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Production efficiency of 'BRS Pujante' cowpea using single and dual Kc for irrigation[1]

Eficiência produtiva do feijão-caupi "BRS Pujante" usando irrigação com Kc único e dual

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HIGHLIGHTS:

The highest water consumption at cowpea occur in 3rd stage.
Chlorophyll indices are not altered by the use of different types of Kc.
The use of dual Kc can optimize the water use in cowpea.

ABSTRACT: The objective of this study was to evaluate the production efficiency of cowpea (*Vigna unguiculata* L. Walp.), 'BRS Pujante', from the weather-based irrigation scheduling using single and dual Kc. The study was carried out in randomized block design with two treatments (single and dual crop coefficient) and 12 replicates. Chlorophyll a, chlorophyll b and total chlorophyll contents, soil matric tension, number of pods per plant, number of grains per pod, average 100 grains weight, total grain yield and water use efficiency were evaluated. Scheduling with single and dual Kc did not interfere with chlorophyll pigments. Single Kc promoted tension values closer to zero during cowpea development stages III and IV. Significant difference was observed only for the average 100 grains weight, with higher value for dual Kc. The irrigation depth with the single Kc was 360.8 mm and there was a 9.3% water saving when compared to dual Kc, without significantly affecting cowpea yield. It is possible to use irrigation scheduling with single Kc for the stages I and II and dual Kc for the stages III and IV of cowpea, 'BRS Pujante'.

Key words: *Vigna unguiculata* L. Walp, irrigation water use efficiency, weather-based scheduling

RESUMO: Objetivou-se avaliar a eficiência produtiva do feijão-caupi (*Vigna unguiculata* L. Walp.) 'BRS Pujante' a partir do manejo climatológico de irrigação usando Kc único e dual. O estudo foi conduzido em delineamento experimental de blocos casualizados com dois tratamentos (coeficiente de cultivo único e dual) e 12 repetições. Avaliou-se o teor de clorofila a, b e total, a tensão matricial do solo, o número de vagens por planta, o número de grãos por vagem, o peso médio de 100 grãos, a produtividade total de grãos e a eficiência no uso da água. Os manejos com Kc único e dual não interferiram nos pigmentos clorofilianos. O Kc único proporcionou valores de tensão mais próximos a zero durante os estágios III e IV de desenvolvimento do feijão-Caupi. Observou-se diferença significativa apenas para o peso médio de 100 grãos, com superioridade para manejo com uso do Kc dual. O uso de 360,8 mm de lâmina de irrigação com o Kc único, proporcionou economia de 9,3% no uso da água quando comparado com o Kc dual, sem afetar significativamente a produtividade. É possível usar o manejo de irrigação com Kc único para as fases I e II do feijão-caupi 'BRS Pujante', e o Kc dual para as fases III e IV.

Palavras-chave: *Vigna unguiculata* L. Walp, eficiência no uso da água irrigação, manejo climatológico

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Introduction

Beans are one of the main foods consumed by the human population, playing a relevant role in the diet, mainly as a source of proteins, carbohydrates and minerals (Azevedo et al., 2015; Gomes et al., 2017). According to Borém & Carneiro (2013), the average yield of the crop is from 700 to 1,000 kg ha^{-1}, but its potential is greater than 2,000 kg ha^{-1} under adequate water conditions (Ramos et al., 2012; Oliveira et al., 2015; Moreira et al., 2016; Gonçalves et al., 2017).

There are gaps to be filled for the correct irrigation scheduling of cowpea, especially for 'BRS Pujante', which is a high-yield cultivar developed by Embrapa Semiárido, by crossing lines of the genotypes 'TE 90-180-26F' and 'Epace 10', both indicated for irrigated areas (Souza et al., 2016).

The crop coefficient (Kc) in turn can be either single or dual. Single Kc is indicated for practical purposes of irrigation with intervals ranging from one week to longer. Dual Kc, on the other hand, is recommended for frequent irrigations and in scientific research (Allen et al., 1998; Silva et al., 2012).

Souza et al. (2016) comment on the lack of information about the influence of irrigation scheduling on the production characteristics of the bean crop of the genus Vigna, citing the example of the cultivar 'BRS Pujante', for which there are no conclusive experimental records regarding the values of crop coefficients (Kc, especially the dual Kc), duration of phenological stages and strategies to control water use.

One of the problems in using dual Kc is the large amount of equations that must be employed to obtain it; however, the experimental results have made it possible to affirm its superiority in terms of water use efficiency compared to the single Kc methodology (Cancela et al., 2015; Paredes et al., 2015; Pereira et al., 2015; Qiu et al., 2015).

Thus, considering the lack of practical information on the efficiency of these irrigation scheduling methods for the crop in the region, the objective of this study was to evaluate chlorophyll and the production efficiency of 'BRS Pujante' cowpea from the weather-based irrigation scheduling using single Kc and dual Kc.

Material and Methods

The study was conducted in an experimental area of the Federal Institute of Education, Science and Technology of Sertão Pernambucano, IF Sertão, Zona Rural Campus, Petrolina, PE, Brazil. The area is located at 09° 20' 13" S latitude and 40° 42' 02" W longitude and average altitude of 413 m, and the climate is classified as BSh, according to Köppen's classification, that is hot and dry semi-arid, with annual mean precipitation about 400 mm and evapotranspiration higher than 2000 mm year^{-1} (Azevedo et al., 2003).

Analysis was performed in soil collected in the 0-0.20 m layer, at 15 different points, following the recommendation of Teixeira et al. (2017). The soil of the experimental area was classified as Ultisol, and its physico-chemical characteristics are described in Table 1.

Irrigation scheduling using single Kc and dual Kc in 'BRS Pujante' cowpea plants was studied, adopting a randomized block design, replicated in 12 blocks.

The experimental unit was composed of 4-m-long rows with five plants per meter, totaling 20 plants per plot and experimental area of 108 m^2. The 2 m of each plot were considered as useful area, i.e., 10 useful plants.

Soil tillage was performed by plowing and harrowing. Planting was performed by sowing two seeds per hole, using the spacing of 1.00 x 0.20 m (Santos et al., 2007), totaling 50,000 plants ha^{-1}.

Thinning was performed 15 days after sowing (DAS), in order to maintain only one plant per hole, when the treatments began to be applied. Fertilization was performed by fertigation and the amounts of fertilizer were obtained based on the fertilizer recommendation for the state of Pernambuco (Cavalcanti, 2008), considering the results of the soil analysis. Cultivation practices and crop scheduling were carried out according to the technical recommendations of Câmara & Freire Filho (2001).

The Kc values (Kc_{med} = 1.05; Kc_{end} = 0.35 for single Kc; Kcb_{med} = 1.1 and Kcb_{end} = 0.25 for dual Kc), as well as reference evapotranspiration (ETo) by the Penman-Monteith method and the calculation methodology, were obtained/performed according to Allen et al. (1998).

A drip irrigation system was adopted, using low-density polyethylene drip line with drippers spaced at 0.20 m, unit flow rate of 1.61 L h^{-1} at a pressure of 131 kPa and efficiency of 86.22%. For Kl coefficient, the method proposed in Bernardo et al. (2019) was used, where Kl is equal to the percentage of the wetted area, which was 40% in the experiment, i.e., Kl = 0.4.

Prior to planting, the water application uniformity test was performed in the irrigation system, and the Christiansen's uniformity coefficient (CUC) and distribution uniformity coefficient (DUC) were determined, which were equal to 97.25 and 95.80%, respectively, values higher than those recommended for drip irrigation (Bernardo et al., 2019).

Irrigation scheduling was performed according to the criteria established for the treatments and the adopted calculation methodology was that of Allen et al. (1998) and Bernardo et al. (2019), using fixed irrigation schedule. Reference evapotranspiration (ETo) data were obtained daily from the INMET automatic weather station of Petrolina, PE, and the data of air temperature (maximum, minimum and mean), relative air humidity (maximum, minimum and mean), ETo and precipitation are shown in Figure 1.

Table 1. Chemical and physical-hydraulic characteristics of the soil of the experimental area

pH (1:2.5) H_2O	EC (dS m^{-1})	Pav. (mg kg^{-1})	K	Na	Ca	Mg	Al	H + Al	BD (kg dm^{-3})	FC	PWP
			(cmol$_c$ kg^{-1})							(% Weight)	
7.33	0.54	33.62	0.38	0.04	1.16	0.38	0.0	0.66	1.60	9.38	5.42

pH - Hydrogen potential; EC - Electrical conductivity; Pav. - Available phosphorus; K - Potassium; Na - Sodium; Ca - Calcium; Mg - Magnesium; Al - Aluminum; H + Al - Hydrogen plus aluminum; BD - Bulk density; FC - Moisture content at field capacity; PWP - Moisture content at permanent wilting point

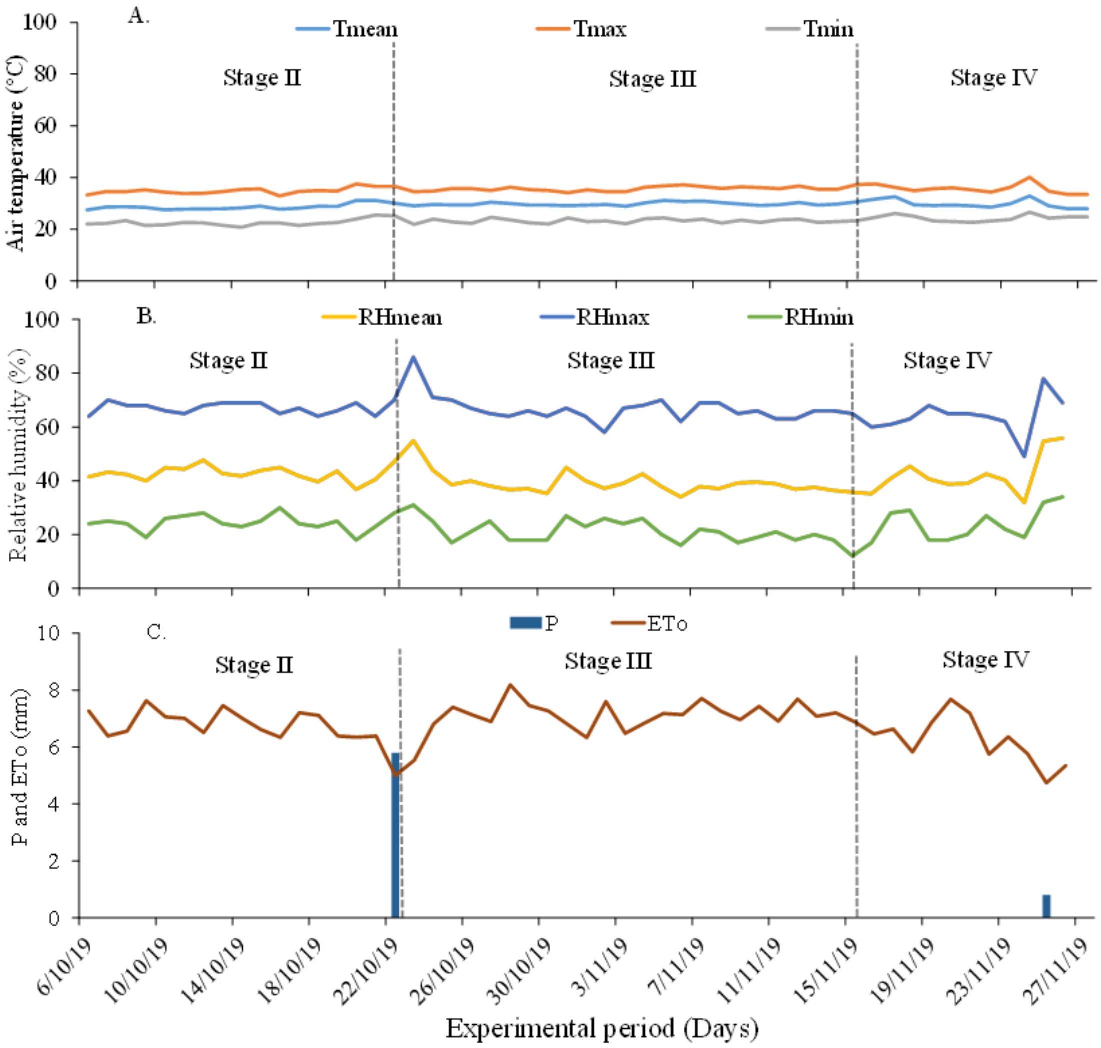

Figure 1. Maximum (Tmax), minimum (Tmin) and mean (Tmean) air temperature (A), maximum (RHmax), minimum (RHmin) and mean (RHmean) relative air humidity (B), and reference evapotranspiration (ETo) and precipitation (P) (C), in the period from 06/10/2019 to 27/11/2019

The air temperature was within the range considered ideal for cowpea, 9 to 38 °C (Farias et al., 2015). In the period in which this climatic variable was analyzed, the maximum temperature was exceeded in only one day (24/11/2019, value of 40.10 °C, Figure 1A).

Soil moisture was monitored along the experimental period, in addition to physiological and yield analysis, in order to enable the quantification of water use efficiency.

For soil moisture monitoring, eight puncture tensiometers were installed at 0-0.20 m depth and eight at 0.20-0.40 m depth, distributed in four random blocks, totaling 16 tensiometers, checked three times a week (soil water retention tension) from collections using analog tensimeter. Readings were performed in the early hours of the morning and the soil matric tension (Ψ_t) (data in kPa) was obtained by subtracting the water column in the tensiometer body (hwa) (data converted to kPa) from the tensiometer reading (Ψ_t) (data in kPa), using Eq. 1.

$$\Psi_s = \Psi_t - \text{hwa} \quad (1)$$

Chlorophyll a, chlorophyll b and total chlorophyll indices were estimated at 50, 55 and 60 days after sowing (DAS) in 10 plants of the useful plot, from readings in the first mature leaf per plant, using a ClorofiLOG chlorophyll meter, CFL 1030 model from Falker®, whose general calibration curve estimates the values based on the SPAD reading.

At 72 DAS, cowpea production was determined based on the number of pods per plant (NPP) and the number of grains per pod (NGP), both by simple counting. The average 100 grains weight (100GW) (g) was determined with the count of 100 grains.

These data of NPP, NGP and 100GW were used to estimate the average cowpea yield per plant (Y), which was extrapolated to yield in kg per hectare in each treatment.

From the data of yield (Y) (kg ha^{-1}) and water depth applied (La) (mm) in each plot, water use efficiency (WUE) (kg m^{-3}) was determined according to Eq. 2.

$$\text{WUE} = \frac{Y}{La} 0.1 \left[\text{kg m}^{-3}\right] \quad (2)$$

The data were subjected to analysis of variance and the means were compared by F test. These procedures were performed with SISVAR 5.6 software (Ferreira, 2014).

Results and Discussion

The crop cycle lasted 72 days, similar to those of other varieties of cowpea, which ranged from 63 to 78 days, in studies conducted in the cities of Juazeiro, BA and Boa Vista, RO, Brazil, with drip irrigation in a semi-arid climate (Locatelli et al., 2014; Gonçalves et al., 2017).

By analyzing the gross irrigation depths (GID) applied at stages II (development stage), III (intermediate stage) and IV (final stage) of cowpea cultivation (Figure 2A), it can be observed that at stage II, the irrigation depth defined by single Kc increased gradually, as for dual Kc since the beginning of this stage, which promoted greater accumulation of the water depth applied in this stage, especially for the dual Kc.

On the other hand, the scheduling in the beginning of stage III using single and dual Kc had constant values of irrigation depth, and the dual Kc management led to a lower applied depth, as in stage IV, when it was possible to notice that there is a reduction in the depth used in both managements. Thus, the use of the single Kc in stage II, as well as the use of dual Kc in stage III, can enable a higher water use efficiency, as well as yield in the cultivation of 'BRS Pujante' cowpea.

Regarding the soil matric tension, it was possible to notice that at 0-0.20 m depth, the irrigation scheduling using single Kc promoted lower values of tension during stages III and IV (Figure 2B), corresponding to a larger amount of water in the soil, making it possible to deduce that there was water percolation when compared to the tension results obtained with the application of dual Kc.

The tension values observed in the 0.20-0.40 m layer, under irrigation scheduling with single Kc, were similar to those observed in the 0-0.20 m layer, i.e., the use of single Kc for irrigation scheduling allowed soil water tensions closer to maximum soil water capacity along the entire experiment (Figure 2C). Moreover, considering that the soil where the experiment was installed was sandy, with tension at field capacity around 100 kPa, the irrigation scheduling with dual Kc, at both depths, made it possible to apply a water depth that would enable greater water comfort for the plant, whereas the situation of tension lower than field capacity may mean leaching of nutrients and water percolation (Bernardo et al., 2019; Rodrigues et al., 2019).

A study carried out by Moreira et al. (2016), who evaluated the application of water depths in cowpea genotypes in

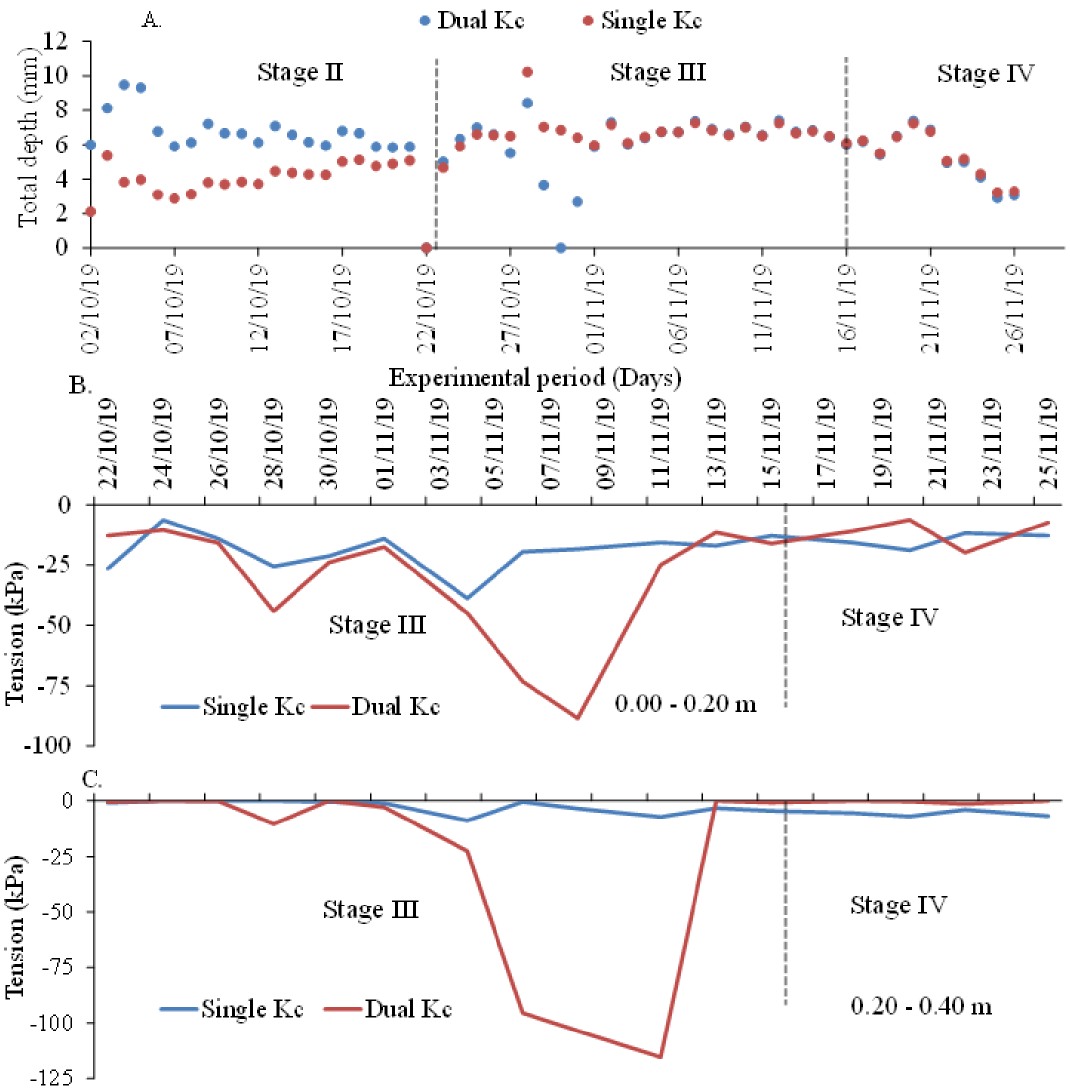

Figure 2. Total irrigation depth applied (Total depth) (A) and variation of soil water tension (Tension) in soil layers of 0-0.20 m and (C) 0.20-0.40 m (B) along the experimental period with 'BRS Pujante' cowpea under irrigation scheduling with single Kc and dual Kc

Table 2. Summary of analysis of variance for the indices of chlorophyll a, chlorophyll b and total chlorophyll (t) at 50 (Chl a 50, Chl b 50 and Chl t 50), 55 (Chl a 55, Chl b 55 and Chl t 55) and 60 (Chl a 60, Chl b 60 and Chl t 60) days after sowing for 'BRS Pujante' cowpea subjected to weather-based irrigation scheduling

SV	DF	Mean square								
		Chl a 50	Chl b 50	Chl t 50	Chl a 55	Chl b 55	Chl t 55	Chl a 60	Chl b 60	Chl t 60
Block	11	14.101^{ns}	19.08^{ns}	0.375^{ns}	128.43^{ns}	1006.48^{ns}	1458.93^{ns}	77.56^{ns}	401.11^{ns}	538.43^{ns}
Treatment	1	297.59^{ns}	1188.17^{ns}	2242.46^{ns}	177.13^{ns}	5.90^{ns}	247.69^{ns}	4.55^{ns}	1030.97^{ns}	1030.97^{ns}
Error	12	171.81	1078.46	1861.04	59.56	673.20	873.82	142.99	221.69	301.59
CV (%)		2.96	13.09	6.22	1.77	10.10	4.26	2.75	5.59	2.48
		Treatment means								
Single Kc		443.59 a	249.94 a	693.53 a	433.94 a	256.42 a	690.37 a	434.88 a	273.04 a	707.92 a
Dual Kc		442.06 a	251.72 a	693.78 a	439.38 a	257.42 a	696.79 a	434.88 a	259.93 a	694.82 a

SV - Source of variation; DF - Degrees of freedom; ns - Not significant according to F test; CV - Coefficient of variation

Paraíba state, Brazil, showed that the increase in water depth maintained moisture content close to field capacity, even in deeper layers, and the most comfortable moisture condition was obtained using single Kc, but this may not be transformed into production, as will be discussed.

According to the effect of irrigation scheduling using single Kc and dual Kc on chlorophyll contents of cowpea plants at 50, 55 and 60 days after sowing (DAS), there was no significant effect between blocks and treatments in any of the analyzed periods (Table 2). This may be related to stress intensity because, under both scheduling conditions, the soil water tension was close to zero, with a large amount of available water, and sometimes close to field capacity, especially for the dual Kc (Figures 2B and C).

Although chlorophyll is the main pigment responsible for capturing the light energy used in photosynthesis, it is one of the main factors related to the photosynthetic efficiency of plants and, consequently, to the growth and adaptability to different environments (Taiz et al., 2017).

By analyzing the production characteristics of cowpea plants under irrigation scheduling using single and dual crop coefficients (Table 3), it was noted that there were no significant differences between treatments for number of pods per plant (NPP), number of grains per pod (NGP), total grain yield (TGY) and water use efficiency (WUE). However, significant differences were observed between treatments in the average 100 grains weight (100GW) at $p \leq 0.05$ and between blocks at $p \leq 0.01$ (Table 3), which can be relative to differentiation in grain growth, caused by better water balance, especially in plants under dual Kc.

As can be seen in Table 3, the only variable that differed statistically was 100GW, and its mean values with the dual Kc were higher than those obtained with the single Kc, leading to a 6.5% higher mean.

For water use efficiency (WUE), a variable that had no statistical difference, the managements with the use of single and dual Kc were similar (Table 3), without significant reduction in yield. However, Arf et al. (2004) have already emphasized that under lower irrigation depths it is possible to obtain grain yields similar to those of higher depths, thus promoting higher revenues and lower water waste.

Regarding yield (TGY) (Table 3), although an average of 2,560.66 kg ha^{-1} was obtained with a 394.42 mm water depth under the management using the dual Kc, there was no significant difference from the one obtained in the management with single Kc, which led to a value of 2,503.36 kg ha^{-1} with a 360.80 mm water depth.

Table 3. Summary of analysis of variance and Tukey test for number of pods per plant (NPP), number of grains per pod (NGP), average 100 grains weight (100GW), total grain yield (TGY) and water use efficiency (WUE) for cowpea (*Vigna unguiculata* (L.) Walp), 'BRS Pujante' cultivar, under single Kc and dual Kc

SV	Mean square				
	NPP	NGP	100GW	TGY	WUE
Block	5.63^{ns}	1.27^{ns}	24.14**	523950.95^{ns}	3.60^{ns}
Treatment	9.38^{ns}	0.97^{ns}	22.10*	19699.17^{ns}	1.21^{ns}
CV (%)	16.40	6.26	6.44	17.77	17.23
Scheduling Kc	Treatment means				
			(g)	(kg ha^{-1})	(kg m^{-3})
Single Kc	14.72 a	11.61 a	29.61 b	2,503.36 a	6.94 a
Dual Kc	13.47 a	12.01 a	31.53 a	2,560.66 a	6.49 a

*, **, ns - Significant at $p \leq 0.05$, $p \leq 0.01$ and not significant, respectively, according to F test; CV - Coefficient of variation; Means followed by the same letter in the column do not differ by F test at $p \leq 0.05$

It should be emphasized that these values are higher than those obtained by Souza et al. (2011), Brito et al. (2012) and Rodrigues et al. (2019), also for 'BRS Pujante', 1,374.70, 1,422.50 and 1,550.67 kg ha^{-1}, respectively, and those obtained by Locatelli et al. (2014) for 'BRS Guariba', 'BRS Novaera' and 'BRS Pajeú', 1,170.19, 1,308.85 and 1,495.07 kg ha^{-1}, respectively, for cultivation in Boa Vista, RO, Brazil.

The values were also higher than the average yields obtained by Dutra et al. (2015) for 'BRS Guariba' (1,282.10 kg ha^{-1}), 'BR17 Gurgéia' (1,200.12 kg ha^{-1}) and 'BRS Marataoã' (1,436.06 kg ha^{-1}). Marinho et al. (2014) obtained yields from 1,091 to 1,824 kg ha^{-1} with 'BRS Pujante' plants in Petrolina, PE, and Juazeiro, BA, Brazil, spaced at 0.25 x 0.50 m. These authors did not report the irrigation depth applied in the experiment, which denotes the high production potential of this variety in the region of Petrolina, PE, under irrigated condition.

Conclusions

1. Scheduling with single and dual Kc did not interfere with chlorophyll indices.

2. Irrigation scheduling with single Kc promoted tension closer to maximum water capacity of the soil, especially during stages III and IV.

3. Significant difference was observed only for the average 100 grains weight, with higher value for dual Kc scheduling.

4. Using irrigation depth of 360.8 mm with single Kc promoted 9.3% saving in water use when compared to dual Kc, without significantly affecting cowpea yield.

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