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Growth and physiological responses of sunflower grown under levels of water replacement and potassium fertilization

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Water deficit is one of the limiting factors of agricultural production, especially in semi-arid regions. In this sense, the aim of this study was to evaluate the growth and the physiological characteristics of sunflower cv. Hélio 251 at different levels of water replacement and potassium doses in an experiment conducted in the greenhouse of the Center for Technology and Natural Resources of UFCG, Campina Grande, PB. The experiment was laid out in randomized complete block design, by studying five levels of water replacement (40, 60, 80, 100 and 120% of actual evapotranspiration - ETr) associated with potassium fertilizer levels (50; 75; 100; 125 and 150% of the indication for assays). The increase of water replacement levels promoted increase in plant height, stem diameter, number of leaves per plant, leaf area, and dry biomass of leaves, and dry biomass of the stem. The level of 75.25% of ETr provided the highest leaf dry weight (0.88 g). The increase in water replacement from 51.33% of ETr provided a reduction in the SPAD index. Water replacement lower than 100% ETr affected gas exchange of sunflower plants, reducing rate of the rate of the photosynthesis by 66% by the water deficit in the soil. The potassium doses had no effect on sunflower growth at 45 DAS neither they altered gas exchange in sunflower plants in the grain filling stage.

Key words: *Helianthus annuus* L., water stress, SPAD index, gas exchange, rate of the photosynthesis.

INTRODUCTION

Sunflower (*Helianthus annuus* L.) is a very important crop for the Brazilian semiarid region because of its broad climatic adaptability, high drought tolerance and yield (Prado and Leal, 2006), providing a greater competitive advantage over other crops such as soybeans, because it has higher yield per hectar in oil production (Zobiole et al., 2010).

In this sense, sunflower can be used to meet the noble edible oils market, feeding birds, silage production, meal and cake for animal feed, ornamental production as well

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as the possibility of export of grain (Lima et al., 2013). Sunflower accounts for about 13% of all vegetable oil produced in the world, with in recent years, increase in cultivated area (Nobre et al., 2011).

The Brazilian production of sunflower in the 2012/2013 harvest was 110 thousand tons, and the largest producer was the state of Mato Grosso with nearly 85 thousand tons, which corresponds to 64.9% of national production and an average productivity of 1671 kg ha^{-1}. In the Northeast, the highlights are the states of Ceará and Bahia with production of 200 tons and an average yield of 422 kg ha^{-1}(Conab, 2014).

The water needs of the sunflower crop are still not clearly defined. In most cases 400 to 500 mm of water, well distributed throughout the cycle, resulting in yields close to the maximum potential (Castro et. al, 2005). The range between 500 and 700 mm water well distributed throughout the cycle has resulted yields close to the maximum (Acosta, 2009). According to Silva et al. (2007), the total depth of 522.14 mm provides higher grain yield, oil and greater plant height. In this sense, the study of different irrigation levels constitutes a way to determine the water needs of a species in different regions (Azevedo and Bezerra, 2008).

Sunflower is very demanding in potassium, exceeding crops such as corn and soybeans (Uchôa et al., 2011). Following phosphorus and nitrogen, potassium is the element that most influences the growth and production of sunflower dry biomass (Prado and Leal, 2006). The increase in agricultural productivity, resulting from the addition of potassium fertilizers to the soil, mainly varies with the amount of available K and soil fertility (Feitosa et al., 2013). However, the semiarid region is characterized by low natural soil fertility (Menezes and Oliveira, 2008). Thus, the use of supplementary fertilization is indispensable for obtaining good cropyields.

Potassium is a key element for most biological processes in a plant and when it is not available at the lowest dose, it can reduce the development of the crop and consequently its productivity (Malavolta et al., 1997; Castro and Oliveira, 2005). Therefore, it can be said that the quantity of the element present in the soil were sufficient for the nutritional requirements of the culture, and there was no optimization of the cultivation as according to the increased levels of this macronutrient.

The chlorophyll pigments are responsible for the conversion of light radiation energy in the form of ATP and NADPH; therefore, they are closely related to the photosynthetic efficiency of the plants and, consequently, their growth and adaptability to different environments. Present in higher plants under the “a” and “b” forms, the chlorophylls are constantly synthesized and destroyed, whose processes are influenced by internal and external factors to plants. Among the external factors, mineral nutrients stand, by integrating the molecular structure of plants but also by acting in some stage of the reactions leading to the synthesis of these pigments (Taiz and Zeiger, 2013).

The application of indirect chlorophyll meter Minolta SPAD-502 (Soil Plant Analysis Development) Minolta (1989) has been studied for several cultures and with satisfactory results on the evaluation of the nutritional state of N (Zotarelli et al., 2002). However, it is necessary to its calibration for each crop and in every situation. Several studies have shown that SPAD-502 can be used to indirectly assess the nutritional status of N and consequently infer about the need for fertilization of many cultures (Fox et al., 1994). In addition to N, other elements such as S, Mn and Fe cause chlorosis of the leaves, when they are at the adequate levels in plants, which highlight its importance in chlorophyll synthesis (Malavolta et al., 1997). SPAD readings provide a correlation with chlorophyll content in leaf. The values are calculated by the differential reading of the amount of light transmitted through a sheet in two wavelength regions (650 to 940 nm), and light absorption by chlorophyll occurs at the first wavelength (Swiader and Moore, 2002).

Several physiological indices are related to the use of water by plants. In this sense, rate of the photosynthesis and stomatal conductance are highlighted because an osmotic adjustment, such as stomatal closure, allows plants to escape from dehydration and turgor loss for maintaining the water content in the cells (Roza, 2010). Investigations concerning physiological characteristics responses of sunflower crop to water stress conditions are less conclusive (Silva et al., 2013). One way to find out whether the culture is under adequate growing conditions is related to the gas exchange of the plant because the plant under stress tends to reduce your cell water potential, performing the closing of the stomata and the formation of photoassimilates (Taiz and Zeiger, 2013).

Considering these facts, the objective of this work was to evaluate the growth, the physiological characteristics behavior through gas exchange and SPAD (Soil Plant Analysis Development) index, and the production of sunflower cv. Hélio 251 at different levels of water replacement and potassium doses.

MATERIALS AND METHODS

Location of the experiment

The experiment was carried out from November 2013 to January 2014 under greenhouse conditions at the Agricultural Engineering Department of the Federal University of Campina Grande, Paraiba State, Brazil located in the municipality of Campina Grande, Paraiba State with geographic coordinates 7º13’11’’ S, 35º53’31’’ W and altitude of 547.56 m.

Experimental design and treatments

The treatments were carried out in a randomized block design, in a 5 × 5 factorial experiment (five water replacement levels and five

Table 1. Mean values of plant height (PH), stem diameter (SD), number of leaves (NL), leaf area (LA), dry biomass of leaves (DBL), dry biomass of the stem (DBS), and SPAD index of sunflower due to the water replacement levels (%Etr) and doses of potassium (DK%).

%Etr	PH (cm)	SD (cm)	NL	LA (cm^2)	DBL (g)	DBS (g)	SPAD (%)
40	58.28	1.135	19.07	2785.71	0.76	0.29	50.28
60	61.27	1.281	20.47	3404.98	0.87	0.29	50.13
80	66.87	1.352	21.73	4032.77	1.29	0.33	50.48
100	69.22	1.439	22.80	4882.55	1.24	0.36	48.89
120	71.50	1.489	23.40	4871.48	1.16	0.33	48.15
DK%							
50	63.42	1.29	20.47	3665.75	1.09	0.34	49.00
75	65.01	1.35	21.67	3989.96	1.02	0.32	50.70
100	66.20	1.38	22.00	4155.49	1.22	0.31	50.17
125	66.49	1.34	21.53	4069.97	1.03	0.32	49.30
150	65.99	1.32	21.80	4069.32	0.94	0.30	48.75

potassium fertilization doses) with three repetitions, total of 75 experimental units. The treatments were water replacement levels corresponding to 40; 60; 80; 100 and 120% of actual evapotranspiration (ETr) and five potassium doses corresponding to 50; 75; 100; 125 and 150% of the indication for potassium application according to Novais et al. (1991), whereas 100% corresponds to 150 mg K kg^{-1} of soil.

The real crop evapotranspiration (ETr) was estimated from the drainage lysimeter as described by Bernardo et al. (2008). Therefore, consumption of water by plants was determined from the control treatment (ETr 100%), obtained from the difference between the applied volume and the anterior irrigation drained volume, resulting in consumed volume, when multiplied by the factors 0.4; 0.6; 0.8; 1.0 and 1.2, obtaining irrigation of 40, 60, 80, 100 and 120% of ETr, respectively. Furthermore, the application of water replacement levels began at 16 days after sowing.

Conduct of the study

Each experimental unit consisted of a plastic vase filled with 14 kg of soil with the following chemical characteristics according to the methodology of Embrapa (2011): pH (H_2O) = 5.8; Ca = 2.37 $cmol_c$ kg^{-1}; Mg = 3.09 $cmol_c$ kg^{-1}; Na = 0.37 $cmol_c$ kg^{-1}; K = 0.18 $cmol_c$ kg^{-1}; H + Al = 1.78 $cmol_c$ kg^{-1}; OM = 21.20 g kg^{-1}; P = 53.60 mg kg^{-1}.

Six sunflower seeds (cultivar Hélio 251) were sown on November 11, 2013 directly in the pots at a 2 cm depth. A simple hybrid with achenes striated color presents an average cycle of 100 days, average plant height of 1.87 m, and average yield under irrigation conditions of 4631 kg ha^{-1}(Aquino et al., 2013). Sixteen days after sowing (DAS), seedlings were thinned to two plants per pot.

In foundation, fertilizers were applied per pot: 8.07 g of monoammonium phosphate and urea 3.11 g, as indicated by Novais et al. (1991). The soil material after conditioning in the experimental units (pots) was moistened at field capacity. Potassium fertilization was divided into three times and applied via fertigation at intervals of seven days from 24 DAS, being applied per pot to treat 100% recommendation 23.2 g of potassium chloride.

Analyzed variables

When the plants reached the harvest stage (45 DAS) were evaluated the following components: plant height (PH) in cm; stem diameter (SD) in cm; number of leaves per plant (NL); leaf area (LA) in cm^2, measured by non-destructive method Maldaner et al. (2009) according to Equation 1; dry biomass of leaves (DBL), and dry biomass of the stem (DBS) (g) by drying in air forced circulation stove at a temperature of 65°C until constant weight; the relative chlorophyll content (SPAD index) with the use of a chlorophyll meter SPAD-502, in the second fully expanded leaf from the apex to the plant base.

$$LA = 0.1328 \times L^{2.5569} \qquad (1)$$

Where, LA = leaf area (cm^2); L = length of midrib of the leaves of each plant (cm)

Gas exchange was measured at 60 DAS on the third leaf from the apex, using portable equipment analysis through infrared (IRGA) and the following physiological characteristics variables were determined: Internal CO_2 concentration (Ci) (μmol m^{-2} s^{-1}), stomatal conductance (*gs*) (H_2O mol m^{-2} s^{-1}), transpiration (*E*) (H_2O mmol m^{-2} s^{-1}), and CO_2 assimilation rate (rate of the photosynthesis) (*A*) (μmol m^{-2} s^{-1}). Based on these data, it was determined the water use efficiency (WUE) (*A*/*E*) [(μmol m^{-2} s^{-1}) (mmol H_2O $m^{-2}s^{-1}$) $^{-1}$] (Carneiro, 2011; Silva et al., 2013).

Statistical analysis

The experimental data were analyzed by ANOVA. The data were subjected to analysis of variance using F test at 5% significance level for all analyzes. In case of significant effect, it was proceeded regressions (linear and quadratic). All analyses were performed using statistical software SISVAR (Ferreira, 2011).

RESULTS AND DISCUSSION

Variance of analysis

The means of the variables analyzed in this study are presented in Table 1. It can be observed that the higher values of % ETr (100 and 120) presented the highest mean values for PH, SD, NL, LA, DBL and DBS; on the other hand, the lowest values of % ETr (40, 60 and 80) presented the highest values for SPAD (%). However, based on the results presented in Table 2, it can be observed that the increase in water replenishment levels

Table 2. Test result of 'F' for plant height (PH), stem diameter (SD), number of leaves (NL), leaf area (LA), dry biomass of leaves (DBL), dry biomass of the stem (DBS), and SPAD index of sunflower due to the water replacement and potassium levels.

Source	F test						
	PH	SD	NL	LA	DBL	DBS	SPAD
Water replacement (RH)	**	**	**	**	**	**	*
Linear regression	**	**	**	**	**	**	**
Quadratic regression	ns	ns	ns	ns	*	ns	*
Doses of K (DK)	ns	ns	ns	ns	ns	ns	ns
Interaction (RH x DK)	ns	ns	ns	ns	ns	ns	ns
Block	ns	ns	ns	**	*	**	*
CV (%)	6. 48	6. 59	8. 44	12. 50	35.0	17.91	4.53

(**), (*); (ns) significant at (p≤ 0.01) and (p≤ 0.05); no significant, respectively, for the F test.

Table 3. Summary of the analysis of variance for the gas exchange variables: internal CO_2 concentration (Ci) (CO_2 mmol m^{-2}), stomatal conductance (*gs*) (mol H_2O m^{-2} s^{-1}), transpiration (*E*) (mmol H_2O m^{-2} s^{-1}), rate of the photosynthesis (*A*) (CO_2 µmol m^{-2} s^{-1}) and instantaneous water use efficiency (WUE) [(µmol m^{-2} s^{-1}) (mmol H_2O m^{-2} s^{-1}) $^{-1}$] at 60 DAS on the basis of irrigation levels and potassium fertilization.

Source	F test				
	Ci	*gs*	*E*	*A*	WUE
Water replacement (RH)	**	**	**	**	**
Linear regression	**	**	**	**	**
Quadratic regression	ns	ns	ns	ns	ns
Doses of K (DK)	ns	ns	ns	ns	ns
Interaction (RH x DK)	ns	ns	ns	ns	ns
Block	ns	ns	ns	ns	ns
CV (%)	23.43	24.49	15.31	29.84	37.19

(**), (*); (ns) significant at (p≤ 0.01) and (p≤ 0.05); no significant, respectively, for the F test.

(HR) had a significant effect on all variables for linear regression. On the other hand, there was no significant effect due to applied of potassium. For significant data, regression analyses were used with adjustment of the greatest determination coefficients (p ≤ 0.05). All analyses were performed using statistical software SISVAR (Ferreira, 2011): fertilizer levels (DK) and the interaction between HR x DK factors for any variable analyzed.

This result demonstrated that the doses of K behaved similarly in the different levels of irrigation used in this experiment, used, which may be related to low nutritional demand of sunflower early in the growing season, especially in the first 30 days after emergence (DAE) accordingly (Castro and Oliveira, 2005). However, Uchôa et al. (2011) studied the three production components of sunflower under different potassium doses in coverage and they found significant effect of potassium application on growth of the analyzed variables and production of sunflower. Corroborating Zobiole et al. (2010) mentioned that the greater absorption of potassium by sunflower occurs after 74 DAE. However, Uchôa et al. (2011) studying the three sunflower cultivars producing components subjected to various doses of potassium coverage, observed significant effect of potassium application on the growth and production of sunflower. The omission of K significantly reduced plant height, stem diameter, leaf area and dry biomass sunflower, as observed by Prado and Leal (2006).

The summary of the analyzes of variance of physiological characteristics sunflower responses regarding the effects of treatments for the results with the data of internal CO_2 concentration (Ci), stomatal conductance (*gs*), transpiration (*E*), rate of the photosynthesis (*A*), water use efficiency (WUE) and intrinsic water use efficiency are shown in Table 3, where there is the F test indicated that all physiologic variables were changed significantly (p <0.01) only by a factor water replacement. Thus, the potassium doses and the interaction did not affect gas exchange sunflower at 60 DAS.

Plant height (cm) and stem diameter (cm)

The increase in water replacement levels promoted linear

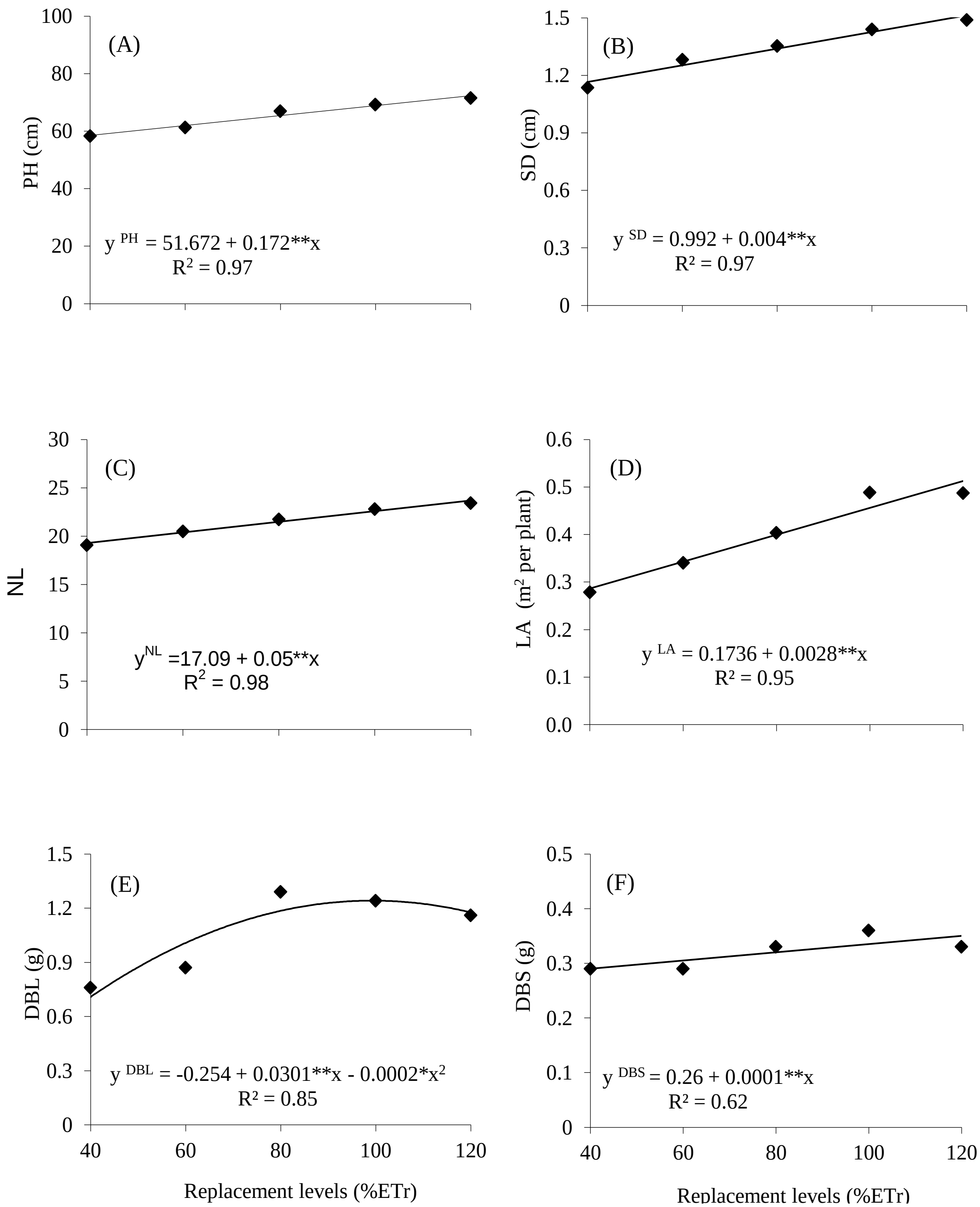

Figure 1. Plant height - PH (A), stem diameter - SD (B), number of leaves – NL (C), leaf area - LA (C), dry biomass of leaves - DBL (D) and dry biomass of stem - DBS (E) of sunflower as a function of water replacement levels - ETr%.

increase in plant height (PH) and stem diameter (SD) in sunflower plants (Figure 1A and B), corroborating by Viana et al. (2012) who found a linear increase on PH and SD sunflower plants cv. Catissol-01 with increasing water depth. The largest PH and SD values were 72.31 and 1.47 cm, respectively, with the level of ETr 120%, which corresponded to an increase respectively, 19.03 and 21.73% in relation to irrigation with 40% of ETr. Such results may be related to increased water potential of the cells, favoring larger cell elongation and hence increased growth. Accordingly, it was found that plant growth depends directly on the water absorption. The water inlet

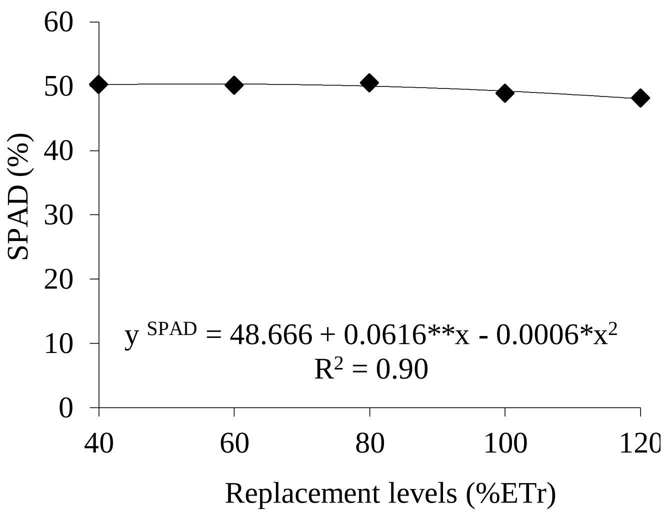

Figure 2. Sunflower SPAD index as a function of water replacement levels - ETr%.

in the cell produces an internal pressure, known as pressure or turgor potential (P or Ψp), which expands the protoplast from the cell wall may also increase the cell size (Taiz and Zeiger, 2013).

According to Nezami et al. (2008) water deficiency leads to reductions in water potential of stem cells composing until reaching a water potential level below the minimum necessary to trigger the cell elongation process of internodes resulting reductions in height and stem diameter of the plants. However, these values are lower than reported by Biscaro et al. (2008), who obtained at 45 days after seeding (DAS) the values of 1.84 and 114.7 cm to the PH and SD respectively in sunflower plants genotype Hélio358. Studying the same genotype, Gomes et al. (2010) obtained at 40 DAS values for PH and SD respectively, 101.22 and 1.97 cm.

Number of leaves and leaf area (cm^2)

The increase in irrigation water depths promoted linear increase in the number of leaves per plant (NL) and leaf area (LA), and the highest values obtained with the level of 120% of ETr, which corresponded to an increase respectively, 18.33 and 44.09% compared to the level of 40% of ETr (Figure 1C and D).

In this sense, it was found close connection between the NL and LA of sunflower plants. According to Taiz and Zeiger (2013) the water stress affects plant leaf expansion, which is dependent on the cell turgidity state. These results are consistent with those reported by Dutra et al. (2012), who observed an increase in NL and LA sunflower cv. Embrapa 122/V-2000 when subjected to higher water availability.

Despite the increase observed in the NL (23.57 leaves per plant) and LA (5120.8 cm^2 per plant), these values are lower than reported by Silva et al. (2012) who obtained at the 52 DAS 29.09 leaves per plant and LA 73121.6 cm^2 per plant of sunflower cv. Multissol grown without water stress.

Dry biomass of leaves and stems (g)

According to the regression equation (Figure 1E), it can be observed the adjustment in the quadratic model for dry biomass of leaves (DBL), which was observed an increase until the level of 75.25% ETr (0.88 g). From this value, there is little reduction in DBL. However, with regard to the dry biomass of the stem (DBS) (Figure1F), it was increased linearly with increasing water replacement levels, with higher values obtained when the plants were submitted to irrigation with the level of 120% of ETr (0.27 g), corresponding to an increase of 3.7% in relation to the application of 40% of ETr. According to Andrade and Abreu (2007) the production of dry biomass in sunflower is adversely affected by water deficit conditions due to adaptive physiological characteristics mechanisms, anticipation of leaf senescence that leads to restriction of leaf area, and consequently the surface area exposed to losses due to transpiration. In this sense, it is observed that the leaf expansion is very sensitive to water stress, being completely inhibited under moderate stress levels, a fact that severely affects the photosynthetic rates and, consequently, the biomass production of shoots. Similar results were reported by Dutra et al. (2012) which obtained an adjustment to the quadratic model for dry biomass and leaf and stem with the increase of the water supply. Oliveira et al. (2012) observed linear increase of dry weight of leaves and stems of sunflower cv. Embrapa 122 / V-2000 with the increase in levels of available water in the soil. Despite the dry biomass increase obtained with increasing water depths, the values are lower than those reported by Gomes et al. (2010), who obtained dry biomass values greater than 11 g in water stress conditions at 40 DAS.

SPAD Index

Regarding the SPAD index (Figure 2), there is better fit to the data for the quadratic regression model, where it was observed an increase until the level of 51.33% of ETr (50.24) corresponding to an increase of 0.15% compared to the level 40% of ETr. From this point, it was observed that there was a reduction of 5.63% in relation to the application of 120% of ETr. According to Dutra et al. (2012), the excessive increase of the water content in the soil can cause increased leaf senescence by elevating the concentration of abscisic acid and ethylene, and induces increase of chlorosis due to chlorophyll degradation. The Nezami et al. (2008) stated that water

stress causes an increase in sunflower SPAD index. However, the water restriction on reduction in chlorophyll content has also been reported in sunflower plants (Kiani et al., 2008).

The results obtained in this study for sunflower growth at 45 days after emergence point to the need to apply irrigation depths with values above the soil field capacity (100% ETr).However, the study in a protected environment prevents, in part, that the data obtained in field conditions are represented accurately, since there are alterations in climate conditions such as temperature, solar radiation, wind, humidity and atmospheric composition, interfering directly on evapotranspiration (ET). Inside the greenhouse, usually the ET is less than the one observed externally, which is justified by the partial opacity of the plastic cover to solar radiation and by reducing the action of the winds. According to Rosenberg et al. (1989), evapotranspiration inside a greenhouse is around 60-80% lower than the one observed externally.

Gas exchange

The drought conditions was decreased the amounts of gas exchange. Similar results have been reported by Cechin et al. (2010), who observed reduction in physiological characteristics variables such as rate of the photosynthesis, stomatal conductance and transpiration in sunflower leaves as a result of water stress. This contrasts the findings of Silva et al. (2013), which stated that the sunflower crop can be irrigated at 50% ET in all phenological phases without damage to the photosynthetic process, when they assessed gas exchange sunflower subjected to drought regimes at different growth stages.

Studies carried out by Silva et al. (2011) analyzed the influence of six irrigation levels on productive performance of two sunflower cultivars (Catissol-01 and Embrapa 122V-2000), and it was noted that most irrigation depth (150% evaporation of the class A pan) provided the greatest potential for producing achenes in both cultivars.

The regression analysis of means of variables related to gas exchange for the isolated effect of irrigation factor is presented in Figure 3. The linear model fitted the values of all variables, notably the change in internal CO_2 concentration (Figure 3A). Plants grown under 60% of the blade ETr maintained a higher carbon content in the internal substomatal camera with 299.73 μmol m^{-2} s^{-1}, decreasing 41.1% for water conditions imposed by the application 120% irrigation replacement. Possibly, these results were influenced by the CO_2 assimilation rate (rate of the photosynthesis -Figure 3D).

Plants with larger water supplies in the soil increased linearly the photosynthetic rate, increasing 7.36% as a unit in rate of the photosynthesis to each percentage of ETr applied in relation to lower water replacement. Thus, an increase in the demand for CO_2 was observed in plants irrigated with larger water replacement, reducing the Ci. Although significant, there is low variation in stomatal conductance and transpiration, as shown in Figure 3B and C, respectively. In this sense, the carbon input diffusion process for substomatal camera depends on the opening of the stomata, which reflects the transpiration (Machado et al., 2011; Taiz and Zeiger, 2013).

Since the gas exchanges are regulated through the stomatal movement, the external CO_2 absorption promotes increased transpiration; likewise, reduction of transpiration limits the carbon entering the camera substomatal (Shimazaki et al., 2007). Thus, it is necessary that the plants have higher water use efficiency, that is, the maximum absorbing CO_2 with minimal water loss (Jaimez et al., 2005; Taiz and Zeiger, 2013).

By analyzing the effect of applied irrigation water, it is verified that the reduction in water availability reduced the WUE (Figure 3E), the behavior was linear, with greater use in the assimilation of CO_2 per unit of water lost observed in 120% of ETr. Similar results were obtained by Brito et al. (2012) when evaluated the physiological characteristics behavior of citrus under water stress; these authors point out that achieving better physiological characteristics aspects enables greater formation of biomass plants.

In this sense, these results are consistent with those reported by Soares et al. (2015) to assess the biomass of sunflower cv. 'Hélio 251' on the basis of irrigation with different levels of fluid replacement and potassium fertilization, where it was observed that the fluid replacement levels up to 120% of ETr linearly increased the mass of the total seeds and mass of hundred sunflower seeds.

Conclusions

Under experimental conditions, the application of potassium in the soil did not influence the growth and production of sunflower cv. Hélio 251. The growth and production of sunflower cv. Hélio 251 was significantly influenced by increasing water replacement levels. The level of 75.25% of ETr provided the highest DBL (0.88 g). Increasing water replacement from 51.33% ETr provided a reduction in the SPAD index. Potassium fertilization as the conditions of this study does not alter gas exchange in sunflower plants in the grain filling stage. Water replacement lower than 100% ETr affected gas exchange of sunflower plants, reducing rate of the photosynthesis by 66% by the water deficit in the soil. The largest values of rate of the photosynthesis and instantaneous water use efficiency was 17.181 CO_2 μmol m^{-2} s^{-1} and 6.00 μmol m^{-2} s^{-1} / mmol $m^{-2}s^{-1}$ H_2O as a result of 120% ETr

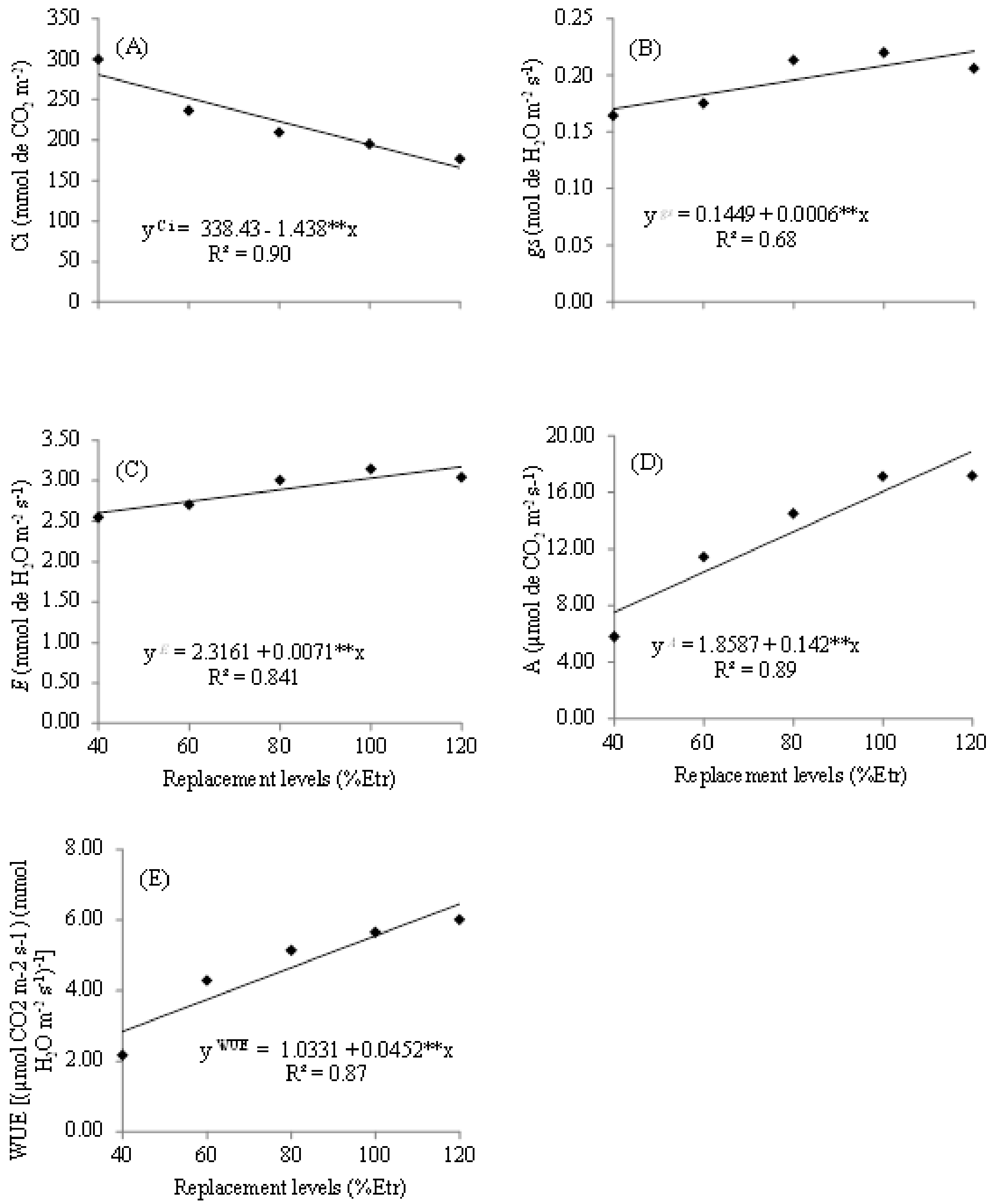

Figure 3. Regression analysis for values of variables: (A) internal concentration (Ci) of CO_2 (CO_2mmol m^{-2}) (B) stomatal conductance (*gs*) (H_2O mol m^{-2} s^{-1}) (C) transpiration (*E*) (H_2O mmol m^{-2} s^{-1}), (D) rate of the photosynthesis (*A*) (CO_2 µmol m^{-2} s^{-1}) and (E) water use efficiency (WUE) [(µmol m^{-2} s^{-1}) (H_2O mmol m^{-2} s^{-1}) $^{-1}$] at 60 as a function of water replacement (% ETr).

water replacement.

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Abbreviations

PH, Plant height; **SD,** stem diameter; **NL,** number of leaves per plant; **LA,** leaf area; **DBL,** dry biomass of leaves; **DBS,** dry biomass of the stem; **ETr,** real crop evapotranspiration; **SPAD** index, relative chlorophyll content; **DAS,** days after sowing; **Ci,** CO_2 concentration; ***gs*,** stomatal conductance; ***E*,** transpiration**;** ***A*,** CO_2 assimilation rate; **WUE,** water use efficiency.

Conflict of Interests

The authors have not declared any conflict of interest.

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