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Canopy temperature and agronomical performancein groundnut under intermittent drought in lysimetric system

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Abstract
The objective of this study was to evaluate the effect of intermittent water deficit on canopy temperature and yield component of six groundnutgenotypes. Thus, two experiments were conducted under lysimetric system conditions in 2018 and 2019 at ICRISAT Sahelian Center. The six genotypes were assessed in a randomized complete block design, with 4 replications and 2 water regimes, well-watered (WW) and intermittent water deficit (WS) imposed at 30days after sowing. Phenology and agromormorphological data were collected including the date of emergence, date 50% flowering, canopy temperature (CT), and yield components. Our findings showed significant decrease of almost parameters measured except the canopy temperature where a significant (up to 38%) increase was observed. The genotypes 55-437, ICG 12991and ICGV 97183 revealed highest yielding, while JL-24 was the lowest yielding. Theindex of canopy conductancewas significantly and positively correlated to pods number and weight and haulm weight.

Keywords:*Groundnut, Intermittent Drought, Canopy Conductance, Lysimeter, Yield*

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I. Introduction

Groundnut (*Arachis hypogaea* L.) is an important crop both in subsistence and commercial agriculture in arid and semi-arid regions of the world(Ratnakumar *et al.*, 2009). It is also the main crop rotation component in many sub-Saharan countries. Groundnut yield is low and instable in these regions due to biotic and abiotic constraints (Singh *et al.*, 2014). In the semi-arid areas, drought stress is the major constraint of groundnut productivity and the cause of yield instability (Bhatnagar-Mathur *et al.*, 2007).Drought stress affects severely the pod yield and other growth and physiological parameters (Reddy *et al.*, 2003; Nigam *et al.*, 2005; Songsri *et al.*, 2008, Hamidou et al., 2018). Yield loss of groundnut can reach 56-85%, depending on crop growth stages, drought intensity and duration (Nautiyal *et al.*, 1999; Shinde *et al.*, 2010; Hamidou et al., 2012).

In west Africa, unpredictable and intermittent periods of water deficit commonly occur almost each year during growing season in most of groundnut production area and reduce pods and haulm yields up to 46% to 55% respectively (Ratnakumar and Vadez, 2011; Hamidou *et al.*, 2012; Hamidou *et al.*, 2018). Previous studies showed that the total water transpired by plants was an important trait associated to drought tolerancein groundnut(Clavel *et al.*, 2005; Puangbut *et al.*, 2009).Under water stress conditionsthe first responses of plant is stomatal closure followed by reduction of the transpiration,thus minimizing water losses through transpiration(Mabhaudhi *et al.*, 2013).Previous finding reported that groundnut genotype with high roots characters could maintain high plant water status and yield under long term and terminaldrought(Songsri *et al.*, 2008; Junjittakarn *et al.*, 2014). Roots characters are drought-adaptative traits(Ding *et al.*, 2017).Physiological traits like canopy temperature has been used as an indicator of stomatal aperture, which is considered as sensitive response to soil water deficit (Grant *et al.*, 2006; Testi *et al.*, 2008; Taghvaeian *et al.*, 2014). It was reported that stomata progressively close under water deficit followed by a reduction of leaf water status to understate water loss(Zaman-Allah *et al.*, 2011). Both the reduction of leaf expansion and the closure of stomata at high soil moisture thresholds will slow down soil water depletion and would be beneficial under long drought spells. Water stress is known to induce stomatal closure, and hence, reduce evaporative cooling and increase leaf temperature(Pilon *et al.*, 2018).

Thermal imaging using infrared (IR) is today an established technology for the monitoring of stomatal responses and for phenotyping plants for differences in stomatal behavior (Jones *et al.*, 2009). Recent studies showed that canopy temperatures under well-watered conditions also provide an indication of potential yield performance during drought and could effectively be used as a technique to assess genotypic response to drought (Talebi, 2011). The effects of terminal water stress on canopy temperature and canopy conductance have been assessed on chickpea(Zaman-Allah *et al.*, 2011) and on cowpea(Ndiso *et al.*, 2015).As far as we know, there is no information on the effects of drought stress on canopy temperature and the canopy conductance index in groundnutunder Sahelian environment.

This studyaims to investigate water deficit effect on canopy conductance and agronomical performance of groundnut genotypes in lysimeter conditions.

II. Material and methods

Two experiments were conducted duringtwo years (Y), from end-August to November 2018 and 2019under lysimetric system conditions 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). Six genotypes of groundnut including JL-24, ICGV 97183, 55-437, 12CS-116, 12CS-79 and ICG 12991 were assessed.These genotypes were selected based on their response to drought stress under field conditions. ICG 12991, ICGV 97183 and 55-437 were considered as tolerant; 12CS-116 and 12CS-79 were intermediate while JL 24 was sensitive (Hamidou *et al.*, 2012; Jongrungklang *et al.*, 2013).

Experimental Conditions

The lysimetric system was well described in our previous works (Halilou *et al.*, 2015). All lysimeter tubes (PVC cylinders) were placed upright in 1 m deep trench, over which the weighing mechanism could be moved to select individual cylinders for weighing. The tops of the cylinders were equipped with metal collars and chains to allow the lysimeter tubes to be lifted and weighed. The lysimeter tubes weighting procedure involved a crane balance (S-type load cell with a 200 kg load capacity; Mettler-Toledo, Geneva, Switzerland) connected to a block chained pulley to lift the tubes. The soil (5.8 pH_{H2O} (1:2.5), 3.6 mg Bray-P kg^{-1}, 0.1% organic matter and 81 mg total N kg^{-1}) used to fill the lysimeter tubes was collected from the farm of ICRISAT Sadoré station. Top soil (0-20cm) and deep soil (20-100cm) from the farm were collected separately. To mimic the field conditions, the lysimeter tubes (25 cm diameter, 130cm height) were filled with deep soil (100 cm height) followed by top soil (20 cm height). The upper 10 cm of the tubes was left empty to allow the application of a layer of anti-evaporation beads and for watering.

The experimental design was a randomized complete block design with 4 replications, six genotypes (G) and two water regimes (WR), well-watered (WW) and water stress(WS). Three seeds were sown by hand; seedlings were thinned at 14 days after sowing (DAS) and two plants were left per tubealso, two grams of Diammonium Phosphate (DAP) were used after thinning to fertilize (N, P) the soil.

WW regime was a full irrigation (90% of field capacity) until harvest while WSregime, imposedfrom 50% flowering time to maturity date,was an intermittent water stress consisting of cycles of drying (irrigation interruption) and re-watering (1000 mL of water per tube) when the majority of WS plants showed clear wilting symptoms (Hamidou et al., 2012). Given the diameter of the lysimeter tubes, this was equivalent to 16 mm of water when extrapolated to a field condition(Hamidou *et al.*, 2018). Prior to impose WS, the lysimeter tubes were water saturated, drained during 24 hours to reach field capacity and the soil surface was covered with a 2cm thick layer of polyethylene beads to minimize soil evaporation.

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 was 29.19°C in 2018 and 30.66°C in 2029, while the mean relative humidity was 54.69% in 2018 and 45.87% in 2019.

Measurements

a) Phenology

After sowing, the dates of emergence, dates flowering start and 50% flowering (flowering of half of the plants by genotype) and the maturity date were recorded on both WW and WS plants

b) **Canopy temperature and index of canopy conductance**

The canopy temperature (CT) of WW and WS plants was estimated from thermal images obtained from an infrared camera (IR FlexCam thermal imager, Fluke Ti55FT -20/7.5, IR-Fusion, 600 ºC, 20 mm, 7.5 HZ). The images were taken at 2m above the canopy at the time of high VPD of the day (between 1 and 2 pm). The images were taken 14 days after stress imposition (DASI) corresponding to pegging stage and 30 DASIcorresponding to pod fillingtime. The software Smart View (Fluke thermography Everett, WA, USA) was used to analyze the images and estimate the canopy temperature. Wet surface (Th) and dry surface (Ts) temperatures were measured by using the camera. The Th was measured on fresh leaves separated from the plants (genotypes) and soaked in water for 5 minutes. As for the Ts, it was measured on loose sheets and dried in the oven. The measured canopy temperature was used determined the canopy conductance which was estimated indirectly by calculating the index of canopy conductance (Zaman-Allah *et al.*, 2011) according to the following formula: ICC = (Ts – CT)/(CT-Th) with CT = canopy temperature measured by the camera; Ts = dried leaves temperature and Th = wet leaves temperature.

c) Yield components

After harvest, pods number was counted, pods and haulm weight were determined. The pod weight was multiplied with a correction factor of 1.65 (Duncan *et al.*, 1978) to adjust for the differences in the energy requirement for producing pod dry matter compared with vegetative partand the harvest index (HI) was calculated: HI=pod weight*1.65\ (pod weight*1.65+haulm weight)

Data analysis

The analysis of variance (ANOVA) was performed to assess the effect of genotype (G), water regime (WR) and their interactions for the different traits measured. GENSTAT 17th edition (VSN International Ltd, Hemel Hempstead, UK) was used to perform statistical analyses. Student Newman Keuls test was used to compare means. Microsoft office Excel 2016 Software (Microsoft Corp., Redmond, WA, USA) was used for linear regression by plotting different traits to determine the r^2 and regression equation.

III. Results

a) Phenology

A significant (P<.001) genotypic variation and year effect were observed for 50% floweringand maturity date. The flowering ranged from 22 to 26 and 23 to 27DAS respectively in 2018 and 2019. It was also observed significant interaction G×WR×Y (P< 0.001) on the maturity date.Thus, under WW conditions, ICG 12991, JL-24 and 55-437 were late maturing (96 DAS) whereas ICGV 97183,12CS-116 and 12CS-79 were earliest maturing (92DAS) genotypesacross years. Under WS condition, JL-24and ICGV 97183 had higher day of maturity than ICG 12991, 55-437 and 12CS-79(82DAS)in 2018 and 2019.

b) Water deficit effect on canopytemperature (CT) and canopy conductance index (ICC)

The analysis revealedsignificant effect of water regime (WR), years (Y) and interactionWR×Y (P<0.001) for CT and ICC during both stages and years (Tables 1 and 2). In 2018 and 2019, CT of stressed plants increased respectively up to 30 and48%; 17 and 29% respectively at 14 and 30DASIwhereas ICC was reduced up to 79 and 83%, 59 and 81% at 14 and 30DASIrespectively.

WW plants showed the lowest CT compared toWS plantsduring both stages and years (Table 1). Similarly, ICCof WW plants was higher than ICC of WS plants across year (Table 2).

Table1.Canopy temperature under well-watered and water stress conditions in 2018 and 2019.
G= genotypes; WR= water regimes; Y= year; WW=well-watered; WS =water stress; DAS = days after stress imposition. Means with the same letter are not significantly different within the same treatment by SNK multiple range test

Treatment	14DASI				30DASI			
	2018		2019		2018		2019	
	WW	WS	WW	WS	WW	WS	WW	WS
Genotype								
55-437	31.35a	42.05a	31.35a	37.10a	33.00a	46.86a	32.08a	40.66a
ICGV 97183	32.24a	42.71a	32.17a	39.27a	32.05a	47.07a	33.35a	41.65a
JL-24	31.96a	42.43a	32.36a	37.48a	31.59a	47.77a	32.35a	42.74a
12CS-116	32.47a	42.97a	32.67a	38.53a	31.86a	47.50a	32.58a	42.43a
12CS-79	31.94a	43.41a	32.14a	37.57a	31.13a	47.62a	32.49a	41.39a
ICG 12991	32.71a	43.35a	3.55a	38.16a	32.98a	47.55a	32.97a	42.87a
Mean	32.11	42.80	32.39	38.35	32.07	47.40	32.67	42.11
G			0.214				0.285	
WR			<0.001				<0.001	

Y	<0.001	<0.001
GxWR	0.420	0.390
GxY	0.217	0.364
WRxY	<0.001	<0.001
GxWRxY	0.064	0.110

Table2.Index of canopy conductance under well water and water stress condition in 2018 and 2019.With G= genotypes; WR= water regimes;and Y= year; WW=well-watered; WS =water stress; DAS = days after stress imposition.Means with the same letter are not significantly different within the same treatment by SNK multiple range test

Treatment	14DASI				30DAS			
	2018		2019		2018		2019	
	WW	WS	WW	WS	WW	WS	WW	WS
Genotype								
55-437	2.93a	0.58a	2.27a	1.00a	2.27a	0.49a	2.24a	0.42a
ICGV 97183	2.37a	0.50a	2.53a	0.68a	2.5a	0.46a	2.03a	0.49a
JL-24	2.21a	0.54a	2.11a	0.75a	2.71a	0.43a	2.26a	0.36a
12CS-116	2.29a	0.51a	2.17a	0.79a	2.59a	0.44a	2.04a	0.41a
12CS-79	2.19a	0.55a	2.42a	0.84a	3.44a	0.45a	2.31a	0.38a
ICG 12991	1.96a	0.54a	2.07a	0.86a	2.07a	0.46a	2.08a	0.40a
Mean	2.49	0.53	2.00	0.82	2.68	0.46	2.16	0.41
G	0.216				0.114			
WR	<0.001				<0.001			
Y	<0.001				<0.001			
GxWR	0.274				0.738			
GxY	0.199				0.694			
WRxY	<0.001				<0.001			
GxWRxY	0.755				0.162			

c) Intermittent water deficit effects on yield components

A significantgenotype variation(P=0.037), water regime effect(P< 0.001) and interactionG×Y(P=0.002), WR×Y (P< 0.001) and G×WR×Y in haulm were recorded in 2018 and 2019. Water deficit significantly (P< 0.001) decreased the haulm weight plant^{-1}up to 60% and 72% respectively in 2018 and 2019.Under WW, 12CS 79, ICG 12991 and 12CS 116produced the highest haulm while JL-24produced the lowest across years. Under WS conditions,12CS 116,ICVG97183, 55-437 andICG 12991 showed higher haulm weight compared to JL-24 in 2018 and 2019. (Figure 1a, b).

The ANOVA of pods number per plant showed a significant difference between genotype(P×0.001), water regime(P<0.001), year(P<0.001); significant interaction WR×Y(P=0.017) and G×WR(P=0.022) (Figure 2). Itwas reduced up to 46 and 72% respectively in 2018 and 2019.The highest pods numberper plant wasobserved under WWcompared to WSregime during both years. The genotypicvariation revealed that 55-437 had the highest pods number while 12CS-116 showed the lowest during both years and water regime (Figure 2a and).

Significant G×WR×Y (P=0.024) was observed on the pod weight).Under WW conditions, ICG 12991showed the highest performance while the lowest wasobserved onJL-24 during both years. Under WS conditions,55-437, ICG 12991 and ICG 97183 had the highest podsweight whereas JL-24 showed the lowest in 2018 and 2019. WS decreased pod weight up to 66% and 86% respectively in 2018 and 2019 (Figure3a and b).

The harvest index (HI) revealed a very significant variation across year (P<0.001), water regime effect (P< 0.001) and significant interaction between genotype and year (P=0,043) and water regime and year (P<0.001). The highest HI (0.49) was recorded in 2018and the lowest (0.31) in 2019 under WS condition. Genotypes ICVG 97183, 55-437 and ICG 12991 showed the best HI best in 2018and 2019 under WS(Fig 4a and b).

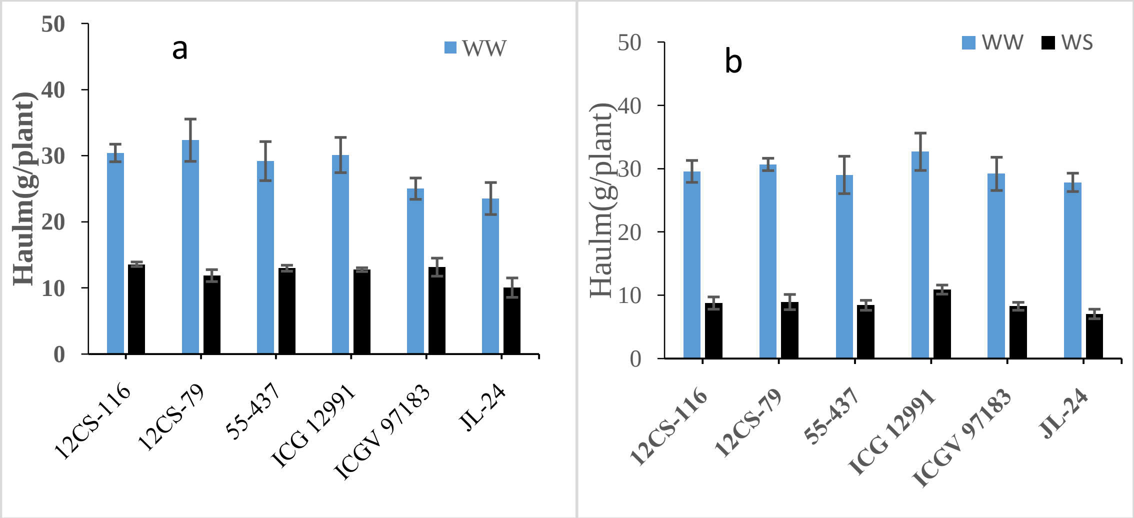

Figure1. Haulm weight of 6 groundnut genotypes under WW and WS regimes in 2018(a) and 2019(b)

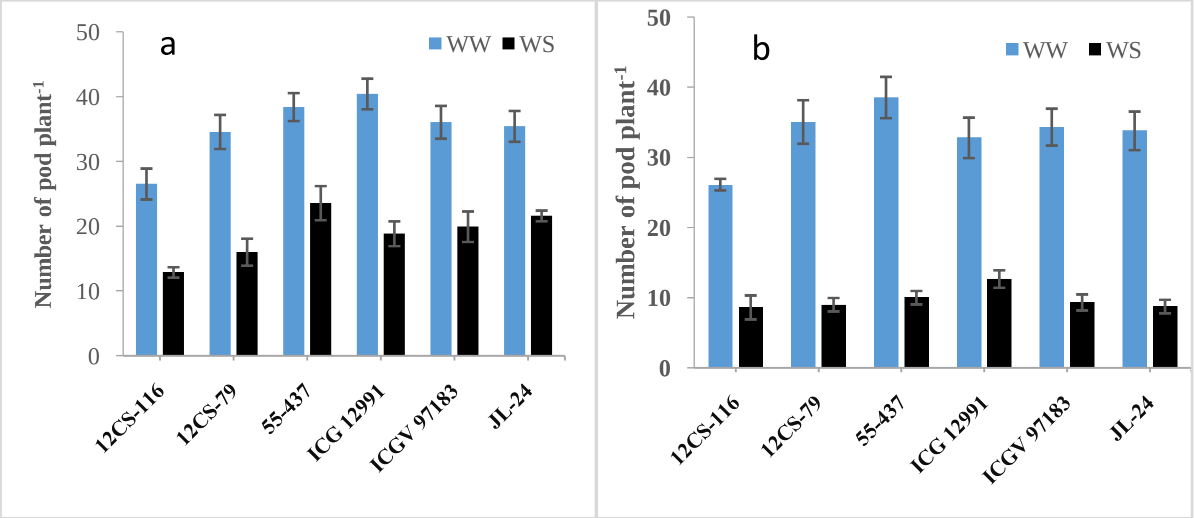

Figure2. Pods per plant under WW and WS regimes in 2018(a) and 2019(b)

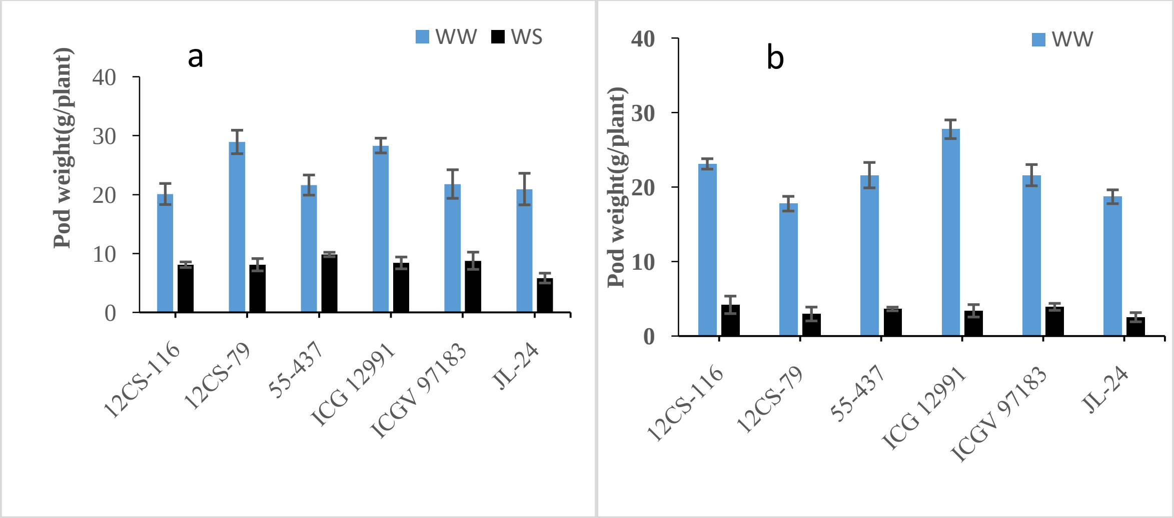

Figure3. Pod weight under WW and WS regimes in 2018(a) and 2019(b)

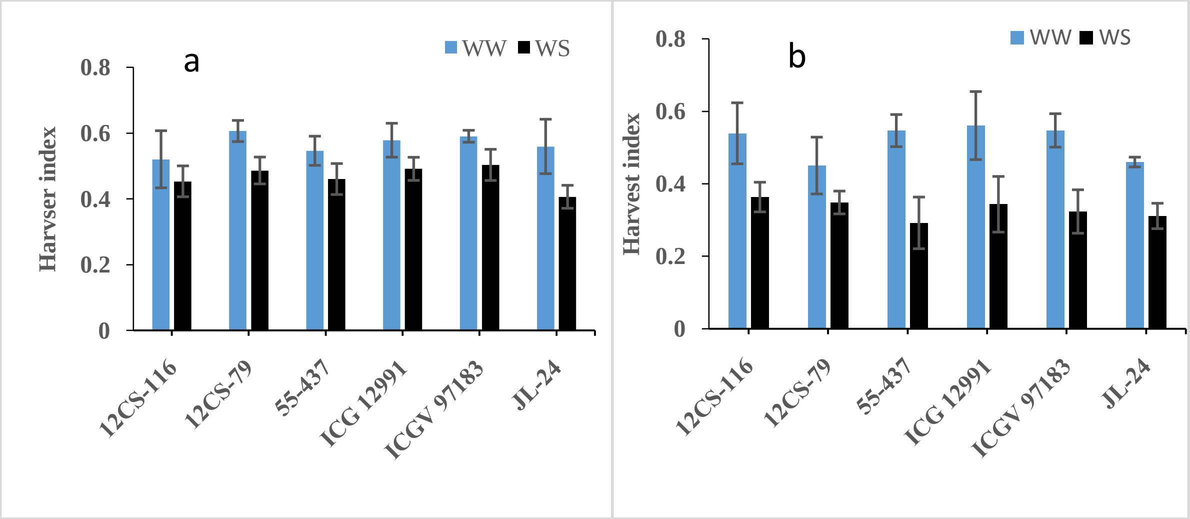

Figure4. Harvest Index under WW and WS in 2018(a) and 2019(b)

Relationship between index canopy conductance (ICC) at podfilling (30DASI) with yield components under WW and WS conditions

Under WS condition, apositive and significant correlation (r = 0.70) was found between pod weight and ICCin both year(Figure5b).The number of pods was alsopositivelyand slightlycorrelated (r= 0.20) to ICC (Figure6b).A positive and significant correlation was found betweenhaulm weight and ICC (r =0,25)during both years (Figure7b).However,ICC was not correlated to yield under WW condition.

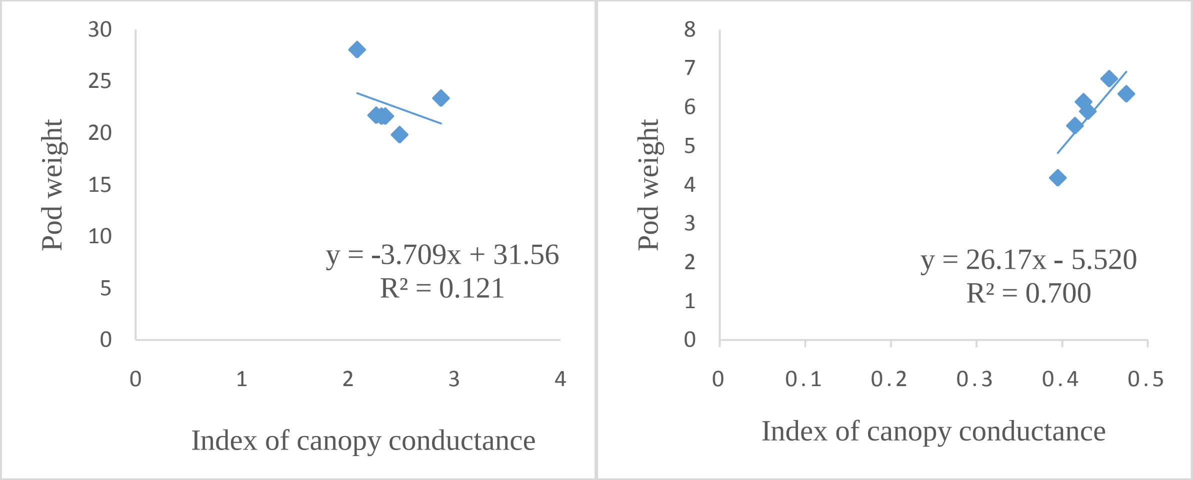

Figure5. Relationship between pod weight and index of canopy conductanceunder WW(a) and WS (b) conditions

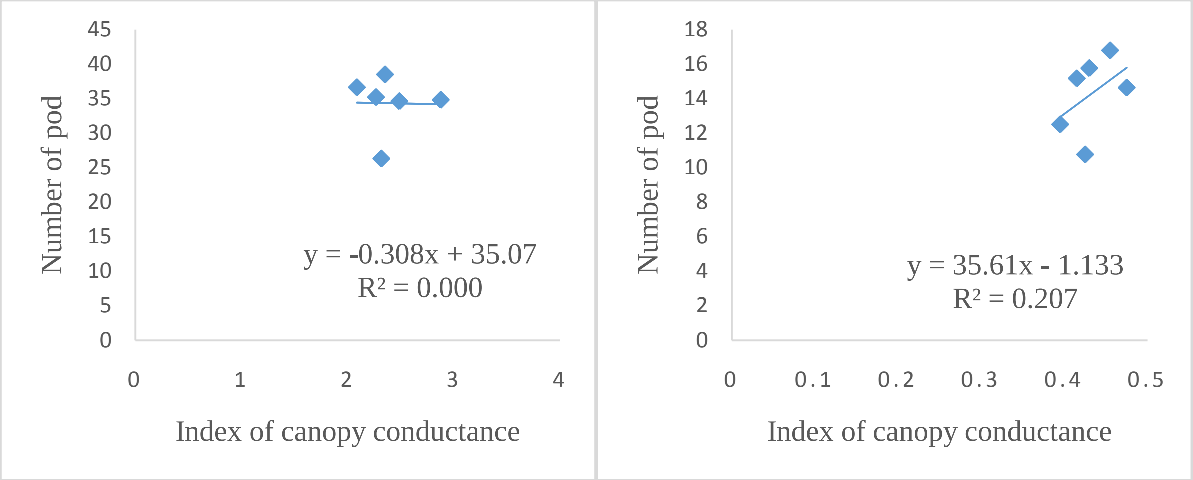

Figure6. Relationship between number of pod and Index of canopy conductanceunder WW(a) and WS (b)

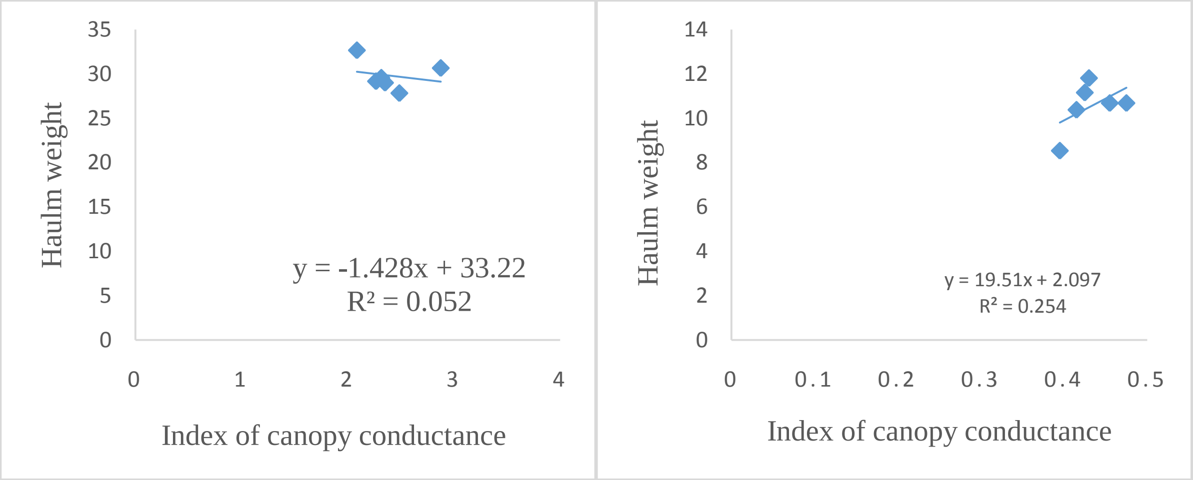

Figure7. Relationship between haulm weight and index of canopy conductanceunder WW(a) and WS(b)

IV. Discussion

Drought is one of the most significant environmental stresses in agriculture worldwide. The findings of this study showed that when water stress progress, theCT increased and ICC decreased. An increase of CT under WS was also observed previously on groundnut(Koolachart *et al.*, 2013). In general plants responded to drought by closing their stomata followed by decreasing transpiration whichincreasesleaf temperature(Agbicodo *et al.*, 2009). Authorsreported that plants growing under water stress conditions have lower stomatal conductance and this contributes to save water and keep longer the tissues water status(Farooq *et al.*, 2009; De Lima Pereira *et al.*, 2016).Stomata closure is a drought avoidance mechanism and one of the first steps in a plant's adaptation to water deficit(Khan *et al.*, 2010). As consequence, the fixation of CO_2 is reduced and photosynthetic rate decreases , resulting in less assimilates production for growth and yield(Mafakheri *et al.*, 2010). Our results did not show a significant genotypic variation under WS in both years indicating that all genotypes responded the same way.The effect of WS was severe on haulm, pod weight, number of pods, number ofseeds and HI.Previous studies showed that yield component of groundnut decreased under water limited conditions(Ravindra *et al.*, 1990; Jørgensen *et al.*, 2011; Mahantesh *et al.*, 2018). Other authors reported that on groundnut, WS induced stomata closure which limits the CO_2 fixation, reduce photosynthesis leading to a reduction of organic matter(Vorasoot *et al.*, 2003; Koolachart *et al.*, 2013). The harvest index (HI) was considered as trait for drought tolerance and the reduction of pod yield led to decrease the HI(Nigam *et al.*, 2005; Girdthai *et al.*, 2010). Our findings showed that intermittent water stress decreased HI in bothyears.Same results were reported previously (Jørgensen *et al.*, 2011; Ndiso *et al.*, 2015). The ability for crops plant to allocate assimilatesaccumulated to seeds during the post flowering period is a potential sources of yield stability under terminal drought environments(Turner *et al.*, 2001).The significant and positive correlation between ICC, pod weight, number of pods, and haulm weight under WSsuggest that tolerant genotypes to water stress had high ICC. This may indicatethat canopy conductance contributes to yield. In this study,the lack of relation between ICC and yield under WW showed that stomata function was very important when plant wasstressed. Thegenotypic variations observed for haulm production showed that 12CS-116, 55-437, ICGV 97183 and ICG 12991 produced higher haulmunder WS conditions.The genotypes55-437, ICG 12991and ICGV 97183 produced the highest numberof pod and pod weightplant^{-1}both years. This maysuggestthat 55-437 and ICGV 97183 can more translocate assimilates from vegetative organs to pods. Under WS in both year, 55-437, ICG 12991 and ICG 97183 had the lowest CT, the highest ICCand was early maturing suggesting that these genotypes confirmedtheir drought tolerance.Songsri *et al.* (2013) reported thatgenotypes with high stomatal conductance could maintain relatively high-water use efficiency under water stress conditions, and this led to high organic matter production.

V. Conclusion

The intermittent water deficit causes significant decrease of almost parameters investigated. The absence of genotypic variation on canopy temperature indicates the same way of responding to water deficit to alert for irrigation. The significant and positive correlation between index of canopy conductance and yield suggested that ICCshould be used as selection criteria for drought tolerance. Under WS in both year, 55-437, ICG 12991 and ICG 97183 had the highest ICC and were higher yieldingwhich suggeststolerance to the intermittent water stressand ICC as relevant drought tolerance related.

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