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Research Article

Assessment of Groundnut Elite Lines under Drought Conditions and Selection of Tolerance Associated Traits

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Investigation of groundnut genotypes response to drought stress could contribute to improving drought tolerance and productivity. The objective of this study was to investigate new improved groundnut varieties response to drought stress under controlled conditions to identify tolerant materials and drought tolerance related traits. Thus, three experiments were conducted during off-seasons: two experiments in lysimetric system in 2017 and 2018 and one experiment in pots in 2017, to assess twelve varieties in a randomized complete block design with 2 water regimes and 4 replications. The water regimes were a full irrigation (WW) and an intermittent drought imposed at flowering times (WS). The investigated morphophysiological traits like transpiration, specific leaf area, root dry matter, root length density, and yield components decreased under WS. Significant year effect and genotypic variation were observed on most of investigated traits. Genotypes ICGV 92206 and ICGV 06319 showed low transpiration and revealed high pod yielding and early maturing genotypes under both water regimes, while genotypes ICGV 92035, ICGV 92195, ICGV 02038, ICGV 07211, and ICGV 07210 were drought-sensitive for pods production but produced high haulm under both water regimes. ICGV 92206, ICGV 02005, ICGV 02125, and ICGV 06319 showed higher yielding than 55-437 and Fleur 11. In this study, low total transpiration to control water loss, chlorophyll content, and root length density revealed drought tolerance associated traits for pod production, while TTW, TE, RDW, and RV revealed drought tolerance associated traits for fodder production.

1. Introduction

Drought is widely known as the major factor limiting global agricultural production. In semiarid zones, especially in West Africa, drought can occur at any stage of crop cycle and often leads to devastating effects in plant growth, development, metabolism, pod yield, and grains quality. Yield reduction due to drought stress is highly variable depending on timing, intensity, and duration [1–3].

Recent studies have shown that physiological characteristics such as amount of transpired water, transpiration efficiency, specific leaf area, stomatal conductance, and osmotic adjustments are associated with drought tolerance [4, 5]. For instance, reduction of transpiration under water stress led to dehydration avoidance due to lower stomatal conductance in order to conserve water, while increased transpiration led to high stomatal conductance associated with intensive roots elongation to deeper part of the soil profile [5–7]. Transpiration efficiency (TE) as a component of water use efficiency (WUE) was correlated with pod yield, haulm yield, and specific leaf area under drought condition and was suggested as a selection criterion for yield improvement [4, 5, 8]. Many studies reported that root traits are also important for identifying drought-resistant mechanisms of plants [9–11]. Root characteristics such as root dry weight (RDW), deep rooting, root length density (RLD), and root distribution have been identified as drought-adaptive traits that can be used as selection criteria for drought resistance [4, 12].

Groundnut (*Arachis hypogaea* L.) is a very common legume widely cultivated in West Africa where it represents the main source of agricultural income for farmers and contributes largely to food and feed [5, 13]. In this area, it is usually grown under rainfed conditions. Most of the Sahelian countries were known to be particularly vulnerable to climate change and climate projections show closer frequencies of extreme weather events, higher temperatures, and increasingly scarce water resources [14]. Intermittent drought in Sahelian zones decreased yield of groundnut up to 52% [3]. To sustainably alleviate the water deficit effects and improve groundnut production in drought-prone environments, it is imperative to develop and release drought-tolerant varieties [10, 15]. Groundnut breeding efforts at ICRISAT have recently selected new varieties improved for high yield and resistance to diseases (leaf spots). The release and adoption of these new varieties in Sahelian countries where drought is occurring almost each year requires assessment under water deficit conditions. Therefore, the objectives of this work were to (i) investigate the groundnut elite lines response to drought stress under controlled conditions and select tolerant varieties and (ii) identify relevant drought tolerance related traits for groundnut improvement programs in Sahelian environment.

2. Material and Methods

2.1. Materials. Twelve groundnut genotypes were assessed in pot and lysimetric system conditions. Ten genotypes (ICGV 02005, ICGV 02038, ICGV 02125, ICGV 06319, ICGV 07210, ICGV 07211, ICGV 92035, ICGV 92195, ICGV 92196, and ICGV 92206) were new improved varieties never tested for drought tolerance, while two cultivars (55-437 and Fleur 11), largely cultivated in Sahelian area, were selected as checks for drought tolerance and sensitivity, respectively.

2.2. Methods

2.2.1. Experimental Conditions. Three experiments (two in lysimetric system and one in pots) were conducted at the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), Sahelian Centre (ISC) in Sadoré (45 km south of Niamey, Niger, 13°N, 2°E) during off-season. The first lysimeter experiment and the pot experiment were conducted from March to June in 2017 (year 1), while the second lysimeter experiment was conducted from March to June in 2018 (year 2). The temperature and relative air humidity were collected using a temperature and relative humidity recorder (Gemini Tinytag Ultra 2 TGU-4500 Data logger Ltd., Chichester, UK) located in the crops canopy. During the experiments, the mean temperature (minimum and maximum) varied between 27.2 and 41.8°C in 2017 and between 25.9 and 43.9°C in 2017, while the mean relative humidity varied between 27% and 66.7% in 2017 and between 14.4% and 45.9% in 2018.

2.2.2. Lysimeter Experiments. The lysimetric system was well described in previous works [16–18]. The lysimeter tubes were PVC cylinders with diameter 25 cm and height 130 cm. Each tube was equipped by metallic collars and chains for lifting and weighing. To perform the weighing, a pulley was hooked to a tripod (which can move on the trench) and connected to a crane balance (S-type load cell with a 200 Kg load capacity; Mettler-Toledo, Geneva, Switzerland). The balance displayed the weight of lifting tube. The soil used to fill the tubes was collected from a farm in Sadoré station and had the following characteristics: 5.8 pH H_2O (1:2.5), 3.6 mg Bray-P kg^{-1}, 0.1% organic matter (C), and 81 mg total N kg^{-1}. The upper 10 cm of the tubes was left empty to allow the application of a layer of antievaporation beads and for watering. Three seeds treated with captan were sown by hand and 15 days after sowing (DAS) seedlings were thinned to two plants per tube. After thinning, two grams of Diammonium Phosphate (DAP) were applied. The experimental design was a randomized complete block design with 2 water regimes, 12 varieties, and 4 replications. The water regimes were well water (WW) until harvest and water stress (WS) imposed at flowering time when 50% plants (at least 2 among 4 plants) of each variety reached flowering. The WS was an intermittent drought consisting of cycles of drying (irrigation interruption) and rewatering (1000mL per tube) when the majority of WS plants showed clear wilting symptoms [2]. Prior to imposing WS, one of two plants of each tube was sampled; the tubes were water-saturated and drained during 2 days to reach field capacity. The soil surface of each tube was covered with a 2 cm thick layer of polyethylene beads to minimize soil evaporation [19].

2.2.3. Pots Experiments. Pots with diameter 25 cm and height 20 cm were used to conduct the experiment. The experimental conditions and design were as described in above lysimeter experiment except of one plant was left by pot after thinning at 15 DAS. The main objective of pots experiment was to investigate root traits.

2.2.4. Measurements. Measurements were conducted on both WW and WS plants during lysimeter and pots experiments. Phenology and root characteristics were measured in both pots and lysimeter trials during year 1. The SPAD Chlorophyll Meter Reading (SCMR), leaf area (LA), specific leaf area (SLA), total transpired water (TTW), transpiration efficiency (TE), and pods and haulm weight were measured during year 1 and year 2 in lysimeter experiments.

(a) Plant Phenology and Harvest. Flowering and maturity dates of each variety were recorded when 50% plants reached flowering and maturity times. After maturity, plants were harvested and pods were separated from each plant. Haulm was partitioned into leaves, stems, and roots. Leaves were scanned to measure the LA and dried during 48 h at 70°C to determine the SLA. Root traits were measured using a scanner and WinRHIZO software (Regent Instruments Canada Inc., Quebec, Canada). Pods, haulm (stems and leaves), and roots were dried to determine dry weights.

(b) SPAD Chlorophyll Meter Reading (SCMR). The SCMR was measured at flowering time, 60 (DAS), and maturity time on the third leaf counting from the top. The SPAD chlorophyll meter (Minolta SPAD-502 meter, Tokyo, Japan) was used to record on each leaflet of the tetra foliate leaf beside the midrib the SCMR and care was taken to ensure that the SPAD meter

sensor fully covered the leaf lamina and that interference from veins and midribs was avoided.

(c) Total Transpired Water (TTW) and Transpiration Efficiency (TE). The day before water stress imposition, one of the 2 plants per tube was harvested, dried at 70°C for 2 days and the initial biomass (IDM) was determined. During water stress period, transpiration was measured via a gravimetric procedure. Thus, lysimeter tubes were weighed regularly (twice per week). As there was no evaporation or draining, the difference of consecutive lysimeter tubes weights, plus water added after the previous weighting, was equivalent to the transpiration [20]. The total transpired water (TTW) of WW and WS plants was determined for each individual plant as the sum of the transpirations measured after each weighing process. At maturity, plant of each cylinder was harvested, pods were separated, and haulm was dried at 70°C for 2 days for determining the final dry matter (FDM). The transpiration efficiency (TE) was calculated as

$$TE = \frac{(FDM - \text{mean IDM})}{TTW}. \tag{1}$$

(d) Leaf Area (LA) and Specific Leaf Area (SLA). LA was recorded using the leaf area meter (Leaf Area Meter LI-3100, LI-COR Inc., Lincoln, Nebraska 68504-0425, USA). Thus, plant of each tube was harvested and leaflets were removed before scanning in the leaf area meter which displayed the total leaf area (cm^2). Leaves were oven-dried at 70°C for 48 h and weighed to determine the leaf dry weight (LDW) and the specific leaf area (SLA) was calculated as

$$SLA\left(cm^2g^{-1}\right) = \frac{\text{leaf area}}{\text{leaf dry weight}} \tag{2}$$

(e) Root Dry Weight (RDW), Root Length (RL), Root Length Density (RLD), Root Volume (RV), and Root Diameter (RD). Roots traits were investigated in pot and lysimeter experiments in year 1. After harvest, plants roots were carefully extracted and cleaned out in pots and tubes by using a low water shoot. Wire mesh sieve (2 mm) was installed during cleaning out to minimize the loss of roots. Each plant root was then separated from the organic debris and weed roots manually by floating the sample material on water in trays. The length of total root was measured (RL) and then each root extracted was suspended in a transparent tray with 2-3mm film of water for easy dispersion of roots and scanned using a scanner. The total root length (RL), root volume (RV), and root diameter (RD) of each sample were measured after scanning and by using the image analysis system (WinRHIZO, Regent Instruments Inc.); the root length density (RDL) was calculated as RDL (cm/cm^3) = total root length/root volume.

The root dry weight (RDW) was determined after oven drying at 70°C for 72 h and weighing.

2.3. Statistical Analysis. GENSTAT 14th edition (VSN International Ltd., Hemel Hempstead, UK) was used to perform statistical analyses. Analysis of variance (ANOVA) was performed to assess the effects of genotype (G), water regime (W), year (Y) and their interactions for the different traits measured. Microsoft Office Excel 2013 Software (Microsoft Corp., Redmond, WA, USA) was used for linear regression by plotting different traits to determine the R^2 and regression equation.

3. Results

3.1. Phenology. Date of flowering and maturity recorded showed significant genotypic variation in pot (P<0.02) and lysimeter (P<0.001). The flowering date ranged from 23 to 28 DAS in pot. The genotypic variation observed on maturity date in pots experiment showed that ICGV 02125 and ICGV 06319 were the earliest maturing genotypes (87 and 89 DAS, respectively), while ICGV 02038, ICGV 92195, ICGV 92196, and Fleur 11 were the latest maturing genotypes (94, 95, 95, and 96 DAS, respectively).

In lysimeter experiments, the flowering date ranged from 20 to 22 DAS in year 1 and from 26 to 30 DAS in year 2. It was also observed that ICGV 92206, 55-437, and ICGV 02038 (89 DAS) were the earliest maturing genotypes in both years, while the latest maturing genotypes were ICGV 02125 (114 DAS), ICGV 92195 (111 DAS), ICGV 92035 (111 DAS), and ICGV 92196 (111 DAS) in year 1 and ICGV 92035 (92 DAS), ICGV 02005 (92 DAS), and ICGV 92195 (100 DAS) in year 2.

3.2. Intermittent Drought (WS) and Agronomic Parameters. Significant difference (P<0.01) was observed across years for pod and haulm weight in lysimeter experiments (Table 1). WS reduced significantly (P<0.001) the pod weight up to 74 and 75% in year 1 and year 2, respectively. Significant (P<0.001) genotypic variation was also observed on pods weight under both WW and WS treatments (Table 1). Genotype ICGV 92206 showed the highest pod weight under both water regimes and across years, while genotypes ICGV 02038, ICGV 07210, and ICGV 07211 showed the lowest pod weight under both water treatments and years. Haulm weight was also significantly reduced (P<0.001) under intermittent water stress up to 62 and 44%, respectively, in year 1 and year 2. The highest haulm weight was obtained under WW conditions. Significant difference (P<0.001) was observed among genotypes under both WW and WS treatments during year 1 and year 2 (Table 1). Genotypes ICGV 07210, ICGV 92035, 55-437, and ICGV 02125 showed the highest haulm weight under WW in year 1 and year 2, while under WS, ICGV 06319 and ICGV 92206 were the lowest haulm yielding across years (Table 1). A significant genotype by year interaction was also observed for both pod and haulm weight (Table 1).

3.3. Morphophysiological Traits under Intermittent Drought

(a) SPAD Chlorophyll Meter Reading (SCMR). The SCMR measured at flowering time, 60 DAS, and maturity time showed significant difference only at 60 DAS. It showed significant genotype by year interaction (GxY), water regimes

Table 1: Pod and haulm weight of groundnut genotypes under well-watered (WW) and water-stressed (WS) treatments in 2017 (year 1) and 2018 (year 2). *G= genotypes, W = water regimes,* and *Y= year.* ∗ = significant at 5% level. ns = not significant at 5% level. Means with the same letter are not significantly different within the same treatment by Duncan's multiple range test.

Genotypes	Pod weight (g plant^{-1})				Haulm weight (g plant^{-1})			
	Year 1		Year 2		Year 1		Year 2	
	WW	WS	WW	WS	WW	WS	WW	WS
55-437	2.16a	0.62a	5.26abc	0.24a	77.13b	38.33bc	55.65d	27.76bcd
FLEUR11	0.64a	0.34a	5.51abc	0.67a	72.47b	29.40abc	34.12ab	26.96bcd
ICGV 02005	2.67ab	1.66ab	7.66cd	1.10ab	71.38b	39.80bc	55.41d	29.63d
ICGV 02038	2.02a	0.15a	4.77abc	-	88.35c	37.45bc	39.57abcd	24.54bc
ICGV 02125	4.60ab	0.44a	6.63bc	3.04c	77.31b	30.41abc	55.58d	24.01b
ICGV 06319	3.30ab	1.08ab	6.48bc	1.19ab	55.58a	25.97ab	43.98bcd	24.05b
ICGV 07210	2.82ab	0.27a	2.42ab	-	126.59f	38.98bc	49.01bcd	27.20bcd
ICGV 07211	1.73a	0.29a	3.85abc	-	90.50c	39.17bc	27.49a	24.65bc
ICGV 92035	0.77a	0.31a	7.34cd	0.91a	116.33e	42.75c	55.25d	27.49bcd
ICGV 92195	2.53ab	0.31a	1.35a	-	107.26d	38.61bc	52.68cd	28.53cd
ICGV 92196	4.21ab	0.49a	4.94abc	1.44ab	109.34d	41.54c	47.67bcd	26.11bcd
ICGV 92206	6.86b	2.29b	11.07d	2.61bc	74.70b	19.84a	37.38abc	19.29a
Means	2.86	0.69	5.61	1.4	88.91	35.19	46.15	25.85
G (F prob)	<.001∗ ∗ ∗				<.001∗ ∗ ∗			
W (F prob)	<.001∗ ∗ ∗				<.001∗ ∗ ∗			
Y (F prob)	<.001∗ ∗ ∗				<.001∗ ∗ ∗			
G x W (F prob)	0.697ns				0.074ns			
G x Y (F prob)	<.01∗∗				<.01∗∗			
G x W xY (F prob)	0.298ns				0.231ns			

effect (P<0.01), and genotypic variation (P<0.01) within year. In year 1, genotypes ICGV 02125 and ICGV 06319 showed the highest SCMR, respectively, under WW and WS, while the lowest SCMR were observed on ICGV 07211 and Fleur 11 under WW and WS conditions, respectively. In year 2, the highest SCMR was observed on ICGV 92206 (WW) and ICGV 06319 (WS), while ICGV 02038 (WW) and 55-437 (WS) showed the lowest (Table 2).

(b) Leaf Area (LA) and Specific Leaf Area (SLA). ANOVA of LA and SLA data showed a significant variation among genotypes (P<0.001 and P<0.01, respectively) and water regimes (P<0.001) during both years. Drought stress reduced significantly leaf area (LA) and specific leaf area (SLA), respectively, up to 64 and 27% in year 1 and 46% and 15% in year 2. The highest LA was obtained with ICGV 92035 and ICGV 02005, while the lowest LA was obtained with ICGV 92206 and ICGV 06319 across year and under both water treatments (Figures 1(a) and 1(b)). In year 1 experiment, genotypes 55-437, ICGV 06319, and ICGV 02125, showed the highest SLA under WW conditions, whereas under WS, ICGV 02125, ICGV 02005, and ICGV 92035 showed the highest SLA. Under both water WW and WS treatments, ICGV 92206 and ICGV 07210 showed the lowest SLA (Figure 1). In year 2, the genotypic variation showed that ICGV 07211 and Fleur 11 revealed the highest SLA under WW condition and ICGV 92195 and ICGV 02038 showed the highest SLA under WS. Under WW condition, the lowest SLA was observed on 55-437, ICGV 92206, and ICGV 06319 and on genotypes ICGV 02125 and ICGV 06319 under WS (Figure 1).

(c) Total Transpired Water (TTW) and Transpiration Efficiency (TE). Significant difference (P<0.01) was observed across years for TTW. It decreased significantly up to 59 and 46%, respectively, in year 1 and year 2. Significant (P<0.05) genotypic variation and water treatments effect (P<0.001) were also observed. In year 1 experiment, ICGV 92035, ICGV 92196, and ICGV 92195 showed the highest TTW under both water regimes, while ICGV 92206, ICGV 02125, and ICGV 06319 showed the lowest (Figure 2). In year 2 experiment, the highest TTW under WW was observed on 55-437, ICGV 02005, and ICGV 02125 and on ICGV 92196 and ICGV 92195 under WS, while genotypes ICGV 02038, ICGV 07211, and ICGV 06319 showed the lowest TTW under both water regimes (Figure 2).

TE investigated under WW and WS showed a significant (P<0.001) water regimes effect and genotypic variation (P<0.001). TE decreased significantly under WS conditions up to 14 and 9%, respectively, in year 1 and year 2. In year 1 experiment, genotypes with the highest TE under WW conditions were ICGV 92035, ICGV 02125, and ICGV 92196, while ICGV 02005 and ICGV 06319 showed the lowest TE. Under WS, the highest TE was observed on 55-437, ICGV 92035, and ICGV 92196 and the lowest observed on ICGV 92206, 06319, and Fleur 11 (Figure 2). Under WW in year 2 experiment, genotypes with highest TE were ICGV 92035, ICGV 92196, and ICGV 06319, while ICGV 07211, ICGV

Table 2: SPAD Chlorophyll Meter Reading (SCMR) of groundnut genotypes in the well-watered (WW) and water-stressed (WS) treatments at 60 DAS in 2017 (year 1) and 2018 (year 2) in lysimeter experiment. *G= genotypes, W = water regimes,* and *Y= year.*

Genotypes	Year 1		Year 2	
	WW	WS	WW	WS
55-437	38.4ab	37.43ab	40.67ab	32.87a
FLEUR11	39.13bc	34.92a	41.83ab	36.87b
ICGV 02005	42.4cd	36.12a	40.43ab	37.2b
ICGV 02038	41.73cd	41.63cd	38.7a	41.27cde
ICGV 02125	43.6d	40.27bc	43.13 ab	43.69e
ICGV 06319	39.7bc	46.33e	42.07 ab	49.77f
ICGV 07210	43.17d	40.97bc	43.13 ab	36.57b
ICGV 07211	37.17a	39.9ab	40.4ab	36.75b
ICGV 92035	41.93cd	41cd	42.13ab	38.27bc
ICGV 92195	38.67ab	42.87cd	39.57a	37.67b
ICGV 92196	38.73ab	38.57ab	40.25ab	40.1bcd
ICGV 92206	40.67bc	41.8cd	45.83b	42.4de
Means	40.44	40.15	41.49	39.44
G (F prob)	<.001∗ ∗ ∗			
W (F prob)	0.006∗∗			
Y (F prob)	ns			
G x W (F prob)	<.001∗ ∗ ∗			
G xY (F prob)	0.02∗			
G x W x Y (F prob)	0.03∗			

∗ = significant at 5% level. ns = not significant at 5% level. Means with the same letter are not significantly different within the same treatment by Duncan's multiple range test.

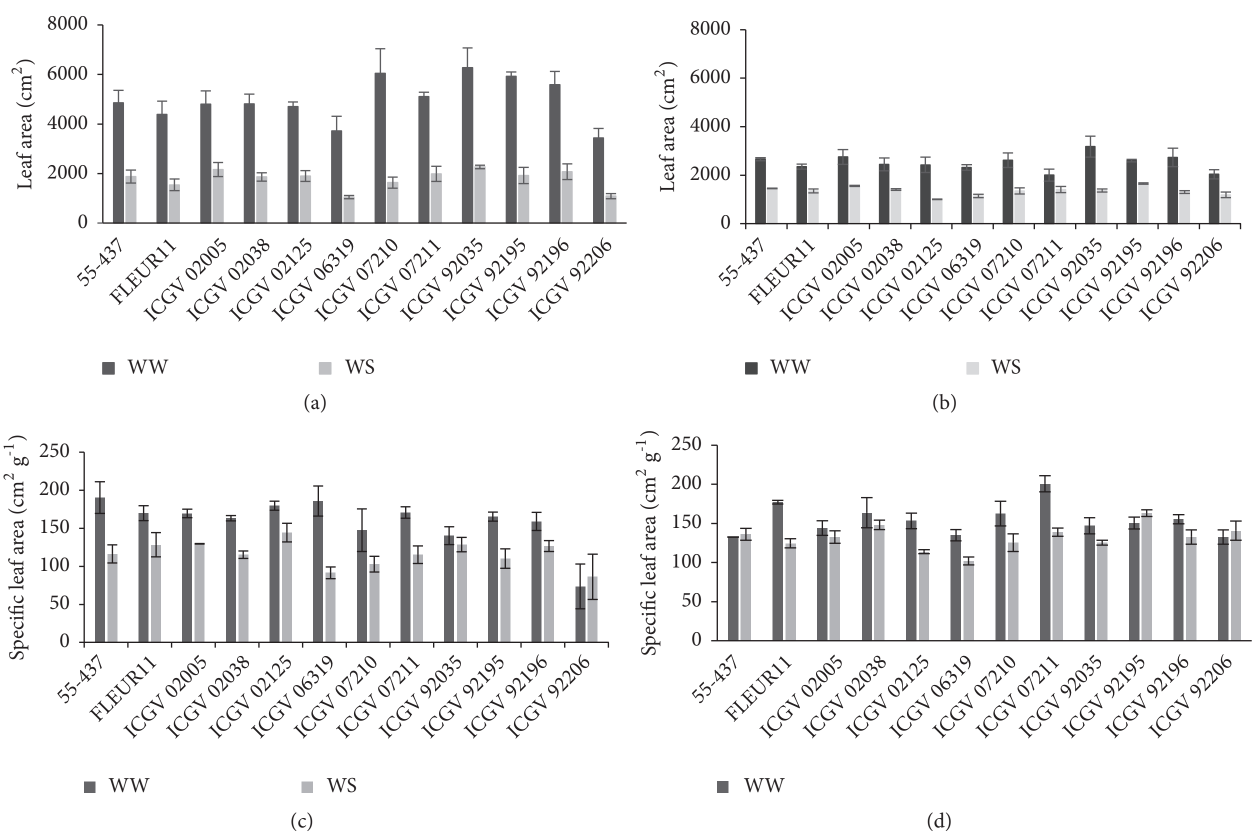

Figure 1: Leaf area (LA) and specific leaf area (SLA) of groundnut genotypes under WW and WS treatments in year 1 ((a) and (c)) and year 2 ((b) and (d)) experiments.

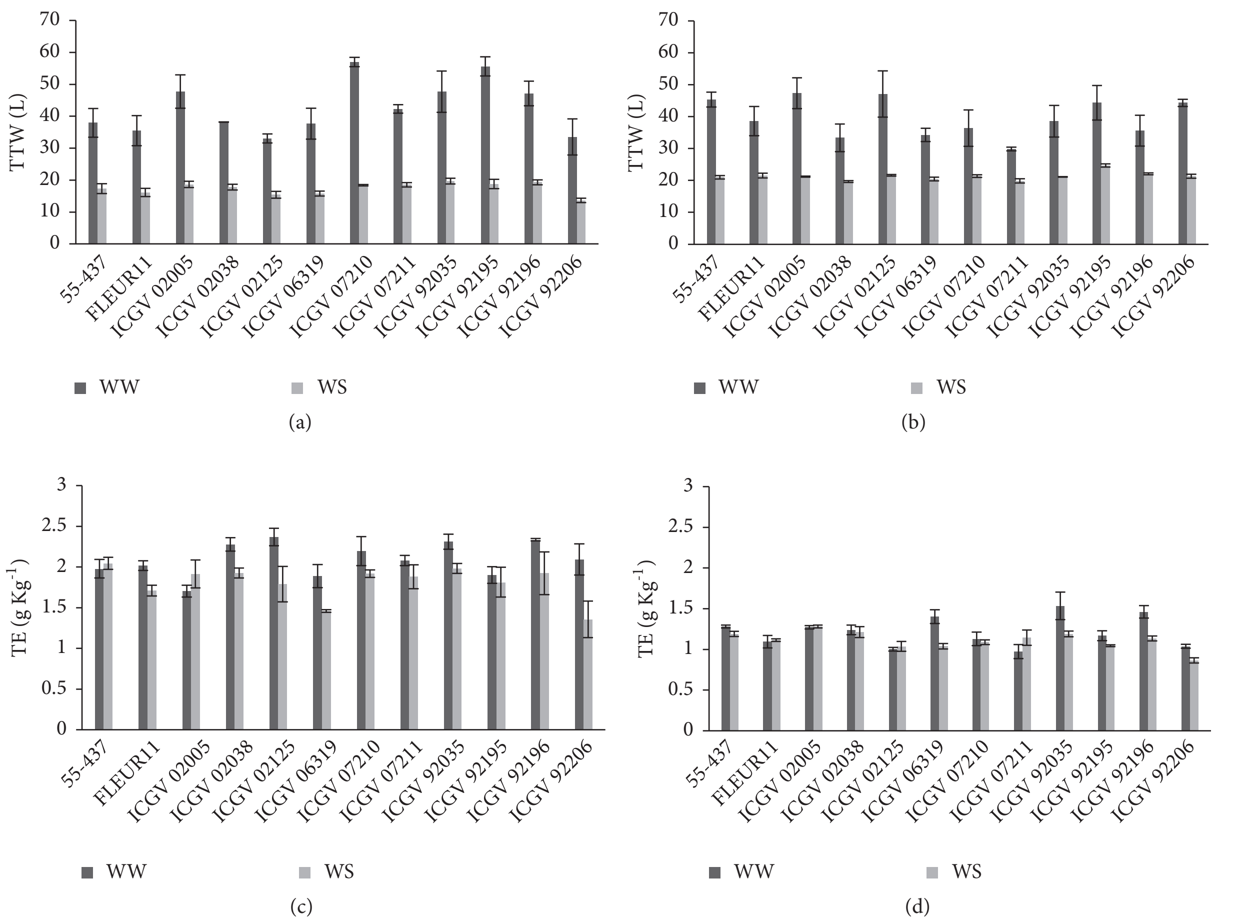

Figure 2: Total transpired water (TTW) and transpiration efficiency (TE) of groundnut genotypes under WW and WS treatments in year 1 ((a) and (c)) and year 2 ((b) and (d)).

92206, and ICGV 02125 showed the lowest TE. Under WS, the highest TE was observed on ICGV 02005, ICGV 02038, and ICGV 92035, whereas the lowest TE observed on ICGV 92206, 06319, and 02125 (Figure 2).

(d) Root Dry Weight (RDW), Root Length (RL), Root Volume (RV), Root Diameter (RD), and Root Length Density (RDL). In lysimeter experiment, significant water treatment effect was observed on RDW (P<0.01), RV (P<0.01), RD (P<0.001), and RLD (P<0.001). Drought stress reduced the RDW, RV, and RD up to 26. 44 and 19%, respectively, while the RDL increased up to 32% (Figure 3(a)). In pot experiment, water stress also affected significantly the RL (P<0.001), RV (P<0.01), RD (P<0.001), and RLD (P<0.001). The decrease due to drought stress was up to 14. 31 and 27%, respectively, on RL, RV, and RD, while RLD increased up to 66% (Figure 3(b)). RDW ranged from 2 to 4.48 g plant^{-1} under WW and from 1.19 to 3.64 g plant^{-1} under WS conditions. RDW decreased up to 16% under WS. The genotypic variation revealed that ICGV 92035, Fleur 11, and ICGV 92196 showed the highest RDW, while ICGV 92206, ICGV 02038, and ICGV 06319 had the lowest RDW under WW conditions. Under WS conditions, the highest RDW was observed on ICGV 92035 and ICGV 92195; the lowest was observed on ICGV 92206, ICGV 02038, and ICGV 07210.

3.4. Measured Traits and Their Relationships under Water Stress Conditions. The linear regression showed a negative relationship(R^2= 0.35 in year 1, R^2= 0.52 in year 2) between pod and haulm weight under WS conditions in lysimeter experiment (Figures 4 and 5). Positive relationship between SCMR and SLA was observed in both year 1 and year 2 lysimeter experiments (data not shown). In both year 1 and year 2 lysimeter experiments, the haulm weight was highly related to TTW (R^2= 0.93 and R^2= 0.11, respectively), TE (R^2= 0.86 and R^2= 0.54, respectively), and LA (R^2= 0.78 and R^2= 0.48, respectively) (Figures 4 and 5).

4. Discussion

Drought stress has been identified as the major environmental factor limiting agricultural productivity and food safety worldwide. In this study, intermittent drought stress decreased significantly the pod and haulm weight. Previous findings reported that pod and haulm yields decreased when

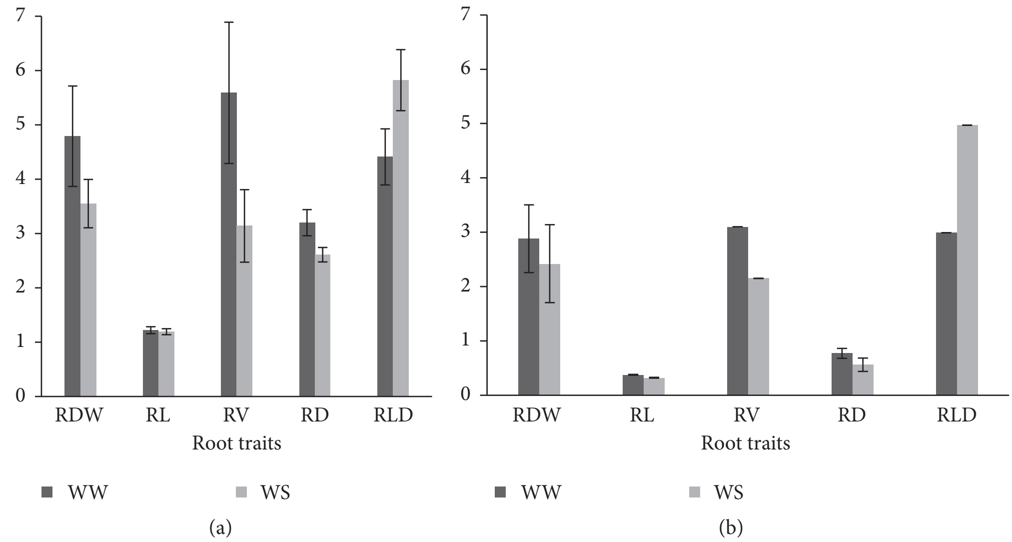

FIGURE 3: Root dry weight (RDW), root length (RL), root volume (RV), root diameter (RD), and root length density (RLD) of groundnut genotypes under well water (WW) and water stress (WS) in lysimeter (a) and pot (b) experiments. Values are in 10^2 for RL, 10^1 for RV, and 10^2 for RLD.

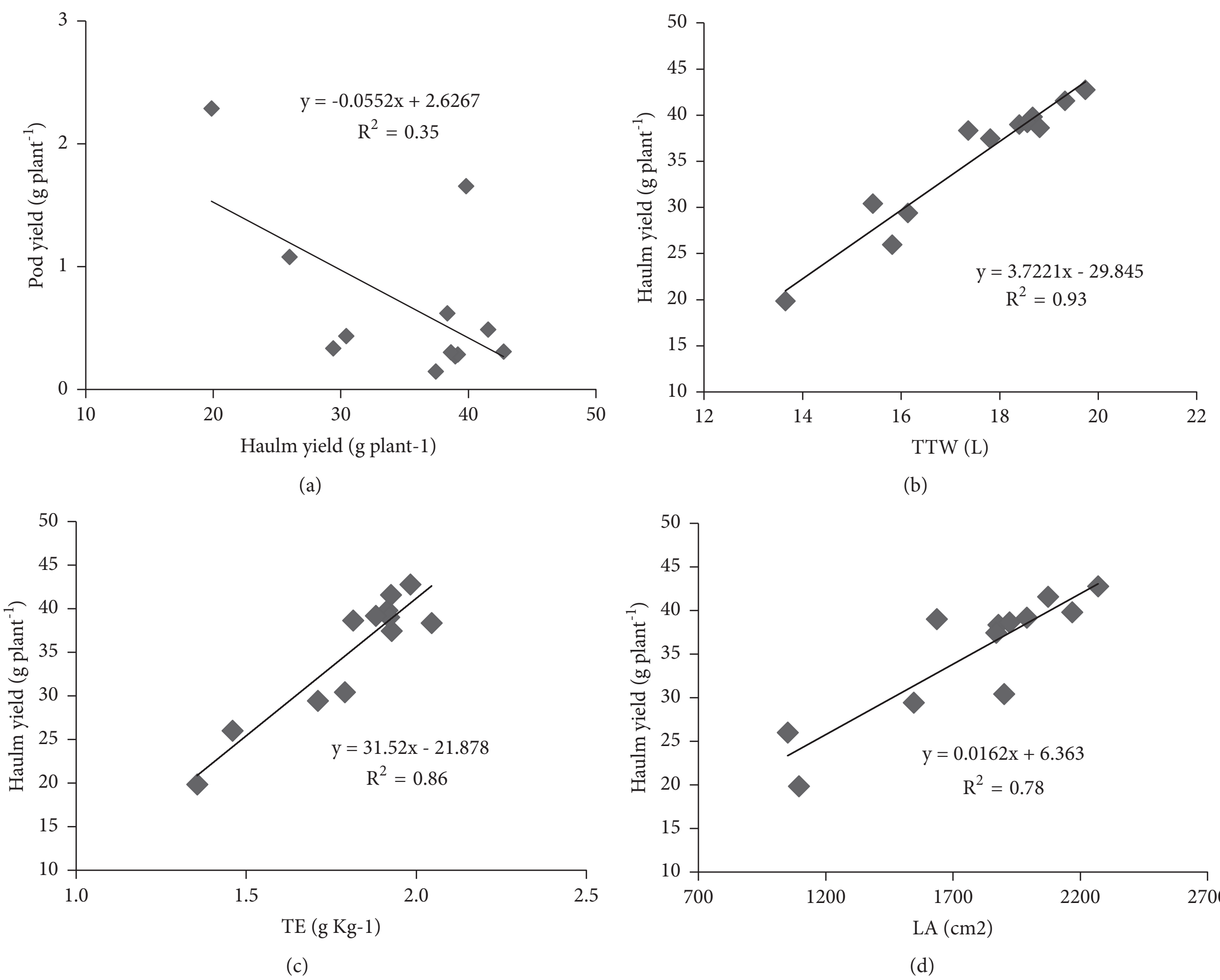

FIGURE 4: Relationship between pod and haulm weight (a) and between haulm weight and TTW (b), TE (c), and LA (d) under WS condition in lysimeter during year 1 (2017) experiment.

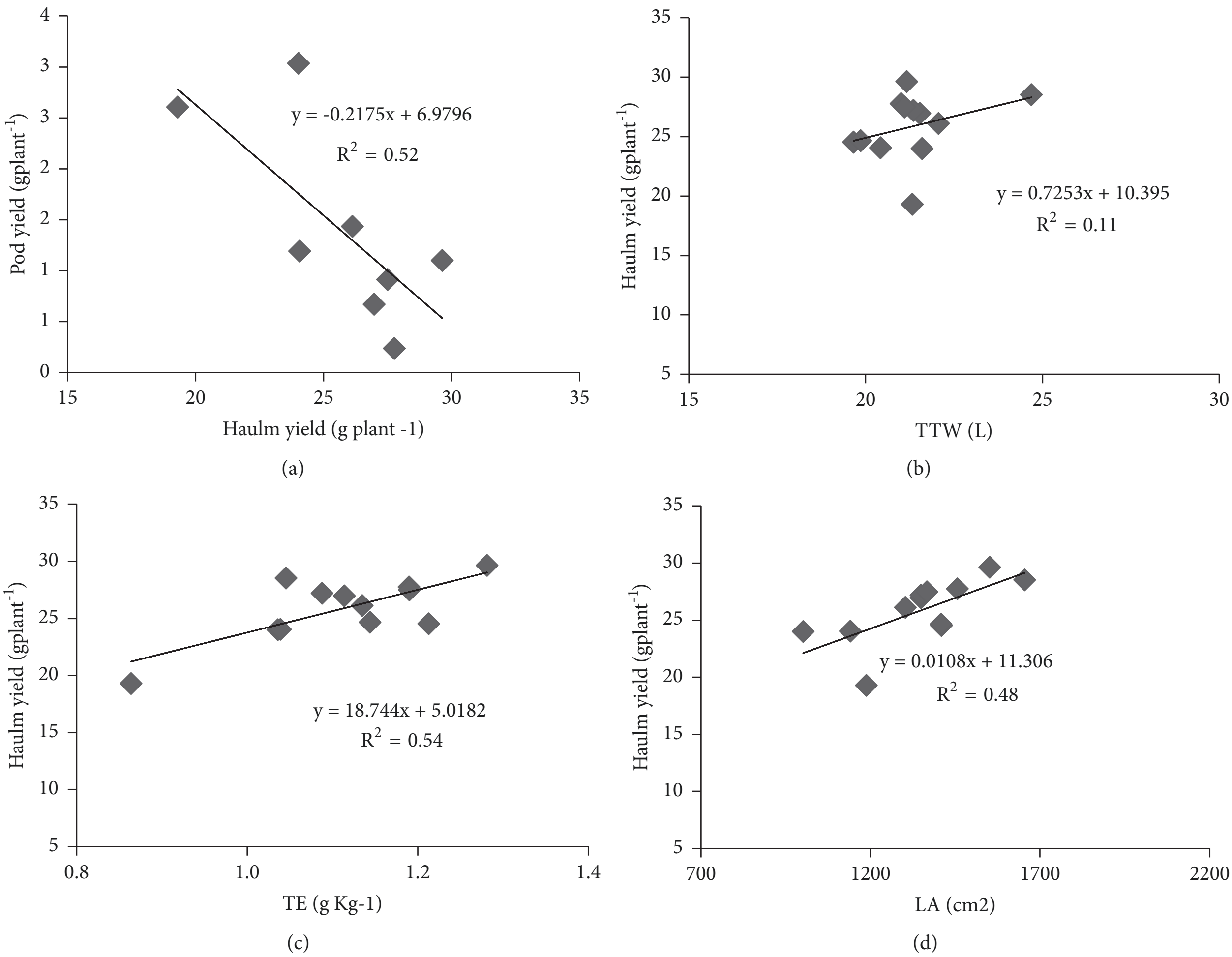

Figure 5: Relationship between pod and haulm weight (a) and between haulm weight and TTW (b), TE (c), and LA (d) under WS condition in lysimeter during year 2 experiment (2018).

groundnut was subjected to drought stress [8, 10, 21, 22]. Our findings showed a negative relationship between pod and haulm weight under WS conditions and indicated that, in response to drought, tolerant genotypes produced much pods and less biomass. Authors [23] reported that well-adapted groundnut genotypes had high partitioning coefficient (dry matter repartition between pod and leaves) and low crop growth rates under drought condition. Our results showed that haulm weight was significantly related with TTW and TE under WS conditions suggesting that high water uptake and high transpiration efficiency in response to drought contributed to high biomass productions. Previous study on groundnut [2] in the same location and period showed high haulm production under drought conditions and high temperature. The positive and high relationship between TTW, TE, LA, and haulm indicates that TTW, TE, and LA are survival traits under drought stress conditions.

The genotypic variations observed in this study revealed that ICGV 92206 and ICGV 06319 were high pod yielding genotypes, early maturing and used less water (low TTW) under both water regimes. These genotypes showed low haulm weight and stable yield across years under WS conditions. With high and stable pod yield associated with controlled transpiration (low TTW), these genotypes revealed drought tolerance. Reference [24] reported that the ultimate goals of any drought research are to select genotypes with high abilities to convert the nutriments assimilated and water into economic yield (pods production) under limited-water conditions. ICGV 92206 and ICGV 06319 revealed promising genotypes to improve pod production in the semiarid area and could be used in groundnut improving programs for drought adaptation and productivity. Our findings revealed also that genotypes ICGV 92035, ICGV 92195, ICGV 02038, ICGV 07211, and ICGV 07210 showed low or any pod yield, high haulm yield, high TTW, and high TE and are part of latest maturing genotypes under WS condition. These genotypes revealed drought sensitivity for pod production but could be recommended for fodder productivity notably in moderate drought-prone environments.

The investigation on TTW to assess the genotypes water requirement showed significant decrease of TTW under WS. Transpiration decrease is considered as one of the most important mechanisms to avoid drought [5, 6]. TTW decrease observed in this study suggests dehydration avoidance due to stomatal control and/or leaf area reduction. Indeed, when water stress increased, stomatal started closing as a mechanism to reduce transpiration in order to conserve water but has the consequence of reducing the net photosynthesis [7, 25]. The LA decrease observed in this study contributed also in TTW reduction under WS to avoid dehydration. TE investigation showed significant water regime effect, a genotypic variation and TE was positively related with haulm weight, SLA, and LA (data not shown) under WS in two years experiments. The genotypic variation revealed that ICGV 92035 and ICGV 02038 showed high TE and high haulm weight under WS. Similar results were found in previous works which reported that high TE under drought stress could be explained by canopy development, specific leaf area, high roots dry matter, and/or chlorophyll content [4, 8, 26–28]. Also, [29] suggests that stomata regulation plays an important role in increasing TE in groundnut, in particular the capacity to restrict transpiration under high VPD. Under WS condition, genotypes with high haulm weight and high TTW showed high TE value while genotypes with high pod weight had low TTW, low haulm weight, and low TE value. The high relationship found between haulm weight and TE indicates that total transpiration contributed to haulm production, while it hampered the partition rate leading to low pod weight. Similar results were observed by [5, 29] who reported that harvest index (HI) varied depending on haulm and pod weight.

In this study, significant and positive relationship was observed between pod weight and SCMR at 60 DAS and maturity stage under WS (data not shown). This suggests that continuing photosynthetic activities under WS will lead to high pods production and reveals drought tolerance trait. High SCMR was observed on the highest yielding genotypes under WS. Indeed, it was reported that drought-resistant plants were able to keep their stomatal open and therefore have a high potential for CO_2 assimilation during severe water deficits [30].

Our findings on RDW, RL, RV, and RD showed significant decrease due to WS. Reference [31] reported significant root traits decrease under drought stress. In addition to leaf area decrease and stomatal closure, RDW, RL, RV, and RD decrease contributed to TTW reduction under WS. Our findings showed also that RDW and RV were negatively correlated with pod weight but positively correlated with haulm weight (data not shown). These results suggest that negative impact of drought stress on root parameters will affect more haulm production than pod yield. However, the roles of root traits in pods yield under drought conditions are diversely interpreted. For instance, authors [4, 15, 32] have shown that high RDW was positive to maintain high TE and improve yield component and can be used as selection criterion for improving drought resistance in groundnut, while [21] reported that RDW alone may not determine the pod yield and other factors are involved.

For most of traits, the significant G×Y interaction observed suggests a close interaction between the environmental conditions in which the experiments were carried out and the genotypic response to drought, leading to some differences in how genotypes performed across years notably under drought conditions.

5. Conclusion

Physiological and agronomic traits were investigated for assessing groundnut lines under drought stress identify promising genotypes and drought related traits. Most of traits investigated in lysimeter and pots experiments showed significant decrease under drought conditions, but significant genotypic variation was observed. Under both WW and WS treatments, ICGV 92206, ICGV 02005, ICGV 02125, and ICGV 06319 showed higher yielding than 55-437 and Fleur 11 (checks). ICGV 92206 and ICGV 06319 revealed drought-tolerant genotypes, while ICGV 92035, ICGV 92195, ICGV 02038, ICGV 07211, and ICGV 07210 were drought-sensitive for pods production but produced high haulm under both water regimes. Low total transpiration to control water loss, less pod weight decrease, SLA, and root length density increase revealed drought tolerance associated trait for pod production, while high TTW, TE, RDW, and RV revealed drought tolerance associated traits for fodder production.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they do not have any conflicts of interest regarding the publication of this paper.

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