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HOANG THAI DINH

WANWIPA KAEWPRADIT

SANUN JOGLOY

NIMITR VORASOOT

ARAN PATANOTHAI

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Nutrient uptake of peanut genotypes with different levels of drought tolerance under midseason drought

Hoang Thai DINH[1], Wanwipa KAEWPRADIT[1,*], Sanun JOGLOY[1,2], Nimitr VORASOOT[1], Aran PATANOTHAI[1]
[1]Department of Plant Science and Agricultural Resource, Faculty of Agriculture, Khon Kaen University, Khon Kaen, Thailand
[2]Peanut and Jerusalem Artichoke Improvement for Functional Food Research Group, Khon Kaen University, Khon Kaen, Thailand

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Abstract: The objective of this study was to investigate the responses of peanut genotypes to midseason drought, regarding in particular nutrient uptakes and their correlations with biomass production and pod yield. The experiment was conducted during the dry seasons of 2011/12 and 2012/13. Five peanut genotypes with different levels of drought tolerance and 2 water regimes (well-watered and midseason drought) were laid out in a split-plot design with 4 replications. Midseason drought was imitated by stopping irrigation at 30 days after planting (DAP) and then rewatering at 60 DAP. The data were recorded for contents of N, P, K, Ca, and Mg in plant tissues, biomass production, yield components, and pod yield at harvest. The results showed that midseason drought significantly reduced the uptake of all nutrient elements. Peanut genotypes with higher levels of drought tolerance took up more nutrients than those with lower levels. The uptake of all nutrient elements contributed to biomass production, pod yield, and the number of pods per plant. ICGV 98305 was the best genotype with the highest uptakes of all observed nutrient elements.

Key words: Biomass, correlation, nutrient, water regimes, pod yield

1. Introduction

Peanut (*Arachis hypogaea* L.) is one of the most important cash crops, as well as food crops and oilseed crops, in the world. However, most of the world's peanut production is grown mostly under rain-fed conditions, where unpredicted and insufficient rainfall or drought seriously affects peanut production (ICRISAT, 2011). Drought not only results in yield loss, but also is the main reason for reduction in nutritional quality of seed (Amir et al., 2005) and increases in aflatoxin contamination (Girdthai et al., 2010).

Like other agricultural crops, peanut requires essential nutrients during its life cycle. However, most nutrients are taken up into the plant in forms of soluble inorganic fertilizers by the root system; therefore, water stress reduces nutrient absorbability and nutrient uptake of the plant (Baligar et al., 2001; Fageria et al., 2002). The reductions in nutrient uptake caused by drought during the flowering (Kulkarni et al., 1988; Kolay, 2008), pegging, pod formation (Kolay, 2008), and pod-filling stages (Kulkarni et al., 1988) were also reported. However, the studies conducted so far have been limited to 1 or 2 peanut genotypes.

Reduction in nutrient uptake as caused by drought can severely reduce plant growth and yield. Nutrition balance is a key factor in diminishing environmental risks and promoting healthy plants with sustainable growth, yield, and quality (Magen, 2008). Improvement of nutrient uptake, therefore, is necessary to maintain acceptable growth and yield under drought. Enrichment of tissue with Ca in groundnut and cowpea (Chari et al., 1986) and with P in white clover (Singh and Sale, 2000) improved drought toleration ability. Similarly, K supplementation proved helpful in mitigating the adverse effects of water stress in peanut and sorghum (Umar, 2006). Accumulation of minerals under drought conditions might be an important trait of drought tolerance in tall fescue (Huang, 2001), soybean (Samarah et al., 2004), and chickpea (Gunes et al., 2006). However, differential responses among species and genotypes for nutrient uptake under drought stress were observed (Garg, 2003). It is still in doubt whether peanut genotypes with higher nutrient uptake under midseason drought conditions are more tolerant in terms of productivity.

The objective of this study was to investigate the nutrient uptake of peanut genotypes and the relationships between nutrient uptake and biomass production, yield components, and pod yield of peanut genotypes under midseason drought conditions. The results will provide a

* Correspondence: wanwka@gmail.com

better understanding of peanut response to drought and appropriate breeding strategies for drought resistance in peanuts.

2. Materials and methods

The experiment was conducted under field conditions during the dry seasons from November to March 2011/12 and 2012/13, at the Field Crop Research Station, Khon Kaen University, Khon Kaen, Thailand (16°28′N, 102°48′E, 200 m above mean sea level). The soil moisture contents of the sandy soil in each year (Table 1) were 10.94% and 10.31% at field capacity and 4.81% and 4.43% at permanent wilting points, respectively.

The meteorological data were recorded daily from sowing until harvest by a weather station located near the experimental field. Under growing seasons in 2011/12 and 2012/13, total rainfalls were approximately 41.8 and 20.8 mm, respectively, and rainfall did not interfere with the drought treatment. Compared to the first year, the relative humidity in the second year was higher from planting day to 50 days after planting (DAP), but it was lower in the later period. There was not much difference in daily average evaporation amount between the 2 years (Figures 1a and 1b). A lower daily average air temperature in the growing season in 2011/12 (from 17.5 to 30.5 °C) was observed in comparison with 2012/13 (from 19.0 to 33.0 °C). The average daily solar radiations were 20.1 and 15.6 MJ m^{-2}, respectively (Figures 1c and 1d).

2.1. Materials and experimental design

A split-plot in a randomized complete block design with 4 replications was used in the experiment. Main plots consisted of 2 water regimes, W1 (well watered at field capacity) and W2 (midseason drought by withholding water from 30 to 60 DAP). Subplots contained 5 peanut genotypes with different levels of drought tolerance. Tainan 9 is a widely planted cultivar in Thailand, but it has low dry matter production (Vorasoot et al., 2003) and is sensitive to drought (Jongrungklang et al., 2012). KS 2 is a released cultivar in Northeast Thailand, but it is also susceptible to drought. KKU 60, a large-seed cultivar, is a newly recommended cultivar and tolerates drought (Jongrungklang et al., 2012). ICGV 98305 is a drought-tolerant line from the International Crops Research Institute for the Semi-Arid Tropics, with high biomass production and pod yield under drought conditions (Nigam et al., 2005). Tifton 8 is a drought-tolerant germplasm with high pod yield that was provided by the United States Department of Agriculture (Coffelt et al., 1985).

2.2. Crop management

The experimental field was plowed 3 times, and then soil samples were taken to determine the soil properties at the last plowing time. The basal dressing mixture of triple superphosphate and muriate of potash was added to each subplot at the rates of 24.7 kg P ha^{-1} and 31.1 kg K ha^{-1}, respectively. The amount of fertilizers was calculated by area of each subplot (5.0 × 5.5 m), spread thoroughly, and incorporated into the soil shortly prior to planting.

Before planting, the 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 to control *Aspergillus niger*. The seeds of Tifton 8 were treated

Table 1. Soil properties from the experimental site at different depths prior to planting.

Parameter	0–30 cm		30–60 cm	
	2011/12	2012/13	2011/12	2012/13
Physical properties				
Sand (%)	93.86	87.29	91.87	85.38
Silt (%)	4.66	9.29	4.02	9.91
Clay (%)	1.48	3.42	4.11	4.71
Chemical properties				
pH	6.49	6.92	6.60	6.42
EC (dS/m)	0.02	0.06	0.02	0.06
Organic matter (%)	0.52	0.55	0.45	0.46
Total N (%)	0.03	0.02	0.03	0.01
Available P (mg/kg)	58.54	34.78	35.99	29.02
Exchangeable K (mg/kg)	57.79	48.81	43.35	41.74
Exchangeable Ca (mg/kg)	340.00	493.33	395.00	465.00
CEC (cmol/kg)	4.19	4.75	4.46	5.99

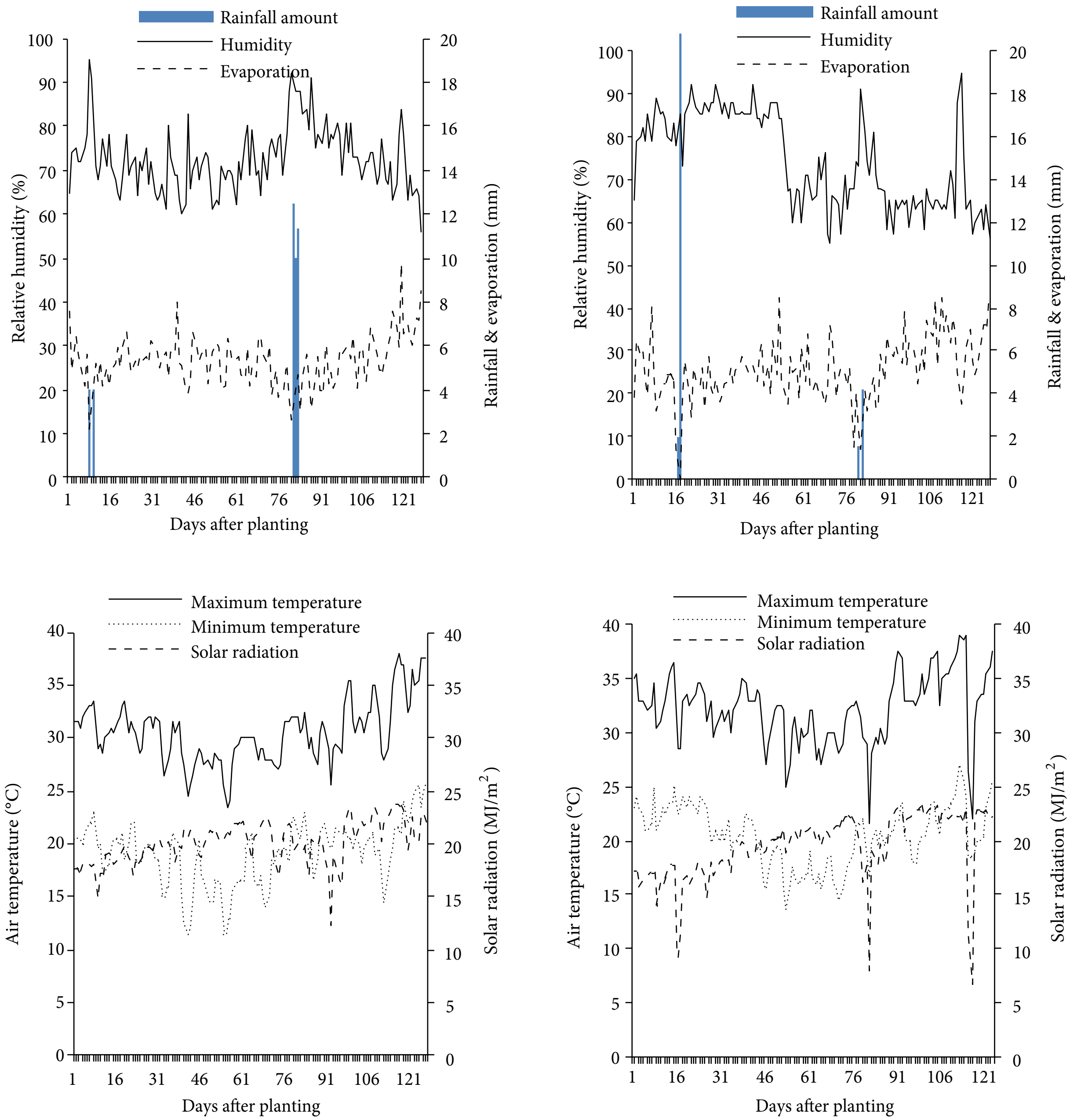

Figure 1. Relative humidity, rainfall and evaporation amount, air temperature, and solar radiation during growing seasons 2011/12 (a, c) and 2012/13 (b, d).

with 48% Ethrel (2-chloroethylphosphonic acid) at the rate of 2 mL L^{-1} to break seed dormancy.

At planting time, 3 or 4 seeds per hill were sown by hand with a spacing of 50 cm between rows and 20 cm between hills. *Rhizobium* inoculation was done by applying diluted water and commercial peat-based inocula of *Bradyrhizobium* (Ministry of Agriculture and Cooperatives, Thailand) at the rate of 13.0 g kg^{-1} seed on peanut rows soon after planting.

Alachlor (2-chloro-2',6'-diethyl-N-(methoxymethyl) acetanilide, 48%, w v^{-1}, emulsifiable concentrate) at the rate of 3 L ha^{-1} was sprayed as preemergent weed control 1 DAP. Hand weeding was practiced during the remainder of the season. Seedlings were thinned to 1 plant per hill at 14 DAP. Gypsum at the rate of 312.5 kg ha^{-1} was applied at 30 DAP to supply calcium for pod development. Pests and diseases were frequently looked for and were controlled when they occurred (Girdthai et al., 2012).

2.3. Irrigation

After sowing, water was supplied by a subsurface drip irrigation system (Super Typhoon; Netafim Irrigation Equipment and Drip Systems, Israel) with a distance of 20 cm between installed emitters and a spacing of 50 cm between drip lines at 10 cm below the soil surface midway between peanut rows. In well-watered plots, soil moisture content was maintained at field capacity for depths of 0–60 cm throughout the crop season. Meanwhile, in moisture stress plots, water was supplied intermittently by stopping supplementation during the period from 30 to 60 DAP. The total amount of irrigation water applied for each plot was calculated as the sum of crop water requirements and soil surface evaporation, which was calculated following the methods described by Doorenbos and Pruitt (1992) and Singh and Russell (1981), respectively.

2.4. Soil moisture

The fluctuations in moisture content levels were monitored by using a neutron soil moisture meter (Type I.H. II SER, No. N0152, Ambe Diccot Instruments Co. Ltd., UK), which can measure soil moisture volume fraction from aluminum access tubes. This was done weekly from planting date to harvest at depths of 30, 60, and 90 cm in each subplot.

2.5. Plant water status

Leaf relative water content (RWC) was used to determined plant water status at 30, 45, 60, 75, and 90 DAP. From the second fully expanded leaf from the top of the main stem, 5 leaflets from 5 sample plants from each subplot were measured between 1000 and 1200 hours on a clear and sunny day (Kramer, 1980). Leaflets from each subplot were put into individual vials with a rubber stopper and placed immediately in a picnic cooler to prevent moisture loss. Leaf fresh weight (FW) was determined as soon as possible in the laboratory, and saturated leaf weight (SW) was determined after leaf ambition in distilled water for 8 h under dim light and a controlled temperature at 24–26 °C. The samples were then oven-dried at 80 °C for 48 h or until constant weight to determine dry weight (DW). RWC was calculated as follows: RWC (%) = (FW – DW) / (SW – DW) × 100.

2.6. Biomass production, pod yield, and yield components

At harvest, 10 plants without roots (shoots and pods) were randomly selected to determine biomass production and pod yield. Shoot samples were oven-dried at 80 °C for 48 h or until a constant weight was achieved, and shoot dry weight was recorded. Pods were removed and counted to determine the number of pods per plant, and were then air-dried to approximately 8% moisture content to determine pod dry weight, the number of seeds per pod, and 100-seed weight. Biomass production was calculated as the sum of the dry weights of shoots and pods.

2.7. Nutrient uptake

The dried shoot and pod samples were ground, and small portions of the samples were then taken randomly to determine mineral nutrient content by appropriate methods for each nutrient element: Kjeldahl digestion method using flow injection analysis for N determination and wet oxidation method using spectrophotometer and flame photometer for P and K determination, respectively (Kaewpradit et al., 2009). The atomic absorption spectrometry method using a spectrophotometer was used to determine Ca and Mg content (Broekaert, 2002). Total nutrient content for each element (g plant^{-1}) was calculated individually by multiplying dry weight and nutrient concentration.

2.8. Data analysis

Analysis of variance was performed according to a split-plot design for each character in each year. The combined analysis of variance was done to test homogeneity of variance for 2 years. The least significant difference (LSD) was used to compare the means of genotypes across water regimes (Gomez and Gomez, 1984). Analysis of variance was computed using the MSTAT-C package (Bricker, 1989). Correlation coefficients between the nutrient uptake of each element and biomass production, pod yield, the number of pods per plant, the number of seeds per pod, and 100-seed weight were calculated across water regimes in each year based on n = 40 (2 water regimes × 5 genotypes × 4 replications) to assess the relationships.

3. Results

3.1. Soil moisture content and plant water status

There were large differences in soil moisture content at 30 cm in depth between the 2 water regimes during the drought period in both years, especially before rewatering at 60 DAP. After withholding water, the soil moisture content in 2012/13 declined faster than that in 2011/12 (Figures 2a and 2b). The differences had downward trends at deeper levels and became similar at a depth of 90 cm (Figures 2c–2f).

Significant variation in RWC between water regimes only occurred at 60 DAP in 2011/12, but it was earlier at 45 DAP in 2012/13 (Figure 3). RWC values were the same at 30 DAP. After that, RWC in the well-watered treatment were stable until 90 DAP, whereas RWC in the drought treatment decreased to the lowest at the last day of drought period (60 DAP) and then recovered after rewatering.

3.2. Effect of midseason drought on nutrient uptakes of peanut genotypes

Differences between years, between water regimes, and among peanut genotypes were significant for nutrient uptakes (Table 2). For all traits, the interactions between year and genotype were significant, but not for water regime

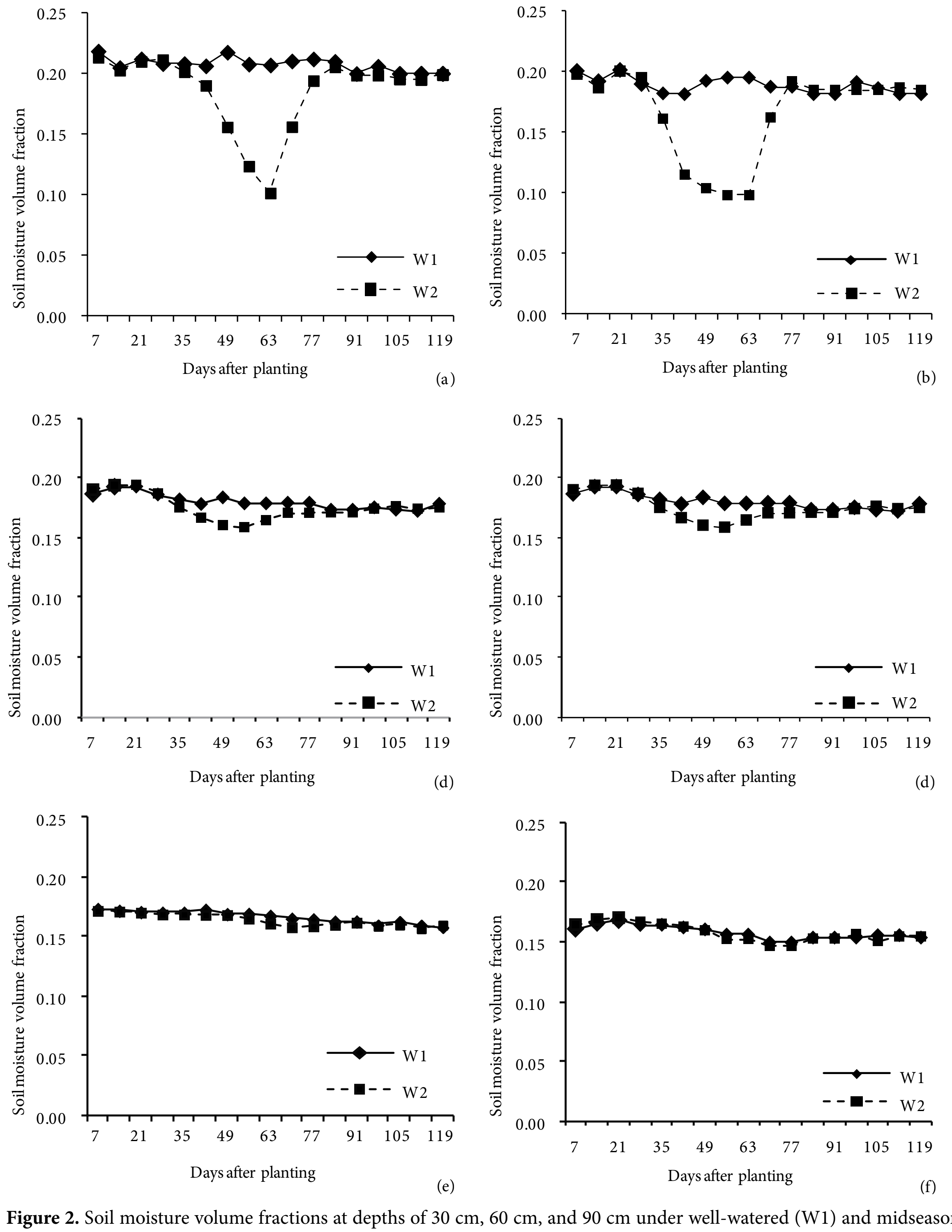

Figure 2. Soil moisture volume fractions at depths of 30 cm, 60 cm, and 90 cm under well-watered (W1) and midseason drought (W2) conditions during growing seasons 2011/12 (a, c, e) and 2012/13 (b, d, f).

and year or genotype. The results indicated that various genotypes were the main source of variations in the uptake of nutrient elements. Genotypes with a high potential for nutrient uptake under well-watered conditions performed well under midseason drought conditions.

Midseason drought significantly reduced the uptakes of N, P, and K ($P < 0.01$) and Ca and Mg ($P < 0.05$) (Table 3). The differences in nutrient uptake among peanut genotypes were also considerable for all observed elements. In general, drought-tolerant genotypes (DTGs) (ICGV

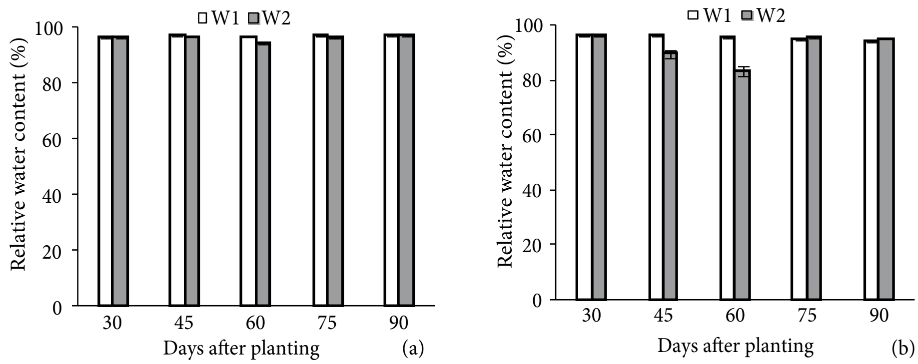

Figure 3. Leaf relative water content under well-watered (W1) and midseason drought (W2) conditions during growing seasons 2011/12 (a) and 2012/13 (b).

98305, Tifton 8, and KKU 60) took up higher amounts of nutrients than did drought sensitive genotypes (DSGs) (KS 2 and Tainan 9), and the differences in N uptakes were much clearer in both years. ICGV 98305 had the highest uptakes, while Tainan 9 had the lowest.

In particular, ICGV 98305, Tifton 8, and KKU 60 took up higher amounts of N than did KS 2 and Tainan 9 in both years. Similarly, DTGs took up P at a higher rate than DSGs in 2011/12. In 2012/13, ICGV 98305 and KKU 60 had higher P uptakes than did both DSGs, whereas Tifton 8 had uptake only higher than Tainan 9. All DTGs took up higher amounts of K than Tainan 9 in both years, but only ICGV 98305 took up higher amounts of K than KS 2 in 2011/12.

ICGV 98305 was the genotype with the highest Ca uptake, while other genotypes were rather similar. DTGs had higher Mg uptake than DSGs in 2011/12. However, in 2012/13, the Mg uptake of KKU 60 was not significantly different from that of KS 2 and Tainan 9.

3.3. Effect of midseason drought on biomass production, pod yield, and yield components of peanut genotypes

Combined analysis showed significant differences between water regimes and among peanut genotypes for biomass production, pod yield, number of pods per plant, and 100-seed weight (Table 4). Differences between the 2 years were significant for almost every trait except for the number of seeds per pod. The interactions were significant between year and genotype, but not significant between water regime and year or genotype for biomass production and pod yield. The interactions were also significant among year, water regime, and genotype for the number of seeds per pod and 100-seed weight; for the number of pods per

Table 2. Combined analysis of variance for nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) uptake of peanut genotypes under well-watered and midseason drought conditions during growing seasons in 2011/12 and 2012/13.

Source of variation	N	P	K	Ca	Mg
Year (Y)	18.69**	0.0270**	7.27**	11.30**	0.1125**
Reps. within year	0.02	0.0009	0.06	0.02	0.0005
Water regimes (W)	1.40**	0.0143**	1.08**	0.12*	0.0267*
Y × W	0.04	0.0002	0.01	0.06	0.0001
Error Y × R × W	0.07	0.0010	0.06	0.01	0.0020
Genotypes (G)	1.86**	0.0154**	0.97**	0.20**	0.0295**
Y × G	0.49**	0.0046**	0.52**	0.17**	0.0089*
W × G	0.02	0.0011	0.11	0.02	0.0032
Y × W × G	0.01	0.0001	0.05	0.02	0.0013
Error Y × R × W × G	0.10	0.0008	0.05	0.02	0.0015
CV(Y × R × W)%	12.6	16.1	18.5	18.7	15.6
CV(Y × R × W × G)%	15.8	14.4	17.0	23.2	13.3

* and ** = significant at the 5% and 1% level, respectively.

Table 3. Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) uptake of peanut genotypes across water regimes during growing seasons 2011/12 and 2012/13 (g $plant^{-1}$).

Source	N	P	K	Ca	Mg
Water regimes					
Well-watered	2.18 a	0.21 a	1.41 a	0.81 a	0.31 a
Midseason drought	1.91 b	0.18 b	1.18 b	0.66 b	0.27 b
Genotypes	Year 2011/12				
ICGV 98305	3.04 a	0.27 a	2.30 a	1.27 a	0.43 a
Tifton 8	2.96 a	0.24 a	1.52 b	0.99 b	0.34 b
KKU 60	2.62 a	0.24 a	1.57 b	0.77 b	0.33 b
KS 2	2.08 b	0.17 b	1.39 bc	0.77 b	0.25 c
Tainan 9	1.92 b	0.16 b	1.20 c	0.85 b	0.28 c
Genotypes	Year 2012/13				
ICGV 98305	1.63 a	0.19 a	1.07 a	0.58 a	0.28 a
Tifton 8	1.71 a	0.18 ab	1.05 a	0.59 a	0.27 a
KKU 60	1.74 a	0.19 a	1.04 a	0.48 b	0.26 ab
KS 2	1.29 b	0.17 bc	0.97 ab	0.50 ab	0.23 b
Tainan 9	1.29 b	0.16 c	0.84 b	0.55 ab	0.23 b

Means followed by the same lowercase letter in a column are not significantly different at the 5% level by LSD.

Table 4. Combined analysis of variance for biomass production, pod yield, number of pods per plant, number of seeds per pod, and 100-seed weight of peanut genotypes under well-watered and midseason drought conditions during growing seasons of 2011/12 and 2012/13.

Source of variation	Biomass	Pod yield	No. pods/plant	No. seeds/pod	100-seed weight
Year (Y)	13,815.4*	678.0*	414.5*	0.098	3423.0**
Reps. within year	162.4	12.2	7.0	0.004	10.6
Water regimes (W)	1915.9**	585.9**	183.9**	0.041**	850.9**
Y × W	8.1	0.3	57.0*	0.025**	235.0**
Error Y × R × W	94.9	7.3	8.1	0.001	7.0
Genotypes (G)	15.4**	694.0**	770.0**	3.734**	2101.2**
Y × G	5.1**	114.4**	28.4	0.076**	386.5**
W × G	1.1	18.9	7.9	0.022*	81.2*
Y × W × G	0.3	7.0	10.4	0.004	115.3
Error Y × R × W × G	145.5	26.5	12.5	0.006	22.5
CV(Y × R × W)%	11.5	9.2	12.0	1.4	4.9
CV(Y × R × W × G)%	14.2	17.5	14.8	3.8	8.9

* and ** = significant at the 5% and 1% level, respectively.

plant, the interactions were only significant between year and water regimes (Table 4).

Drought caused significant decreases in biomass production, pod yield, the number of pods per plant, the number of seeds per pod, and 100-seed weight (Table 5). The differences in biomass production, pod yield, and yield components among peanut genotypes were also significant. In fact, DTGs (ICGV 98305, Tifton 8, and KKU 60) had a

Table 5. Biomass production (BM), pod yield, number of pods per plant, number of seeds per pod, and 100-seed weight of peanut genotypes across water regimes in dry seasons of 2011/12 and 2012/13.

Source	BM (g plant^{-1})	Pod yield (g plant^{-1})	Pods plant^{-1}	Seeds pod^{-1}	100-seed weight (g)
Water regimes					
Well-watered	89.9 a	32.1 a	25.3 a	2.1 a	58.8 a
Midseason drought	80.1 b	26.6 b	22.3 b	2.0 b	52.3 b
Genotypes	Dry season 2011/12				
ICGV 98305	124.7 a	33.4 b	38.5 a	1.8 c	47.5 c
Tifton 8	103.6 b	38.1 ab	26.5 b	1.8 c	51.9 b
KKU 60	100.3 b	43.5 a	27.3 b	1.9 bc	68.4 a
KS 2	82.4 c	21.9 c	16.1 d	2.8 a	42.8 d
Tainan 9	79.5 c	24.5 c	22.0 c	2.0 b	44.4 cd
Genotypes	Dry season 2012/13				
ICGV 98305	76.4 a	28.8 a	30.1 a	1.8 c	54.8 bc
Tifton 8	75.6 a	29.3 a	21.0 bc	1.9 bc	74.1 a
KKU 60	76.0 a	30.0 a	22.9 b	1.9 bc	68.8 a
KS 2	69.1 ab	24.3 b	14.8 d	3.1 a	53.4 bc
Tainan 9	62.0 b	19.8 c	18.9 c	2.0 b	49.3 c

Means followed by the same lowercase letter in a column are not significantly different at the 5% level by LSD.

higher pod yield than did DSGs (KS 2 and Tainan 9) in both years. DTGs also exhibited higher biomass production than DSGs in 2011/12, but in 2012/13 all genotypes were rather similar. DTGs also produced a higher number of pods per plant than both DSGs in the first year, but higher only than KS 2 in the second year. In both years, the 100-seed weights of Tifton 8 and KKU 60 (DTGs) were higher, whereas ICGV 98305 (DTGs) was rather similar in comparison with KS 2 and Tainan 9 (DSGs).

3.4. Relationships of nutrient uptakes with biomass production, yield components, and pod yield

There were positive and significant correlations of all nutrient uptakes with biomass production and the number of pods per plant in both years (Table 6). These correlations in 2011/12 were stronger than those in 2012/13. Moreover, the correlation coefficients among nutrient uptakes with biomass production were higher than those with the number of pods per plant.

Pod yield had significant correlations with the uptake of most nutrient elements, except for Ca in 2011/12 (r = 0.25). The correlations between nutrient uptake with pod yield were weaker in the first year, but somewhat stronger in the later year, compared to correlations between nutrient uptakes and biomass production.

In general, 100-seed weight had positive correlations with uptakes of nutrient elements, while the correlations of the number of seeds per pod with nutrient uptakes were negative. However, the correlation coefficients were significant only between the number of seeds and N, P, Mg, and Ca uptake in 2011/12 or N uptake in 2012/13; 100-seed weight and P uptake in 2011/12; and 100-seed weight and N, K, and Ca uptake in 2012/13.

4. Discussion

In this investigation, the questions underlying the research project were how midseason drought affects nutrient uptakes in peanut, whether peanut genotypes are different in responses to midseason drought, and whether nutrient uptakes are related to pod yield under midseason drought conditions.

The results indicated that midseason drought reduced the uptake of all observed nutrient elements. In previous findings, water deficit during pod filling stages (Kulkarni et al., 1988) and a long-term drought period from 14 days after emergence until harvest (Arunyanark et al., 2012) reduced uptakes of N. Likewise, reductions of K, P, Ca, and Mg uptake as a result of drought at flowering (Kulkarni et al., 1988; Kolay, 2008), pegging, pod formation, and development stages (Kolay, 2008) were also observed. However, contrasting results were reported for increases in biomass and pod yield as affected by early season drought (Puangbut et al., 2009), and this implies that early season drought might increase nutrient uptake as nutrient uptakes were closely related to biomass and pod yield (Table 6).

Table 6. Correlation of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) uptake with biomass production, pod yield, number of seeds per pod, number of pods per plant, and 100-seed weight across water regimes during growing seasons of 2011/12 and 2012/13 (n = 40).

Source	Dry season 2011/12					Dry season 2012/13				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
Biomass production	0.82**	0.88**	0.86**	0.78**	0.83**	0.49**	0.38*	0.50**	0.43**	0.32*
Pod yield	0.69**	0.73**	0.38*	0.25	0.48**	0.53**	0.45**	0.50**	0.43**	0.37**
No. of pods/plant	0.69**	0.77**	0.73**	0.63**	0.77**	0.38*	0.37*	0.37*	0.50**	0.36*
No. of seeds/pod	–0.44**	–0.48**	–0.26	–0.35*	–0.55**	–0.41**	–0.31	–0.10	–0.21	–0.28
100-seed weight	0.20	0.33*	–0.04	0.13	0.16	0.42**	0.28	0.44**	0.33*	0.19

* and ** = significant at the 5% and 1% level, respectively.

Drought can positively affect nutrient uptake if it occurs at vegetative growth stages, but droughts between reproductive stages and harvest negatively affect nutrient uptakes. Drought during vegetative growth may harden the plants, and the plants have more time to recover from drought. For drought in reproductive phases, in contrast, the plants have little chance to recover.

Drought stress due to a decrease in water availability strongly influences nutrient absorption and uptake by plants. Most nutrients are absorbed by plant roots as ions and water is the medium of transport. Under fully irrigated conditions, when soil water potential is high, the absorption and transport of water and nutrients are also high. During water stress, roots are unable to take up nutrients from the soil because of the lack of activity of fine roots, water movement, and ionic diffusion of nutrients (Prasad et al., 2008). Therefore, decreased water availability during a drought generally results in a reduction of total nutrient uptake in crop plants (Baligar et al., 2001; Gunes et al., 2006).

The present study found significant differences among peanut genotypes regarding the uptake of all nutrient elements, and DTGs took up more nutrients than DSGs. The differences between DTGs and DSGs in response to midseason drought for nutrient uptakes could be possibly due to root responses to drought. During midseason drought, the roots of DTGs were distributed in lower soil layers more so than the roots of susceptible genotypes (Jongrungklang et al., 2012). Roots play an important role in drought adaptation in deep soils, where a relation between root depth and pod yield has been established (Vadez et al., 2007). The deep rooting pattern of peanut also permitted the plant to have a chance to take up more Mg and other nutrients in deeper soil (Gascho and David, 1994). Likewise, Otani and Ae (1996) suggested that root length is used by peanuts as an additional mechanism to increase P uptake. Under drought conditions, an increased root depth would contribute to better drought tolerance (Kashiwagi et al., 2006) because the osmotic gradient is sufficient to allow water uptake when the roots contact wet soil (Vadez et al., 2007). Peanut genotypes that have a higher root length density in deeper soil layers have an enhanced drought tolerance (Songsri et al., 2008; Jongrungklang et al. 2012). Therefore, it could be that DTGs, with their deeper root distribution, take up more nutrients from lower soil layers to help the plant against the effects of drought. As variations in nutrient uptakes were present in peanut genotypes, nutrient uptakes may be useful traits when selecting peanut genotypes for resistance to drought. Peanut genotypes that take up high amounts of nutrients under drought conditions can increase drought tolerance ability.

The results of the present study showed positive correlations among the uptakes of N, P, K, Ca, and Mg and biomass production, pod yield, and the number of pods per plant. This indicated that higher peanut yield was attributable to enhanced N, P, K, Ca, and Mg uptakes. In previous investigations, Chang and Sung (2004) had a similar conclusion regarding the uptake of P, K, Ca, and Mg. Peanut pod yield and K uptake increased with increasing K application rate (Laxminarayana and Subbaiah, 1995; Khamparia, 1996). Likewise, P application significantly increased P and K uptake, pod yield (Khamparia, 1996), the number of pods per plant, and pod weight per plant, and it reduced the number of unfilled pods per plant (Singh et al., 1994).

In 2011/12, the correlation coefficients between nutrient uptake and biomass production were stronger than the correlation coefficients between nutrient uptake and the number of pods per plant and pod yield. However, in 2012/13, when soil moisture content reduced faster, the correlation coefficients between nutrient uptake and pod yield were somewhat higher than that with biomass production. The results might indicate that, under mild stress conditions, nutrient uptake was distributed to the whole plant in both vegetative and reproductive organs, but when stress became more severe, the uptake of nutrient elements was concentrated in the reproductive organs. This highlights the importance of nutrient uptake on pod yield of peanut under drought conditions.

The correlations between the uptake of each nutrient element and the number of pods per plant and 100-seed weight were positive, but they were negative with the number of seeds per pod. The results indicate that nutrient uptake under midseason drought contributed to pod yield through higher pod numbers and larger seeds, rather than number of seeds per pod.

In conclusion, midseason drought reduced nutrient uptake in all peanut genotypes. Peanut genotypes with high potential for nutrient uptake under normal conditions performed well under midseason drought conditions. Nutrient uptakes by peanut genotypes with higher levels of drought tolerance were higher than those with lower levels. Uptake of all nutrient elements contributed to biomass production, pod yield, and the number of pods per plant. ICGV 98305 was the best genotype with the highest uptake of all observed nutrient elements, whereas Tifton 8 and KKU 60 were good genotypes with high nutrient uptake across water regimes.

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