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Gas exchange, growth and yield of cowpea genotypes under different irrigation strategies

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Water availability is a major limiting factor for cowpea bean crops, especially in semiarid regions, where it is necessary to adopt more productive and tolerant genotypes and efficient strategies for water use. Thus, an experiment was carried under field conditions in the semiarid region of Pombal city, PB, Brazil. Using a completely randomised blocks design experiment and four replications, in a factorial scheme. The first factor was formed by four cowpea beans genotypes (Costela de Vaca, Pingo-de-Ouro, Paulistinha and BRS Marataoã), and the second factor consisted of five different irrigation strategies (40, 60, 80, 100 and 120% of actual evapotranspiration (ETr)). Gas exchange was evaluated at the V4 stage, dry biomatter formation at the R2 stage and crop yield until 90 days after sowing. The gas exchange from cowpea genotypes was reduced by lower irrigation amounts. For dry biomass formation, greater values in the Pingo-de-Ouro genotype were observed when irrigated with 120% of ETr. Thus, the treatment of 120% ETr improved the growth in dry matter independently of the genotype. The Costela de Vaca genotype had better CO_2 assimilation rates. Paulistinha had the highest productivity among genotypes, and Costela de Vaca had the greatest water use efficiency.

Key words: Assimilation rate, *Vigna unguiculata*, water productivity.

INTRODUCTION

Beans have contributed significantly to the food and economic establishment of humankind due to their market potential, directly and indirectly generating income for small farmers, especially family farms (Agrianual, 2006). The Brazilian north-eastern region has an average cowpea bean yield of about 330 kg ha^{-1} (Freire et al., 2005), which is considered low, since yield potential can reach 3000 kg ha^{-1}, depending on the cultivar (Oliveira et al., 2001; Salgado et al., 2011).

In reality, some studies have pointed out yield improvements when using appropriate irrigation levels (Andrade Junior et al., 2002; Tagliaferre et al., 2013; Dutra et al., 2015). Thus, for good production, irrigation should be used to give crops water they need or techniques should be used to maintain soil moisture to sustain plants growth and production cycles.

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Thus, cultivation in dry season is made possible by irrigation systems, which have great advantages compared to rainfed agricultural systems that causes environmental problems and encumber the cost of irrigated crops (Moura and Oliveira, 2013; Almeida and Costa, 2014).

It is also known that some crops produce economically viable yields even under soil water deficit, while others are sensitive to relatively low water scarcity. This difference could be due to factors related to the root system, especially elements that determine its growth, such as soil physical characteristics, plant genetic characteristics and irrigation systems management (Bernardo et al., 2008). It should be noted that identification of germplasm with water stress tolerance is of interest to breeding programmes, and knowledge of mechanisms related to such differential responses is important.

Therefore, it is important to study potential genotypes through physiological, growth and crop production characteristics to select drought-tolerant genotypes using these variable types (Shaker et al., 2013; Dutra et al., 2015).

Taking into account the importance of cowpea production in the semiarid region of the Brazilian Paraíba state and the need for improved water use efficiency in irrigated production systems, it is necessary to intervene in order to identify improved genotypes, allying productive potential and drought tolerance cultivars, which can optimised water use.

In order to study the ecophysiological behaviour of cowpea genotypes, it is necessary to identify and classify the genotypes regarding their water stress tolerance through growth, gas exchange and yield production while identifying the genotype that provides the greatest water use efficiency.

MATERIALS AND METHODS

The experiment was carried out at the Center of Agrifood Science and Technology - CCTA, Federal University of Campina Grande - UFCG, Pombal city, PB state (6°47'20" S latitude and 37°48'01" W longitude, altitude of 194 m). According to the Köppen classification system, the region has a BSh (hot and dry semiarid) climate, common in semiarid regions.

The experimental design was laid out in a randomized complete block with treatments distributed in a factorial scheme, 4 × 5, corresponding to four cowpea genotypes (Costela de Vaca, Pingo-de-Ouro, Paulistinha and BRS Marataoã) and five irrigation strategies (40, 60, 80, 100 and 120% of actual evapotranspiration (ETr)), with four replications. Irrigation depth differentiation was initiated 15 days after sowing (DAS), and lasted until 90 DAS, consisting of vegetative (V) and reproductive (R) crop stages. The fruit maturation cycle can last up to 90 days depending on the cultivar (Freire et al., 2005).

Costela de Vaca, Pingo-de-Ouro and BRS Marataoã genotypes have indeterminate growth habits and grow in a prostrate manner. The Paulistinha genotype has determinate growth and grows in an erect manner. It should be noted that the BRS Marataoã cowpea genotype came from the breeding programme of Embrapa Meio Norte. The other genotypes were acquired from local producers, as they were commonly grown in the region.

Reference evapotranspiration determination was conducted through soil moisture balance from daily readings using a dielectric diffusivity moisture meter. A sensor was installed in each plot that was designed to receive the 100% ETr irrigation strategy. Thus, irrigation amount (Li) corresponded to the difference between maximum moisture ($cm^3\ cm^{-3}$) (Ɵcc) and current humidity ($cm^3\ cm^{-3}$) (Ɵa). The result was multiplied by the root system depth (Z) and expressed in millimetres, using expression 1 (Equation 1).

In order to determine irrigation amounts in treatments relative to strategies of 40, 60, 80 and 120% of ETr, the value obtained in Eq. 1 was multiplied by coefficients of 0.4, 0.6, 0.8 and 1.2, respectively. The 20 treatments totalled 80 experimental plots with dimensions of 10.8 m^2 (3.6 m × 3.0 m). Sowing involved using double-row spacing, 0.6 × 0.3 × 0.2 m, which allowed for deployment of 144 plants per plot (10.8 m^2), totalling a planting density of 111111 plants ha^{-1}. However, assessments were conducted in four plants per plot, constituting, in sum, an experimental area of 864 m^2. A soil sample was then taken from the 0 to 20-cm-deep layer for chemical characterisation; soil data are shown in Table 1 and were used for plant nutritional management.

During nutritional management, basal dressing was conducted through soil analysis results using 64 g of single superphosphate per linear metre, as recommended by Freire et al. (2005). It is noteworthy that there was no nitrogen or potassium top-dressing application in order to stimulate *Nitrobacter* growth to supply nitrogen. A drip irrigation system was installed inside the double rows using drip tapes with a flow rate of 1.62 L h^{-1} per dripper, with 0.2-m spacing on the tape. After installation, a distribution uniformity test (DUT) was carried out following the methodology by Bernardo et al. (2008), obtaining a DUT of 92%.

Before each irrigation event, soil moisture sensors were taken in the plots from the control treatment (100% ETr) in order to calculate irrigation amounts. In addition, sensors were installed to monitor humidity, obtaining data of available water during the experimental period (Figure 1A). A decrease in available water was observed over time due to an increase in plant absorption, which was replaced by the irrigation water (Figure 1B), as can be seen in the different amounts applied with each irrigation. Regarding moisture behaviour during the evaluation period, overlap in the values was observed, especially in the 100 and 120% irrigation levels, suggesting that the soil only retains its maximum capacity (field capacity). Values above maximum capacity were caused by water loss due to percolation. In addition, during the experimental period, a rain event occurred 7 mm at 52 DAS, which has increase in available water (Figure 1A).

The irrigations amounts are presented in Table 2, with the mean between genotypes. Water demands of 135.7, 203.6, 271.5, 339.4 and 407.3 mm in the irrigation strategies of 40, 60, 80, 100 and 120% of ETr, respectively, which were obtained by the sum of the intake throughout the crop production cycle were presented. Among agronomic practices, weeding was conducted using specific herbicides for cowpea crops. This occurred in addition to pest and disease control with preventive applications of pesticides.

Gas exchange measurements were determined at the V4 stage when the plants had four definitive trifoliates. Specifically, CO_2 assimilation rate (*A*) ($\mu mol_{CO2}\ m^{-2}\ s^{-1}$), transpiration (*E*) ($mmol_{H2O}\ m^{-2}\ s^{-1}$), stomatal conductance (*gs*) ($mol_{H2O}\ m^{-2}\ s^{-1}$) and internal CO_2 concentration (*Ci*) ($\mu mol\ mol^{-1}$) in the first mature leaf from the apex, using the infrared gas analyser of an ADC Bio Scientific Ltd. LCpro+, were assessed. With these data, instantaneous water use efficiency (*iWUE*) (*A/E*) [($\mu mol_{CO2}\ m^{-2}\ s^{-1}$) ($mmol_{H2O}\ m^{-2}\ s^{-1})^{-1}$] was quantified (Brito et al., 2012).

When the R2 flowering stage was reached (45 DAS), with flowers in the bean pod stage, plants were assessed with respect to biomatter and nodulation. Two plants were removed from each plot, regardless of those used in growth assessments, partitioned,

Table 1. Chemical characteristics of soil used for evaluation of cowpea genotypes under irrigation strategies. Pombal, PB, 2015.

pH	EC	P	N	K	Na	Mg	Al	Ca
$CaCl_2$ 1:2.5	**dS m^{-1} 1:5**	**mg dm^{-3}**	**%**	**---------------------cmolc dm^{-3}--------------------**				
6.13	0.09	102	1.70	0.50	0.09	3.35	0.10	5.15
H + Al	**SB**	**(t)**	**(T)**	**V**	**m**	**NaRS**	**MO**	**-**
----------------cmolc dm^{-3}----------				**-----%---------**				**-**
2.97	9.00	9.10	12.06	74.63	0.83	0.75	29.00	-

EC: Electrical conductivity; P: phosphorus; N: nitrogen; K: potassium; Na: Sodium; Mg: Magnesium; Al: Aluminium; Ca: Calcium; SB: Sum of bases; t: efetive Cation Exchange Capacity; T: Cation Exchange Capacity; V: percent base saturation; m: percent aluminium saturation; NaRS: sodium rate saturation; OM: organic matter.

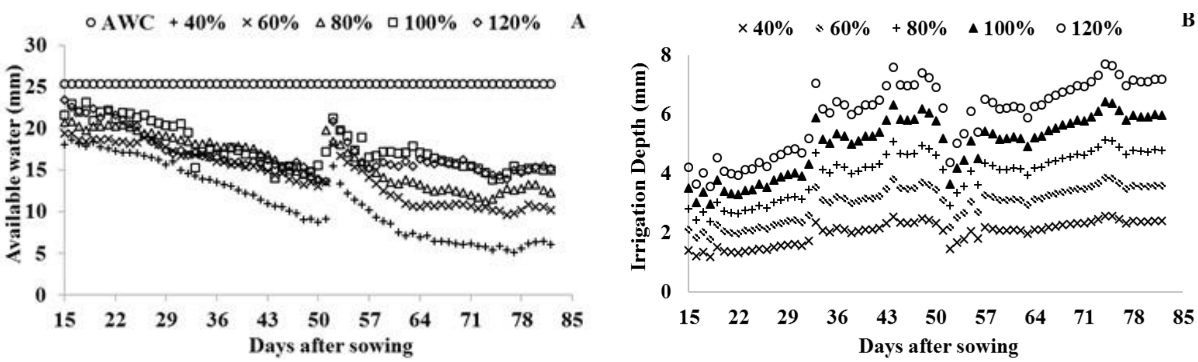

Figure 1. Daily available water in the soil (mm) (A) and irrigation depth (mm) (B) applied daily to cowpea bean genotypes subjected to different irrigation strategies (Pombal, PB, 2015. AWC = available water content; strategies: 40, 60, 80, 100 and 120% of actual evapotranspiration (ETr)).

Table 2. Irrigation amounts (mm) from irrigation strategies applied to cowpea bean genotypes. Pombal, PB, 2015.

Variable	Irrigation strategies (% ETr)				
	40 (%)	**60 (%)**	**80 (%)**	**100 (%)**	**120 (%)**
Irrigation amount (mm)	135.7	203.6	271.5	339.4	407.3

placed inside a forced air circulation oven at 65°C for 72 h and weighed afterward on an analytical balance in order to determine leaf (LDB), petiole (PDB), stem (SDB), root (RDB) and nodule (NDB) dry biomatter. The sums of these biomatter values and total biomatter (TDB) were determined and data expressed in grams per plant.

It should be noted that root collection to determine RDB was performed through the removal of a soil volume corresponding to the plant area (0.6 × 0.3 × 0.2 m) at a depth of 30 cm. The material was washed and sieved in order to keep only roots, same procedure were adopted for all plots.

Yield was assessed in dried beans. Therefore, pods of four plants per plot were harvested and stored during the production cycle until 90 DAS. Dried pods were collected at intervals of 7 days. In each collection, grain weight per plant was obtained. At the end of the experiment, the whole grain yield per plant was summed. Yield value was estimated with the multiplication of grain weight per plant by the number of plants per hectare, in which data were shown as kilograms per hectare.

Data variability were analyse using ANOVA. With F-test for significance, regression analysis was used for irrigation strategies. For the genotype factor, Tukey's test was used at the 5% probability level, using SISVAR software (Ferreira, 2011).

RESULTS AND DISCUSSION

Relative to cowpea plant gas exchange under water stress, was observed a significant interaction effect to *gs*, *E*, *A* and *iWUE* variables, according to ANOVA (Table 3). However, an isolated effect of factors was not observed

Table 3. Summary of analysis of variance for internal CO_2 concentration (*Ci*), stomatal conductance (*gs*) (mol_{H2O} m^{-2} s^{-1}), transpiration (*E*) ($mmol_{H2O}$ m^{-2} s^{-1}), assimilation rate (*A*) (µmol m^{-2} s^{-1}) and instantaneous water use efficiency (*iWUE*) (*A/E*) [($µmol_{CO2}$ m^{-2} s^{-1}) ($mmol_{H2O}$ m^{-2} s^{-1})$^{-1}$] from cowpea genotypes under different irrigation amounts at the V4 vegetative stage. CCTA/UFCG, Pombal, PB, 2015.

Control factor	DF	Mean square				
		Ci	***gs***	***E***	***A***	**iWUE**
Genotype (G)	3	2.687^{ns}	0.001^{ns}	0.027*	0.231^{ns}	0.008^{ns}
Depth (ID)	4	4.228^{ns}	0.024**	0.158**	3.028**	0.088^{ns}
G × ID	12	5.890^{ns}	0.002**	0.018**	0.869**	0.154**
Block	3	6.597^{ns}	0.002*	0.146**	0.715**	0.231*
Error	57	3.085	0.001	0.007	0.109	0.058
CV (%)		12.49	2.83	4.10	6.77	8.25
Mean		140.66	11.68	20.09	48.63	29.19

DF = degrees of freedom; CV = coefficient of variation; **, * and ns = significance to 1%, 5% and non-significant by F-test, respectively.

in the latter two variables. In addition, differences in *E* ($mmol_{H2O}$ m^{-2} s^{-1}) among genotypes ($p \leq 0.05$) were observed. As for the irrigation amount factor, isolated effects stood out regarding *gs* (mol_{H2O} m^{-2} s^{-1}), *E* ($mmol_{H2O}$ m^{-2} s^{-1}) and *A* values ($µmol_{CO2}$ m^{-2} s^{-1}) ($p \leq 0.05$).

The aforementioned variables were measured at the V4 growth stage, which occurred near 30 DAS, about 15 days after differentiation of irrigation strategies began. This shows the importance of gas exchange evaluation in describing water stress effects on the CO_2 influx process. From studying the effects of irrigation amounts on *gs* of each genotype (Figure 2), an increasing linear behaviour was observed in all genotypes, with the exception of Paulistinha. Specifically, 0.058, 0.056 and 0.052 mol_{H2O} m^{-2} s^{-1} from 20% ETr irrigation increased *gs* values of Costela de Vaca, Pingo-de-Ouro and BRS Marataoã genotypes, respectively. In Paulistinha, there was quadratic behaviour, with maximum conductance obtained by applying an irrigation level equivalent to 93.5% ETr.

However, in general, all studied genotypes, even with a 40% Etr irrigation strategy application, showed higher results than those reported by Nascimento et al. (2011), who found values from 0.03 to 0.11 mol_{H2O} m^{-2} s^{-1} when plants were under stress in the reproductive stage. However, the differences may be related to time of stress, as the authors conducted plant evaluations at 43 DAS. Moreover, as noted by the results, water deficit tends to reduce the water flow and, consequently, cell turgidity, providing stomatal closure, which implies *E* and CO_2 influx reductions, as explained by Taiz and Zeiger (2013).

By studying *E* (Figure 2), it was observed that all genotypes were significantly influenced by irrigation levels. In Costela de Vaca and Pingo-de-Ouro, increasingly linear behaviour was observed, with 0.144 and 0.196 $mmol_{H2O}$ m^{-2} s^{-1} increases in *E* values, respectively, for every 20% increase in ETr. Such an *E* increase may indicate higher *A*. However, if it does not occur, water use efficiency tends to decrease. Thereby, net photosynthetic data should be considered when assessing whether this increase is interesting for plants. There is a tendency for water to transform from liquid to gas depending on the water vapour concentration difference between the leaf intercellular spaces and outer air mass (Taiz and Zeiger, 2013), which is optimised with increased water availability.

Regarding *E*, quadratic behaviour was observed for Paulistinha and BRS Marataoã genotypes, with maximum *E* obtained when irrigated with 101.75 and 99.83% ETr, respectively, which can be explained by the fact that plants showed an *E* rate decrease above ideal humidity conditions. This may be attributed to water saturation in the soil, which may have limited the absorption by roots, since water inflow depends on gas exchange conditions in the soil (Taiz and Zeiger, 2013). Even limitations regarding nitrogen accumulation and fixation in the plant may occur (Guimarães et al., 2015).

When analysing *A* (Figure 2), quadratic behaviour can be observed in Costela de Vaca, Paulistinha and BRS Marataoã genotypes, with maximum photosynthetic rates obtained when irrigation was conducted with levels estimated at 83, 100, and 105% ETr, respectively, obtaining 28.97, 26.994 and 25.6 µmol m^{-2} s^{-1}, respectively. These results are higher than those found by Dutra et al. (2015), who studied gas exchange in cowpea under different water levels and found means between 15 and 21 µmol m^{-2} s^{-1} while studying BRS Marataoã. This fact may be attributed to the experimental conditions, as these authors varied levels in relation to reference evapotranspiration, while actual evapotranspiration was used in this paper, indicating that crop water demand should be lower than the atmospheric demand (that is, the crop coefficient (Kc) must be lower than 1.0). It is worth noting that the aforementioned genotypes,

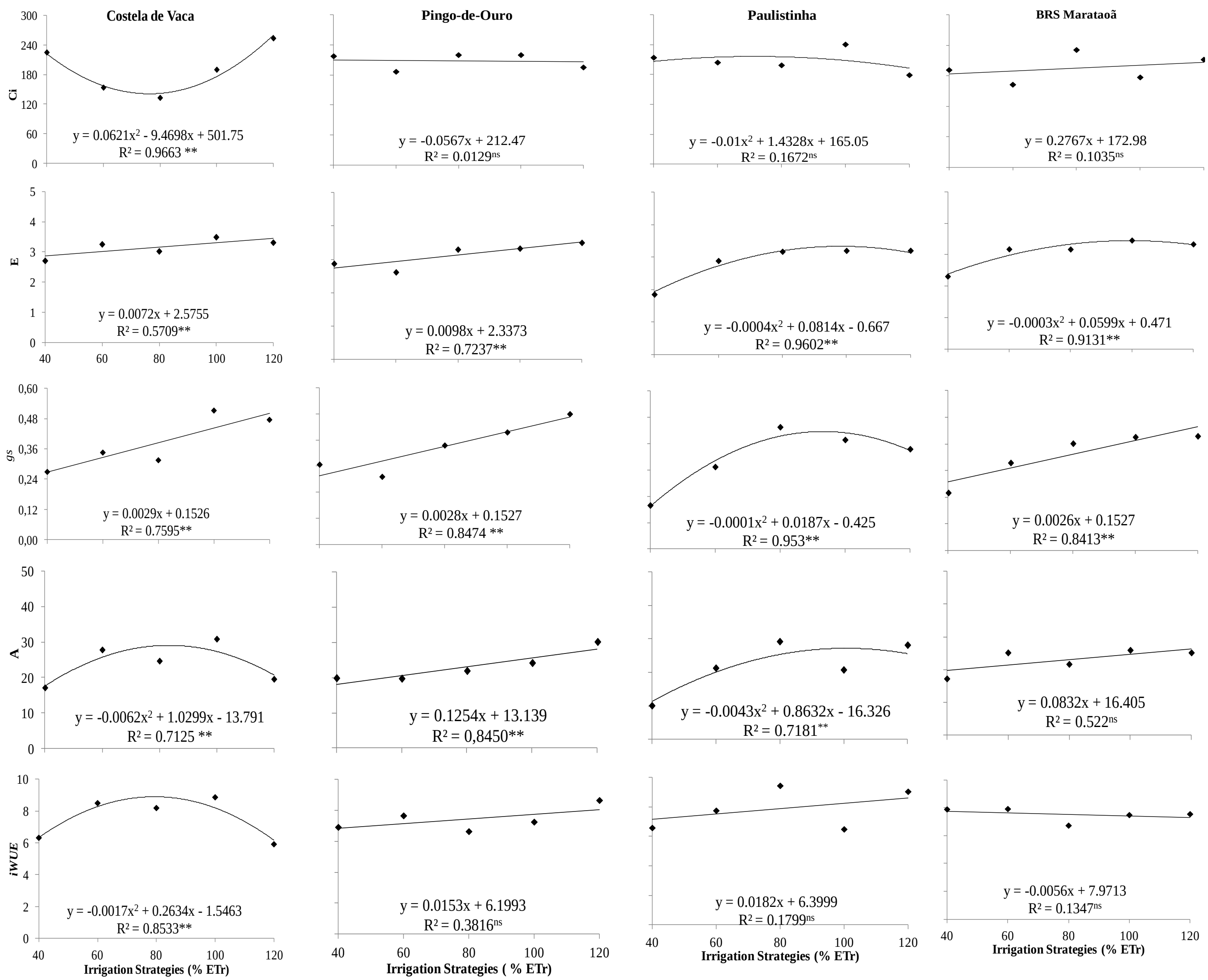

Figure 2. Regression analyses relative to internal CO_2 concentration (*Ci*), stomatal conductance (*gs*) (mol_{H2O} m^{-2} s^{-1}), transpiration (*E*) ($mmol_{H2O}$ m^{-2} s^{-1}), assimilation rate (*A*) (μmol_{CO2} m^{-2} s^{-1}), instantaneous water use efficiency (iWUE) (*A*/*E*) [(μmol_{CO2} m^{-2} s^{-1}) ($mmol_{H2O}$ m^{-2} $s^{-1})^{-1}$] and instantaneous carboxylation efficiency (EiCi) (*A*/*Ci*) from cowpea genotypes under different irrigation amounts at the V4 vegetative stage 45 DAS. CCTA/UFCG, Pombal, PB, 2015.

under stress conditions by deficit and excess water, had a tendency to reduce *A*, corroborating information by Freire (2005), who highlighted that lack of or excess water directly harms plant development.

Regarding the Pingo-de-Ouro genotype, it can be inferred that the 20% linear increase in irrigation amount allowed for an increase of 2.508 µmol m^{-2} s^{-1} in *A*. This result can be explained by the fact that the genotypes were conditioned to higher available water in the soil, increased *gs* and *E*, as noted by Ferraz et al. (2012). This result is interesting, as it may mean greater production potential in growing conditions in which there are no water restrictions.

With respect to water use efficiency, quadratic behaviour was observed for the Costela de Vaca genotype, with maximum efficiency estimated at the 77% ETr level, with a value of 8.65 ((μmol_{CO2} m^{-2} s^{-1}) ($mmol_{H2O}$ m^{-2} $s^{-1})^{-1}$). For Jaimez et al. (2005), the relationship between photosynthetic rate and *E* indicates the *iWUE*, in which values relative to carbon fixed in the plant by each water unit lost are observed. It can be seen that an increase in stomatal chamber conductance allowed for *A* up to the mentioned level, which is due to low CO_2 concentrations, reducing *iWUE*, which is, in turn, related to increases in *gs* and *E*. In a similar situation, Nascimento et al. (2011) observed a reduction in *gs* values when cowpea plants were maintained under low hydric potential, resulting in lower production.

In Pingo-de-Ouro and Paulistinha genotypes, increasing linear behaviour was observed. Specifically, increases of about 0.0153 and 0.0182 ((μmol_{CO2} m^{-2} s^{-1}) (mol_{H2O} m^{-2} s^{-1})$^{-1}$) with each unit increase in ETr strategy were observed. This fact is interesting especially for Pingo-de-Ouro, in which photosynthesis and *E* increases also were observed, indicating that this genotype can produce better under higher irrigation amounts. Thus, Pingo-de-Ouro is more suitable for conditions without water availability restrictions. Moreover, in all genotypes, mean values were higher than those found by Ferraz et al. (2012), who observed an average of 4.3 ((μmol_{CO2} m^{-2} s^{-1}) ($mmol_{H2O}$ m^{-2} s^{-1})$^{-1}$) in the time from 9 a.m. to 10 a.m., showing the potential of these genotypes and of the region for cowpea cultivation.

By studying biomatter formation of cowpea genotype plants under water stress through ANOVA (Table 4), there was no significant interaction between factors of any variable studied. However, significant differences were observed between cowpea genotypes for PDB, SDB, RDB, NDB and TDB. A significant effect of irrigation amount also was observed in all variables, with the exception of RDB. Thus, cowpea biomatter sensitivity is observed when exposed to low water availability in the soil, providing variables that are recommended to determine water stress in cowpea.

Sensitivity may be related to plant adaptation mechanisms to tolerate stress by reducing the leaf area and reducing photosynthetic area and biomatter formation, avoiding increased *E* and controlling its temperature in the environment (Taiz and Zeiger, 2013). Biomatter formation effects also were observed by Dutra et al. (2015), who studied cowpea under different irrigation levels, and by Vale et al. (2012), who evaluated water stress tolerance in common bean, confirming the importance of these variables in the definition of stress conditions. It also should be noted that biomatter was evaluated at the R2 stage, corresponding to 45 DAS, which confirms that water stress affects cowpea plants with an increased exposure period.

By studying PDB, SDB, RDB and TDB formation (Figure 3) in relation to genotypes, significant differences are noted. The highest means were observed for Pingo-de-Ouro for all of these variables, with the exception of NDB, which had the lowest mean. Moreover, it should be noted that BRS Marataoã and Costela de Vaca genotypes did not differ from Pingo-de-Ouro in SDB and TDB variables. These results, therefore, confirm the biomatter formation potential of genotypes with indeterminate growth characteristics, which was more marked in Pingo-de-Ouro. This is of great importance if producing matter for incorporation into the soil is desired.

Although the lowest TDB mean was observed in the Paulistinha genotype, this may be due to its the ‘determinate’ growth type, which has the advantages of mechanised and regular harvest possibilities. It is therefore necessary to evaluate production aspects and production system objectives before choosing the most suitable variety. Although greater dry matter formation was observed for Pingo-de-Ouro, it was noted that this genotype had the lowest NDB, which indicates these plants had more efficient nodulation. Thus, the plants form more dry matter with fewer nodules, which is interesting for breeding programmes or identification studies for the corresponding microorganisms. Regarding irrigation level effects, there was increasing linear behaviour with increasing water availability to plants in all matter accumulation variables studied (Figure 4).

The 120% ETr level provided the most dry matter accumulation, with increases in the order of 95.5, 45.9, 62.3, 120, 13.1 and 70.7% between the lowest and the highest water levels for LDB, PDB, SDB, RDB, NDB and TDB, respectively. Thus, it was observed that higher water availability ensures higher water influx and cellular turgor maintenance, providing conditions for plant growth by cell division and expansion (Taiz and Zeiger, 2013). Significant effects of genotype $\times$ irrigation strategy interaction were observed for cowpea yield as well as isolated effects of studied factors (Table 5). For Cordeiro et al. (1998), the cowpea filling stage is the most sensitive to water stress, which justifies such interaction effects.

By studying yield, differential behaviours of genotypes when subjected to irrigation strategies (Figure 4) were observed. In this sense, the highest yields were observed when irrigation was conducted with levels equivalent to 120% ETr in Pingo-de-Ouro and Paulistinha genotypes, relative to 407.2 mm during the production cycle, which provided an estimated yield of 2025 and 3000 kg ha-1, respectively. In relation to Pingo-de-Ouro, it is emphasised that linear behaviour was observed in most physiological variables, indicating that this genotype needs more water to express its productive potential. However, by applying the same water amount, higher yield was obtained with the Paulistinha genotype, which may be indicated as a cowpea genotype for semiarid climates, where there are water restrictions.

In the BRS Marataoã and Costela de Vaca genotypes, quadratic behaviour was observed, with maximum yields expressed with levels estimated of 97 and 92% ETr, respectively, resulting in estimated values of 1835.23 and 2634.09 kg ha^{-1}, respectively, demonstrating the potential of these genotypes, although they were lower than those obtained with Paulistinha.

On the other hand, the Costela de Vaca genotype produced 2634.09 kg ha^{-1} using a 92% ETr level, which equals 312.2 mm, while Paulistinha produced 3000 kg ha^{-1} with 407.2 mm. Thus, Costela de Vaca produced 0.843 kg of grain for each 1.0 m^3 of water consumed, while Paulistinha produced 0.736 kg for each 1.0 m^3 of

Table 4. Summary of analysis of variance for dry biomatter of leaves (LDB), petioles (PDB), stems (SDB), roots (RDB) and nodules (NDB) and total dry biomatter (TDB) expressed as grammes per plant from cowpea genotypes under different irrigation amounts until 45 days after sowing. CCTA/UFCG, Pombal, PB, 2015.

Control factor	DF	Mean square					
		LDB	PDB	SDB	RDB	NDB	TDB
Genotype (G)	3	1.629^{ns}	5.717**	5.021**	0.175**	0.008*	6.460**
Depth (ID)	4	4.019**	3.502**	1.472**	0.024^{ns}	0.015**	5.785**
G × ID	12	0.550^{ns}	0.058^{ns}	0.324^{ns}	0.015^{ns}	0.002^{ns}	0.801^{ns}
Block	3	0.125^{ns}	0.086^{ns}	0.913^{ns}	0.041^{ns}	0.004^{ns}	0.799^{ns}
Error	57	0.601	0.040	0.253	0.024	0.002	0.812
CV (%)		18.62	9.05	14.15	8.85	4.11	15.12
Mean		4.16	2.22	3.56	1.75	1.10	5.96

DF = degrees of freedom; CV = coefficient of variation; **, * and ns = significance to 1%, 5% and non-significant by F-test, respectively.

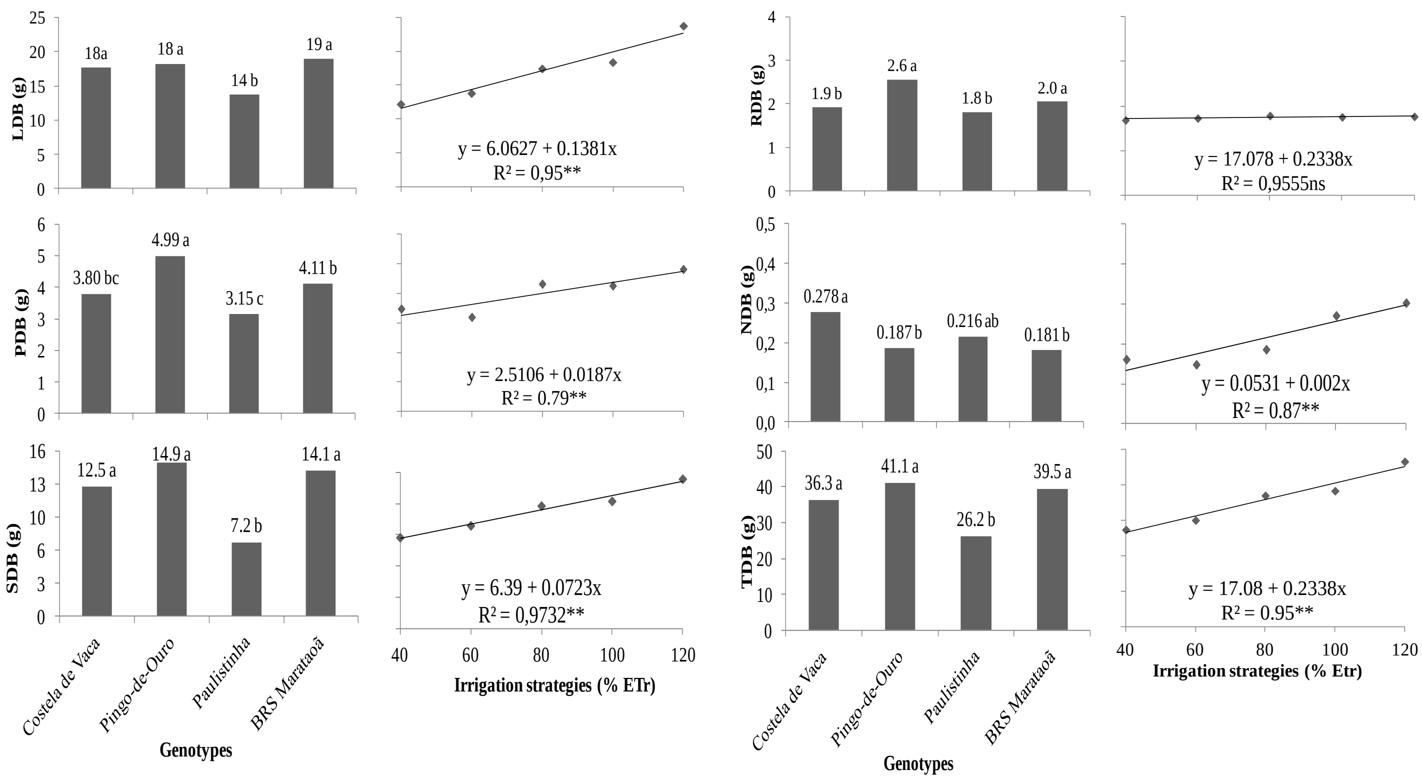

Figure 3. Means based on Tukey's test (p > 0.05) between cowpea genotypes and regression analyses regarding irrigation strategies for leaf (LDB) (g), petiole (PDB) (g), stem (SDB) (g), root (RDB) (g) and nodule (NDB) (g) dry biomatter and total dry biomatter (TDB) (g) until 45 days after sowing. CCTA/UFCG, Pombal, PB, 2015.

water, with better water use efficiency with Costela de Vaca.

Furthermore, BRS Marataoã yield values were slightly higher than those observed by Dutra et al. (2015), who obtained a maximum yield of 1715 kg ha^{-1} when levels equivalent to 100% ETr were applied to the same genotype. In general, the results observed in this study were higher than those observed by Silva and Neves (2011), who found values ranging from 668.70 to 1070.3 kg ha^{-1}, and higher than those reported by Nascimento et al. (2011), who observed a mean yield of 1167 kg ha^{-1}, with variation from 663 to 1529 kg ha^{-1} between genotypes without water stress. Those comparisons show the cultivation potential of these varieties in semiarid regions and the potential of appropriate water use in irrigation.

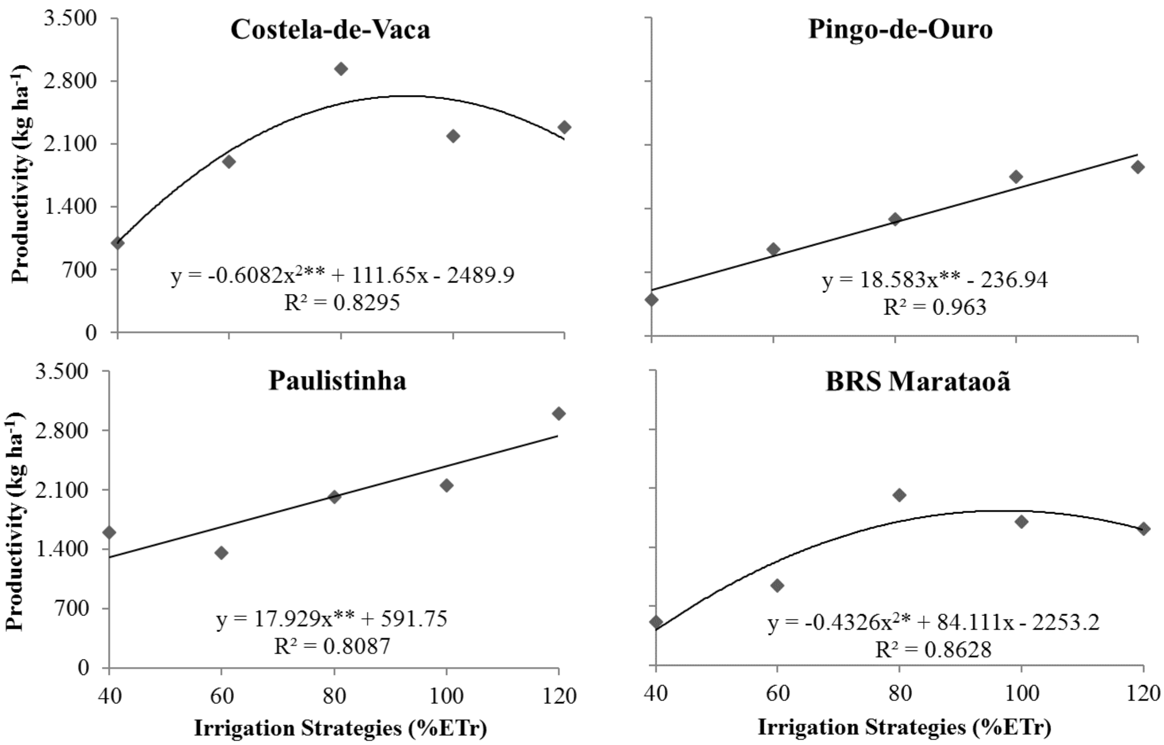

Figure 4. Regression analyses relative to yield (kg ha^{-1}) from cowpea genotypes under different irrigation strategies until 90 days after sowing. CCTA/UFCG, Pombal, PB, 2015.

Conclusions

The highest growths in cowpea were observed in Costela de Vaca and Pingo-de-Ouro genotypes for leaf and dry biomatter formation, respectively. Among the evaluated characteristics, the leaf formation on cowpea genotypes was found to be the most sensitive to water stress. The use of 120% ETr water levels provided the highest growth of total dry biomatter on genotypes. The genotype Costela de Vaca had the highest physiological potential based on photosynthetic rates. The Pingo-de-Ouro genotype needed more water to express its productive potential than other genotypes. Higher productivity was achieved with the Paulistinha genotype (that is, 3000 kg ha^{-1}) when irrigated with 120% ETr, which equals to 407.2 mm in the production cycle. The Costela de Vaca genotype presented the highest water use efficiency (that is, 0.843 kg m^{-3}).

Conflict of Interests

The authors have not declared any conflict of interests.

REFERENCES

Agrianual (2006). Anuário da Agricultura Brasileira. São Paulo: FNP Consultório e Comércio, 520 p.

Almeida JJG, Costa FR (2014). Analysis of the socioeconomic and environmental impacts of irrigated agriculture in the irrigated perimeter of Pau dos Ferros (Rn). Rev. Geografares (16):22-44.

Andrade AS Jr, Rodrigues BHN, Frizzone JA, Cardoso MJ, Bastos EA, Melo FB (2002). Irrigation levels and cowpea. Rev. Bras. Engenharia Agrícola Ambient. 6(1):17-20.

Bernardo S, Soares AS, Mantovani EC (2008). Manual de irrigação. Viçosa: UFV.

Brito MEB, Soares LAA, Fernandes PD, Lima GS, Sá FVS, Melo AS (2012). Physiological behavior of scion/rootstock combination of citrus under water stress. Rev. Bras. Ciênc. Agrárias 7:857-865.

Cordeiro LG, Bezerra FML, Santos JJA dos, Miranda EP de (1998). The cowpea bean (*Vigna ungüiculata* (L.) Walp.) sensibility factor to the water deficit. Rev. Bras. Engenharia Agrícola Ambient. 2(2):153-157.

Dutra AF, Melo AS, Filgueiras, LMB, Silva ÁRF, Oliveira, IM, Brito, MEB (2015). Physiologic parameters and yield components of cowpea grown under water deficit. Braz. J. Agric. Sci. 10(2):189-197.

Ferraz RLS, Melo AS, Suassuna JF, Brito MEB, Fernandes PD, Nunes Júnior ES (2012). Gas exchange and photosynthetic efficiency in common bean ecotypes grown in a semiarid environment. Pesqui. Agropecu. Trop. 42(2):181-188.

Ferreira DF (2011). SISVAR: A computer statistical analysis system. Rev. Ciênc. Agrotecnol. 35(6):1039-1042.

Freire Filho FR, Lima JAA, Ribeiro VQ (2005). Feijão caupi: Avanços tecnológicos. Brasília: Embrapa Informação Tecnológica.

Guimarães SL, Bonfim-Silva EM, Moreira JCF, Bosa CK, Silva SLS, Silva TJA (2015). Effects of Inoculation of Rhizobium on Nodulation and Nitrogen Accumulation in Cowpea Subjected to Water Availabilities. Am. J. Plant Sci. 6:1378-1384.

Jaimez RE, Rada F, Garcia-Nuñez, Azócar A (2005). Seasonal variations in leaf gas exchange of platain cv. 'Hartón' (Musa AAB) under different soil water conditions in a humid tropical region. Sci. Hortic. 104(1):79-89.

Moura MCF, Oliveira LCS (2013). Agricultural activity: production, impact and sustainability. Rev. Iberoam Ciênc. Ambient. 4(1):6-14.

Nascimento SP, Bastos EA, Araújo ECE, Filho FRF, Silva EM (2011). Tolerance to water déficit of cowpea genotypes. Rev. Bras. Engenharia Agríc. Ambient. 15(8):853-860.

Oliveira AP, Araújo JS, Alves EU, Noronha MAS, Cassimiro CM, Mendonça FG (2001). Yield of cowpea-beans cultivated with bovine manure and mineral fertilization. Hortic. Bras. 19(1):81-84.

Salgado FHM, Fidelis RR, Carvalho GL, Santos GR, Cancellier EL, Silva GF (2011). Bean genotypes behavior on offseason at south of state of tocantins. Biosci. J. 27(1):52-58.

Shaker BA, Saeed AB, Ahmed Al-Khalifa BA (2013). Effect of drip irrigation on Phaseolus Bean production under the open field condition of Sudan. J. Agric. Food Appl. Sci. 1(3):86-90.

Silva JAL, Neves JA (2011). Production components and their correlations in caupi bean genotypes in rainfed and in irrigated cultivation. Rev. Ciênc. Agron. 42(3):702-713.

Taiz L, Zeiger E (2013). Plant Physiology (5rd ed.). Associates, Inc. Sinauer, 918 p.

Tagliaferre C, Santos TJ, Santos LC, Santos Neto IJ, Rocha FA, Paula A (2013). Agronomic characteristics of inoculated cowpea as a function of irrigation depth and nitrogen levels. Rev. Ceres 60(2):242-248.

Vale NM, Barili LD, Rozzeto DS, Stinghlin JC, Coimbra JLM, Guindolin AF, Köop MM (2012). Evaluation of tolerance to water stress in beans. Biotemas 25(3):135-144.