, S., Vorasoot, N., Toomsan, B., Kesmala, T., Patanothai, A., Holbrook, C.C., 2013. Association of nitrogen fixation to water use efficiency and yield traits of peanut. *Int. J. Plant Prod.* 7 (2), 225-242.
- Puangbut, D., Jogloy, S., Vorasoot, N., Akkasaeng, C., Patanothai, A., 2011. Association of transpiration efficiency with N₂ fixation of peanut under early season drought. *Int. J. Plant Prod.* 5 (4), 381-394.
- Reddy, T.Y., Reddy, V.R., Anbumozhi, V., 2003. Physiological responses of groundnut (*Arachis hypogaea* L.) to drought stress and its amelioration: A critical review. *Plant Growth Regul.* 41, 75-88.
- Sankar, B., Jaleel, C.A., Manivannan, P., Kishorekumar, A., Somasundaram, R., Panneerselvam, R., 2008. Relative efficacy of water use in five varieties of *Abelmoschus esculentus* (L.) Moench. under water-limited conditions. *Colloids Surf. B: Biointerfaces*. 62, 125-129.

- Schuman, G.E., Stanley, M.A., Knudsen, D., 1973. Automated total nitrogen analysis of soil and plant samples. *Soil Sci. Soc. Am. Proc.* 37, 480-481.
- Singh, B., Singh, G., 2004. Influence of soil water regime on nutrient mobility and uptake by *Dalbergiasisoo* seedlings. *Trop. Ecol.* 45 (2), 337-340.
- Songsri, P., Jogloy, S., Kesmala, T., Vorasoot, N., Akkasaeng, C., Patanothai, A., Holbrook, C.C., 2008. Responses of reproductive characters of drought resistant peanut genotypes to drought. *Asian J. Plant Sci.* 7 (5), 427-439.
- Tanguilig, V.C., Yambao, E.B., O'Toole, J.C., De Datta, S.K., 1987. Water stress effect on leaf elongation, leaf water potential, transpiration and nutrient uptake of rice, maize and soybean. *Plant Soil.* 103, 155-168.
- Toomsan, B., Mc Donagh, J.F., Limpinuntana, V., Giller, K.E., 1995. Nitrogen fixation by groundnut and soyabean and residual nitrogen benefits to rice in farmers' fields in Northeast Thailand. *Plant Soil.* 175, 45-56.
- Vorasoot, N., Songsri, P., Akkasaeng, C., Jogloy, S., Patanothai, A., 2003. Effect of water stress on yield and agronomic characters of peanut (*Arachishypogaea* L.). *Songklanakarin J. Sci. Technol.* 25 (3), 283-288.
- Waliyar, F., Traore', A., Fatondji, D., Ntare, B.R., 2003. Effect of irrigation interval, planting date and cultivar on *Aspergillusflavus* and aflatoxin contamination of peanut in a sandy soil of Niger. *Peanut Sci.* 30, 79-84.
- Walker, M.E., Csinos, A.S., 1980. Effect of gypsum on yield, grade and incidence of pod rot in five peanut cultivars. *Peanut Sci.* 7 (2), 109-113.