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Physiology and Grain Yield of Common Beans under Evapotranspirated Water Reposition Levels

Magalhaes ID[1]*, Lyra GB[1], Souza JL[2], Teodora I[3], Cavalcante CA[3], Ferreira RA[4] and Souza RC[3]

[1]Department of Plant production, Federal University of Alagoas, Brazil
[2]Department of Agronomy, Federal University of Alagoas, Brazil
[3]Department of Agricultural engineering, Federal University of Alagoas, Brazil
[4]Department of Phytotechnology, Federal University of Alagoas, Brazil

Abstract

The aim of this work was to evaluate gas exchanges, photochemical efficiency and yield of common bean grains (crioula variety) grown under different irrigation levels in the state of Alagoas. The experimental design was a randomized block design with four replications. Treatments were composed of crop evapotranspiration fractions (25, 50, 75, 100, 125 and 150% of crop evapotranspiration). Gas exchanges were determined from measurements of internal CO_2 concentration, transpiration, stomata conductance, photosynthetic rate, instantaneous water use efficiency and instantaneous carboxylation efficiency. Chlorophyll a fluorescence evaluations were determined through the potential and effective quantum yield of photosystem II. Chlorophyll content was indirectly measured. The following production components were evaluated: number of pods per plant, number of grains per pods, mass of 1000 grains and grain yield. The water application variation promoted a significant difference for gas exchanges, causing a reduction in the potential and effective photochemical efficiency of common bean. The increase in the application of the irrigation levels directly influenced the SPAD index and the following production components: number of pods per plant and grain yield, obtaining significant values with irrigation level of 125% of ETc.

Keywords: *Phaseolus vulgaris* L.; Water deficit; Yield; Physiological variables

Introduction

Common bean (*Phaseolus vulgaris* L.) is an important crop for the world, since its grains are present in the diet of many countries due to its high nutritional value, being considered the main source of protein for low-income populations and a crop of great economic and social importance [1,2].

Brazil has been the world's largest bean producer in the last 10 years; however, as a result of successive atypical meteorological events and changes in the profile of producers, there were significant decreases in productivity and production, so that between 2012 and 2013, the country lost space in productive competitiveness for Asian countries, which have shown growth over the last few years [3]. The north-eastern region of Brazil is one of the main common bean producers in the country [4]. The state of Alagoas, which cultivation is performed in practically the entire territory, the state of Sergipe and the north eastern region of the state of Bahia compose a strong production belt, representing 22% of the winter production in the year of 2016 [3].

Although common bean is considered a versatile crop due to its easy adaptation to the most diverse environments, its yield is still considered low, with average of 800 kg ha^{-1} [3]. One of the main causes of this small productivity is the spatial and temporal limitation of precipitation, characteristic of semiarid regions. The inadequate management of water resources in irrigation systems contributes to water scarcity in irrigated crops, contributing to waste, with undesirable consequences for the environment. In this sense, the rational use of irrigation water reduces losses through evaporation, runoff, and percolation among others [2]. Irrigation is an essential factor for a good performance of the crop in the field, especially when cultivated in a period of little rainfall. When well-managed, the plant can better express its productive potential, balancing the environmental issue, involving sustainability, when the subject is a shortage of water resources [5].

Like most crops, common bean is sensitive to water stresses, either due to water deficit or excess, being one of the environmental factors that most influence plant yield [6]. The reduction of water availability in the soil causes decrease in productivity for limiting the photosynthetic process, reducing the stomatal conductance and promoting stomatal closure, which in turn has direct implications for transpiration, photosynthesis and leaf temperature [7,8]. In this sense, it is of fundamental importance the knowledge of gas exchanges and photochemical efficiency for the management of plants cultivated under water deficit, aiming at a better crop development, being also determine the adaptation and stability of common bean to certain ecosystems [9].

Although there are studies on the cultivation of common bean (Mantovani et al. [10]; Souza et al. [2]; Brito et al. [4]) with irrigation levels and different management conditions, there is few available information regarding physiological parameters of irrigated common bean crop in north eastern Brazil. In this sense, the aim of this work was to evaluate gas exchanges, photochemical efficiency and grain yield of common beans cultivated under irrigation levels.

Materials and Methods

The experiment was conducted in the experimental area of the Center for Agricultural Sciences (CECA), Federal University of Alagoas (UFAL), Rio Largo, Alagoas (09 ° 28'02 "S, 35 ° 49'43" W, 127 m asl). According to climate classification, the climate of the region is humid and mega thermal, with moderate water deficiency in the

summer and excess water in the winter, mean annual temperature of 25.4°C and total annual precipitation around 1,800 mm, with 70% of this occurring between April and August (Souza et al. [11]; Ferreira et al. [12]). The meteorological data of the experimental period were obtained from the agro meteorological station located 30 m away from the experimental area, and are presented in Table 1.

The local soil was classified as Cohesive Argisolic Yellow Latosol of medium clayey texture, according to analysis of the Department of Soil Physics at CECA/UFAL. The experimental area has topography with slope of less than 2%.

Fertilization was based on soil chemical analysis (Table 2), using 45 kg urea, 111 kg Simple Superphosphate and 78 kg of Potassium Chloride per hectare. At 20 days after planting (DAP), cover fertilization was applied using 89 kg ha^{-1} urea. When necessary, weed and pests were monitored by hand hoeing and chemical insecticides, respectively.

The seeds used in the experiment were *crioula rosinha* variety: undetermined growth habit (type II); upright; 78 days cycle; average of 34 days for flowering; white flowers; green pod, slightly pink in maturation and pigmented pod in harvest [13].

The study was conducted during the dry season, between November and January (2015/2016) using a randomized complete block design, with four replicates. Each experimental plot measured 8 m in length by 10 m in width (80 m²). The total area of the experiment was 1.920 m². Treatments were composed of six irrigation levels established as a function of crop evapotranspiration fractions (ETc) according to Table 3. All treatments received the same irrigation levels in the initial period (15 DAP).

The study adopted Kc of 1.1 and 1.2 for the vegetative and reproductive phases, respectively. These Kc values are recommended by the FAO-56 bulletin for the intermediate stage, and then edaphoclimatic conditions and crop characteristics were adjusted during the experimental period, as recommended by Allen et al. [14]. The ETc values (mm day^{-1}) were calculated by means of equation (Eq. 1).

$$ETc = ET_0 * K_c \tag{1}$$

Where, ET0 is the reference evapotranspiration estimated by the Penman-Monteith method [14].

Seeding was manually performed with three seeds per pit at spacing of 0.50 m between rows and density of 13 to 15 plants per meter, totalling a final stand of 240,000 plants per hectare. At 15 DAP,

thinning was performed, leaving one plant per pit.

The irrigation method adopted was micro-sprinkler, with spacing of 2 × 2.5 m between sprinklers, service pressure of 14 mca, and average flow rate of 50 L h^{-1} per sprinkler and applied gross irrigation level of 5.06 mm h^{-1}.

Soil water content (SWC) was calculated using soil water balance suggested by Thornthweite and Matter [15] and adjusted by Lyra et al. [16] for agricultural crops. The total available water (TAW, mm) was generated for each stage of crop development as a function of the root system effective depth, according to equation:

$$TAW = 1.000 * (\theta_{CC} - \theta_{PMP}) * z \tag{2}$$

Where: θCC is the volumetric moisture in the field capacity (0.2445 m³ m^{-3}) and θPMP is the moisture at the permanent wilting point (0.1475 m³ m^{-3}) determined in laboratory by the retention curve of water in the soil Carvalho [17], and z (m) refers to the depth of the crop root system, ranging from 0.10 to 0.40 m.

Values for readily available water (RAW, mm) were calculated based on equation:

$$RAW = TAW * f \tag{3}$$

Where: f (0.45) refers to the water availability factor [0^{-1}] [14].

Gas exchange measurements were based on the internal CO_2 concentration rate (Ci), transpiration (E), stomatal conductance (gs) and photosynthesis rate (A). From these data, the instantaneous water use efficiency (A E^{-1}) and instantaneous carboxylation efficiency (EiC) (A/Ci) were also calculated. In these evaluations, an infrared gas analyser (IRGA, ADC model LCi, Hoddesdon, UK) with 300 ml min^{-1} air flow and coupled light source of 995 mmol m^{-2} s^{-1} was used. Measurements occurred at 35 DAP, between 8 am and 11 am at stage R5 on three useful plants between pre-flowering and pod formation, on the third fully expanded leaf, counted from the apex of the main branch of the plant (Figure 1).

Concomitant to gas exchanges, chlorophyll a fluorescence evaluations were performed using a portable light-modulated flora meter (Opti Sciences, model OS1-FL, Hudson, USA), from which the potential quantum yield of photosystem II (PSII) (Fv/Fm) was obtained after adaptation of leaves to the dark (H "30 min); yield was also quantified to obtain the effective quantum efficiency of photosystem II (ΦPSII). Evaluations occurred at different times (11 am to noon and noon to 1 pm).

Months	Tar (ºC)	RH (%)	Rainfall (mm)	WS$_2$ (m s^{-2})	ET$_0$ (mm)
November	25.39	69.38	10.42	2.21	140.17
December	25.39	72.88	120.39	1.93	160.40
January	25.75	77.35	170.43	1.65	136.81

Tar: Average air temperature; RH: Mean relative air humidity; WS2: Average wind speed; ET$_0$: Reference evapotranspiration.

Table 1: Agrometeorological data obtained during the experiment.

Lay	pH	*P	Ca	Mg	K	SB	Al	H+Al	T	m	v
Cm	mg dm^{-3}		..........................cmolc dm^{-3}...............................							........%.......	
0-20	5.8	15.2	2.7	1.3	1.15	4.21	0.08	5.4	9.61	1.5	44.2

Lay: Soil layer; pH: Hydrogen potential; P: Phosphorus; Mehlich*; Ca: Calcium; Mg: Magnesium; K: Potassium, SB: Sum of bases; Al: Aluminum, H+Al: Hydrogen plus aluminum; T: Base exchange capacity; m: Aluminum saturation; v: Base saturation.

Table 2: Chemical soil attributes of the experimental area.

ETc %	25	50	75	100	125	150
Total irrigation (mm)	(462.5)	(504.9)	(543.6)	(577.9)	(614.5)	(654.2)

Table 3: Crop Evapotranspiration fractions (ETc %) and total applied water (irrigation+precipitation) in the research.

At stage R5, readings were taken for the indirect determination of the chlorophyll content using SPAD-502 chlorophyll meter (Soil Plant Analysis Development Section, Minolta Camera CO., Osaka, Japan) and expressed using the SPAD index.

At the end of the experiment (78 DAP), the following production components were evaluated: number of pods per plant (NPP) (und plant^{-1}), number of grains per pod (NGP), mass of 1000 grains (M1000G) (g) and grain yield (GY) (kg ha^{-1}). In order to determine the grain yield, the four central lines with length of 5 meters were collected, totalling 10 m^2 for each plot, the GY was calculated, correcting humidity to 13% (wet basis), determined by means of the greenhouse method at 105°C for 24 hours [18].

Data of variables were submitted to analysis of variance up to 5% probability. In case of significance, they were submitted to regressions.

Results and Discussion

The accumulated precipitation during the experiment was 291.6 mm, with a very uneven distribution, therefore justifying the use of irrigation to supply the water requirement of the bean crop. According to Cunha et al. [19], common bean crop requires 300 to 600 mm to obtain high productivity. Thus, average rainfall event of 3.8 mm d^{-1} and frequency of approximately 1 event every 2.2 days were observed, corresponding to 45.4% of days with precipitation. However, there was a very marked intermittent rainfall with 98% concentration of precipitation occurring from the second fortnight of December, when the crop was beginning the reproductive phase, in which the greatest rainfall accumulation was observed in the interval between days 09 to 23 of January 2016, with 135.1 mm, accounting for 46.3% of the precipitation that occurred during the crop, corresponding to a mean per rainfall event of 9 mm d^{-1}. During this period, the maximum rainfall event that was 46.2 mm day^{-1} also occurred (63 DAP). ET0 totalled 382.6 mm, with daily mean of 5 mm and total ETc of 310.2 mm.

The influence of irrigation levels as a function of ETc was evidenced during stages R5 to R7. In these periods, plants presented maximum development of their vegetative canopy and, consequently, high transpiratory surface. As these stages coincided with the second fortnight of December, the period of greatest precipitation, it resulted in low evapotranspiration values.

With 25% of ETc (Figure 2A), the bean crop underwent 32 days in the vegetative stage, with SWC of 210.30 mm and RAW of 228.05 mm; during this period, rainfall was 10.4 mm, with irrigation of 153.75 mm. During the reproductive stage from December 22 to 31, 2015, rainfall was 96 mm, and irrigation was not necessary, because RAW was close to TAW. From January 2, 2016, irrigation was resumed until the first decennial of January. Taking into account the crop cycle, it was verified that 25% of ETc presented 29.9% of the cultivation period below RAW, characterizing water stress for this water level. For 50% of ETc (Figure 2B), water level was 189.39 mm (precipitation and irrigation) for the vegetative phase. In the reproductive phase, the crop remained for a short period with water deficit (6 days) from January 3 to 8, 2016. According to Cunha et al. [19], the most critical stages for bean cultivation, in terms of water deficiency, is from flowering to grain filling, stages R5 to R8 respectively, thus, in this study, the crop was penalized for presenting 7.8% of cultivation period below RAW, evidencing a period of water deficit.

For treatments with irrigation levels of 75%, 100%, 125% and 150% of ETc, no water deficit was verified, since the entire crop cycle was above RAW; however, it was observed that for irrigation levels of 75%

and 100% of ETc (Figures 2C and 2D, respectively) in the vegetative phase, SWC was lower than TAW, but never lower than RAW. This was favoured by the initial irrigation levels in treatments, which ranged from 1.5 to 9 mm per event and were applied during about 95% of the initial phase according to the need. Irrigation and precipitation in this period were 212.2 and 232.7 mm, respectively, keeping SWC very close to TAW until January 3, 2016.

Treatments with 125% and 150% of ETc (Figures 2E and 2F, respectively) always remained with SWC above RAW, being close to TAW up to stage R7, but a 32-day drought occurred (November 17 to 18 December of 2015), being necessary to perform irrigations of 245.71 and 273.29 mm, respectively. The total irrigation amount during the bean crop cycle for irrigation levels of 125% and 150% of ETc was 322.89 and 362.56 mm, respectively.

Figure 1: Photograph of the experiment under different irrigation levels at 35 DAP.
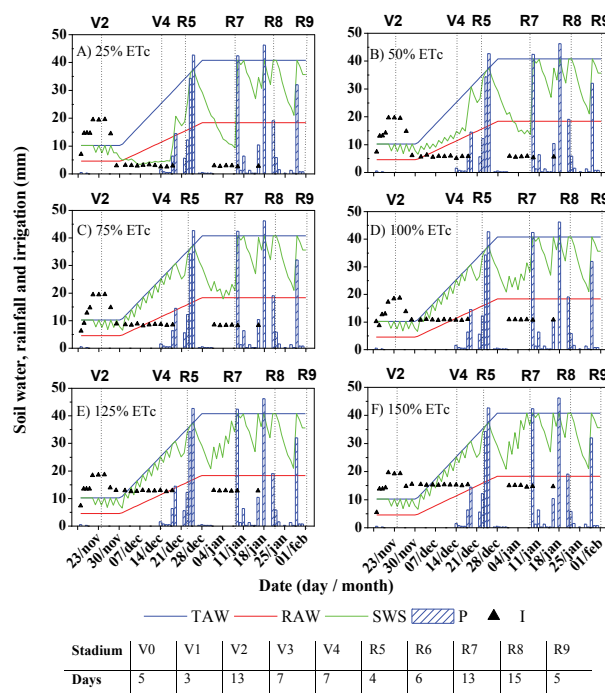

Figure 2: The water balance of the bean crop during the conduction of the experiment. Water balance of common bean crop, with emphasis on the total available water (TAW, mm), readily available water (RAW, mm), soil water content (SWC, mm), precipitation (P, mm) and irrigation (I, mm). Irrigated with 25% of ETc (2A), irrigated with 50% of ETc (2B), irrigated with 75% of ETc (2C), irrigated with 100% of ETc (2D), irrigated with 125% of ETc (2E), irrigated with 150% of ETc (2F). V0 Germination; V1 Emergency; V2 Primary leaves; V3 First trifoliate leaf; V4 third trifoliate leaf; R5 Pre-flowering; R6 Flowering; R7 Formation of pods; R8 Filling of pods; R9 Physiological maturation.

Significant difference among treatments with different irrigation levels was detected for the gas exchange variables: photosynthesis rate (A) ($p<0.05$), transpiration (E), stomatal conductance (gs), internal CO_2 concentration (Ci) ($P<0.01$), instantaneous carboxylation efficiency (EiC) ($p<0.05$) and no significant difference was observed for instantaneous water use efficiency (A/E). With respect to chlorophyll a fluorescence, significant effects were observed for the potential quantum yield of photosystem II (Fv/Fm) ($p<0.01$), effective quantum efficiency (ΦPSII) ($p<0.01$) and SPAD index ($P<0.05$). For production components, significant effects were observed for the following variables: number of pods per plant (NPP) ($p<0.05$) and grain yield (GY) ($p<0.01$) and no significant effects were observed for number of grains per pod (NGP) and mass of 1000 grains (M1000G) (Table 4).

The photosynthetic rate (A) of bean plants was adjusted to the quadratic model with lower value of 13.7 µmol m^{-2} s^{-1} and estimated irrigation levels of 25% of ETc, showing an increase of 13.3% in the A value compared to the highest rate (15.8 µmol m^{-2} s^{-1}) found with estimated 102.5% of ETc (Figure 3A), demonstrating that the net CO_2 assimilation rate was reduced by the water deficiency. Excess water in the soil caused by the application of water above ETc (102.5%) significantly reduced CO_2 assimilation by 5.7%, reaching a value of 14.9 µmol m^{-2} s^{-1} when soil was saturated with 150% of evapotranspirated water. These values corroborate those found by Dutra et al. [8] who verified 15.3 µmol m^{-2} s^{-1} with estimated irrigation level of 90% of ET0. These authors reported that in response to water deficit, plants reduce the opening of stomata, influencing other variables such as photosynthesis and transpiration rates, with negative consequences on crop productivity. Silva et al. [20] reported that under high soil water level, oxygen deficiency occurs, causing stomatal closure, photosystem II damage and photosynthesis reduction. The authors confirm this

information by explaining that under these conditions, there is an increase in the production of abscisic acid and reduction in stomatal conductance, in addition to the high CO_2 concentration found in the intercellular spaces of the mesophyll, suggesting that the stomatal closure is not the only cause of reduction in the photosynthetic rate.

For the transpiration rate (E), quadratic polynomial adjustment was also observed with increase of irrigation levels up to 125% of ETc, in which an increase of 15.3% was observed, calculated from the lowest value (6.09 mmol m^{-2} s^{-1}) obtained with irrigation level of 25% of ETc in relation to the highest value of 7.19 mmol m^{-2} s^{-1} transpired with irrigation levels of 125% of ETc (Figure 3B). Silva et al. [20] found similar results (7.78 and 7.40 mmol m^{-2} s^{-1}) in cowpea plants irrigated with 100 and 50% of water lost by evapotranspiration. E values lower than those described ones (2.96 and 3.41 mmol m^{-2} s^{-1} with irrigation levels estimated at 80 and 40% ET0, respectively) were presented by Dutra et al. [8] who evaluated the physiological parameters of common bean cultivated under water deficit. Lima [21], studying the physiological responses of common bean submitted to water deficit and found reductions up to 90% in the transpiration rate of non-irrigated plants compared to irrigated ones. For Silva et al. [20] the reduction in the transpiration rate is a response to water stress by plants. According to Shimazaki et al. [22], the loss of water by plants is regulated by the activity of guard cells. Pimentel and Perez [23] reported that during the day there is an increase in the transpiration rate of plants due to the inability of some plants to absorb enough water to replace that consumed in the transpiratory process.

The averages of the stomatal conductance variable (gs) had quadratic adjustment, with good predictive capacity ($R2=0.93$ **) (Figure 4A). The best result for gs (0.71 mol m^{-2} s^{-1}) was obtained with

Average Squares							
S.V	GL	35 days after application of treatments					
		A	E	gs	Ci	EiC	A/E
Blade	5	3,76*	0,83*	0.01*	11.13**	0.0074*	0.01 ns
Block	3	3.03 ns	0.15 ns	0.00 ns	0.33 ns	0.0082 ns	0.03 ns
Quadratic	1	8.99**	1.92*	0.06**	11.64**	0.0119 *	0.00 ns
Linear	1	8.62*	0.94 *	0.01*	13.03 ns	0.0223*	0.02 ns
Residue	15	0.68	0.27	0	0.97	0.002	0.03
V.C. (%)		5,45	8,55	9,04	4,41	13,7	0,74
		Fm/Fv		ΦPSII		SPAD	
Blade	5	0.0034**		0.008**		10.81*	
Block	3	0.0001ns		0.001 ns		2.96ns	
Quadratic	1	0.0077*		0.008*		11.40*	
Linear	1	0.0090*		0.031ns		40.43ns	
Residue	15	0.0003		0		2.37	
V.C. (%)		2,54		4,37		5,77	
		78 days after application of treatments					
		NPP	NGP	M1000G	GY		
Blade	5	49.51*	0.14 ns	55.93 ns	586442**		
Block	3	0.43 ns	1.45 ns	166.38 ns	432097 ns		
Quadratic	1	30.72 ns	0.00 ns	76.86 ns	1708078**		
Linear	1	186.57*	0.34 ns	3.47 ns	952641*		
Residue	15	13.94	0.11	67.9	114062		
V.C. (%)		28,63	8,06	3,96	14,65		

S.V: Sources of variation; V.C: Variation coefficient; D.F: Degrees of freedom; **, *: Significant at 1 and 5% respectively; ns: Not significant by the F test at 5% probability; A: photosynthesis rate; E: Transpiration; gs: Stomatal conductance; Ci: Internal CO2 concentration; EiC: Instantaneous carboxylation efficiency; A/E: Instantaneous water use efficiency; Fv/Fm: potential quantum yield of photosystem II; ΦPSII: effective quantum efficiency; SPAD: Soil Plant Analysis Development Section; NPP: Number of pods per plant; NGP: Number of grains per pod; M1000G: Mass of 1000 grains; GY: Grain yield.

Table 4: Analysis of variance for physiological variables and production components of common bean under different irrigation levels.

the application of irrigation level of 100% of ETc, with an increase of 23% in relation to the lowest value (0.54 mol m^{-2} s^{-1}) obtained with irrigation level of 25% of ETc. These results are close to those found by Dutra et al. [8], who obtained gs of 0.51 mol m^{-2} s^{-1} in plants with the lowest irrigation level (40% ET0). Ferraz et al. [9], reported that under water scarcity, there is an increase in the resistance to water vapour diffusion by stomata, confirming the partial closure of stomata observed in this work, which can also be deduced by the less assimilation and accumulation of intracellular CO_2. According to Medrano et al. [24], gs are a factor linked to the global effect of water stress on the physiological parameters, responding to most of the internal and external factors of the plant. Paiva et al. [25], reported that, when the water deficit in
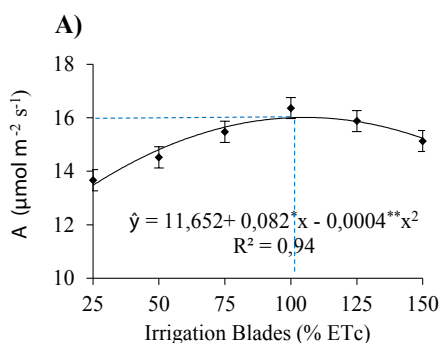

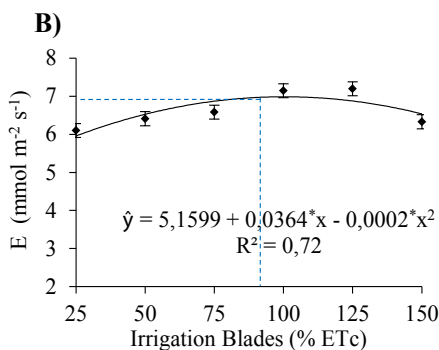**Figure 3A:** Photosynthesis (A) of common bean submitted to different irrigation levels.

Figure 3B: Transpiration (E) of common bean submitted to different irrigation levels.
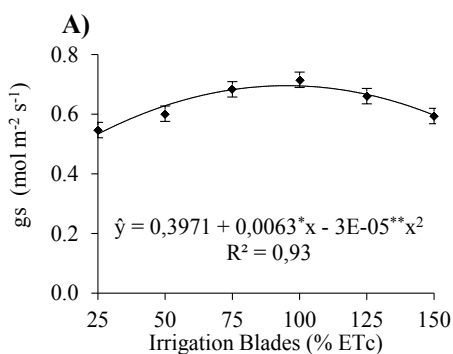

Figure 4A: Stomatal conductance (gs) of common bean submitted to different irrigation levels.
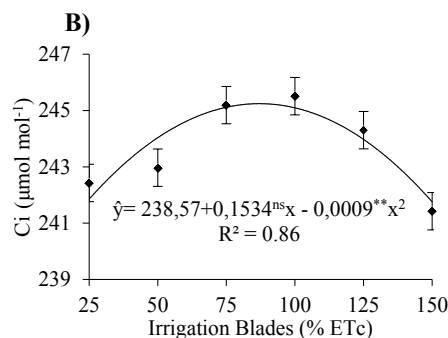

Figure 4B: Internal CO_2 concentration (Ci), of common bean submitted to different irrigation levels.
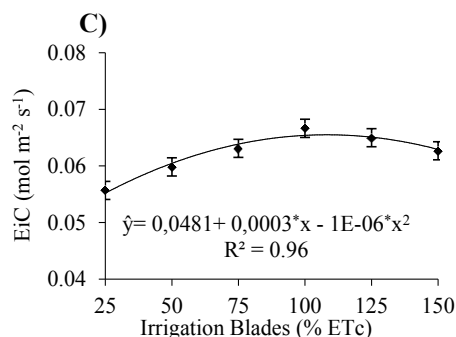

Figure 4C: Instantaneous carboxylation efficiency (EiC) of common bean submitted to different irrigation levels.

the soil is not relevant, gs variations follow the same trend of plants without water restriction, and ratify the importance of gs for directly participating in the growth and development of vegetables, playing a regulatory role in gas exchange activities.

The highest internal CO_2 concentration (Ci), average value of 245.5 µmol mol^{-1}, was observed in plants cultivated under 100% of ETc, being statistically above value observed with 25% of ETc (242 µmol mol^{-1}), evidencing an increment of the order of 4.75% (Figure 4B). This result, with small difference between plants conducted under soil water deficit and 100% of ETc, may be related to the fact that crioulo variety bean plants have greater tolerance to water deficit [26]. According to Bastos et al. [6], the increase in Ci values is indicative of restriction in CO_2 acquisition by the crop submitted to water deficit due to Ci accumulation in the leaf mesophyll, which is directly associated with stomata closure and reduction in CO_2 assimilation.

As for the instantaneous carboxylation efficiency (EiC), expressed by the relationship between net photosynthesis and internal CO_2 concentration (A/Ci), adjustments were similar to the other variables mentioned above (Figure 4C), in which an increase of 16% in relation to the lowest irrigation level was observed, with Ci equal to 0.056 mol m^{-2} s^{-1} and irrigation level of 100% of ETc providing EiC of 0.067 mol m^{-2} s^{-1}. Similar values were found by Dutra et al. [8] with 'BRS Marataoã' bean cultivar, finding EiC of 0.059 mol m^{-2} s^{-1} with estimated irrigation level of 84.5% of ET0. For Silva et al. [20], the A/Ci ratio is used to analyze the non-stomatal factors that hamper the photosynthetic rate and is related to the net photosynthesis rate and CO_2 concentration inside the substomal chamber.

In general, under water stress, plants adopt a conservative mechanism, reducing stomatal conductance and transpiration, thus increasing the water use efficiency. Under these conditions, the photosynthesis rate also ends up being influenced.

The potential photochemical efficiency of PSII measured by the Fv/Fm ratio of common bean under increasing irrigation levels obtained quadratic polynomial response (Figure 5A). A higher Fv/Fm ratio (0.78) was observed with the application of 125% of ETc, decreasing by 1.19% after this level. In the present study, it was observed that when irrigation level of 125% of ETc was applied, there was maximum efficiency in the use of radiation during the assimilation of carbon by plants [27]. The lowest value of this ratio (0.68) occurred in plants submitted to 25% of ETc. Silva et al. [28] reported that when a plant is not under water stress, the Fv/Fm ratio should be 0.75-0.85, while reductions in this ratio indicates some photo inhibitory damage in the reaction centres of PSII. Thus, the value observed in plants submitted to the lowest irrigation level is not within the previously mentioned range, so, it is suggested that the minimum efficiency of the Fv/Fm ratio occurred due to the low water replacement to which these plants were submitted.

According to Tsumanuma and Lunz [29], the Fv/Fm ratio consists of the maximum quantum yield of PSII and reflects the photochemical energy dissipation, indicating the energy capture efficiency through the open reaction centers of PSII. Based on the above, it should be pointed out that soil water deficit due to replacements of less than 50% of ETc results in damage to PSII, reducing the capacity of obtaining energy by the reaction centers, mainly due to the irregularity in the photochemical energy dissipation and reduction of the energy capture efficiency. This damage can also be related to the excess water in the soil, according to the significant reduction in the Fv/Fm ratio observed with irrigation level of 150% of ETc.

In relation to ΦPSII, an increase in its value was observed when the irrigation level was increased up to 15% of ETc (Figure 5B). By deriving the equation, the maximum efficiency value (0.7) was obtained with the aforementioned irrigation level. The lowest ΦPSII value (0.56) was obtained with 25% of ETc, showing a 21% increase when the irrigation level varied from 25 to 140% of ETc. Thus, it is understood that with irrigation (140% of ETc), greater efficiency in the electron transport was observed, reflecting in maximum photosynthetic efficiency.

As for the SPAD index, a quadratic increase as a function of the irrigation levels was also detected (Figure 5C). It was observed that the results of the SPAD index obtained with different irrigation levels increased from 40.93 to 45.75 SPAD units, resulting in a 10.5% increase when the irrigation level increased from 25 to 135% of ETc, with reduction of 0.3% after this level up to the application of 150% of ETc. This result indicates that the amount of chlorophyll in the bean leaf is related to the water status of the plant, which results in high chlorophyll synthesis, consequently increasing the photosynthetic activity and promoting an increase in the yield of this activity [30]. It should be emphasized that, under experimental conditions, values above references do not evidence the need for water replacement.

In relation to production components, Figure 6 shows the results obtained in the production evaluation performed at 78 DAP. In the number of pods per plant (NPP), there was a significant increase attributed to the application of irrigation level of 125% of ETc, with the lowest value observed, on average, 8 pods, with irrigation level of 25% of ETc and mean of 17 pods with application of 125% of ETc, achieving an expressive increase of 52.5% (Figure 6A). These results are higher
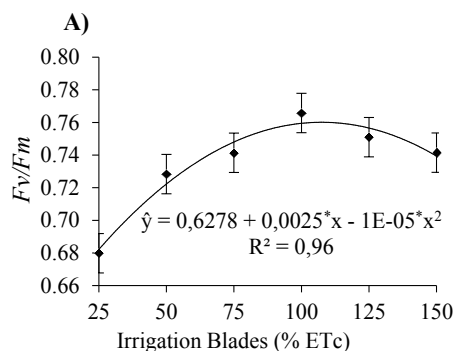
Figure 5A: Potential photochemical efficiency (Fm/Fv) of common bean submitted to different irrigation levels.

$$\hat{y} = 0{,}6278 + 0{,}0025^*x - 1E\text{-}05^*x^2$$
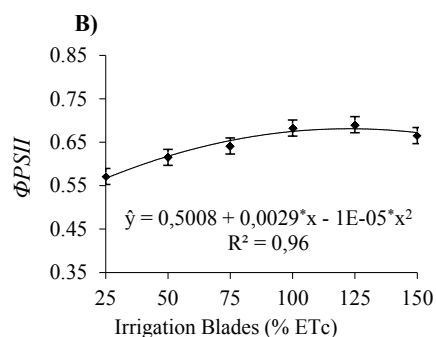$$R^2 = 0{,}96$$

Figure 5B: Effective quantum efficiency (ΦPSII) of common bean submitted to different irrigation levels.

$$\hat{y} = 0{,}5008 + 0{,}0029^*x - 1E\text{-}05^*x^2$$
$$R^2 = 0{,}96$$
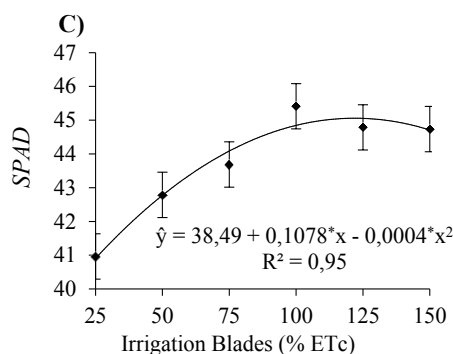
Figure 5C: SPAD index of common bean submitted to different irrigation levels.

$$\hat{y} = 38{,}49 + 0{,}1078^*x - 0{,}0004^*x^2$$
$$R^2 = 0{,}95$$

than those found by Jadoski et al. [31], who found 8.8 pods per plant with 100% of ETc for Guapo Brilhante cultivar, working with irrigation management in Santa Maria, RS. Also working with irrigated bean cultivation, Silveira et al. [32] obtained 10.8 pods per plant. Guerra et al. [33] used Pérola cultivar under irrigation and obtained NPP equal to 14.

Grain yield (GY) and NPP showed quadratic behavior (Figure 6B). This shows that treatment with 125% of ETc obtained maximum productivity (2.230 kg ha^{-1}). Similar values were observed by Gomes et al. [34], who obtained productivity of 2.224 kg ha^{-1} with the highest irrigation level (120% of ET0), studying the agronomic performance of common bean under irrigation in the north western region of

Figure 6A: Number of pods per plant (NPP) of common bean submitted to different irrigation levels.
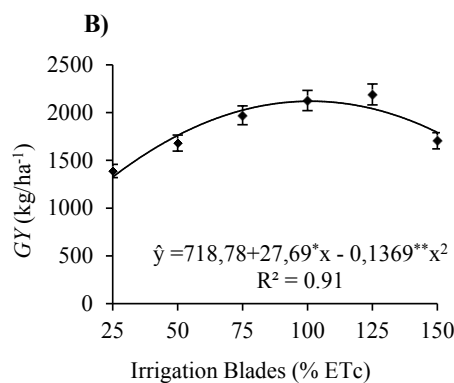
Figure 6B: Grain yield (GY) of common bean submitted to different irrigation levels.

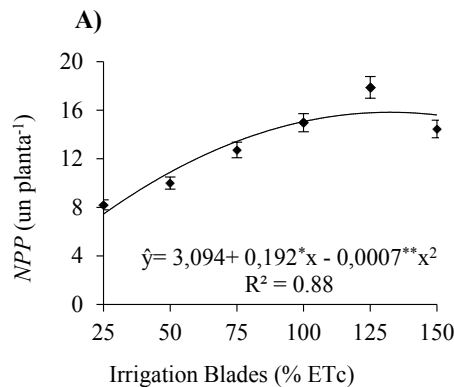Paraná. Brito et al. [4] found 1.487 kg ha^{-1} in cultivation without water restriction in the state of Alagoas. According to Silva et al. [28] bean crop can reach yields of more than 3.000 kg ha^{-1} in irrigated crops with high technological level.

Thus, the potential of common beans in the production of NPP and PROD in situation of non-water restriction was demonstrated.

Water deficit in the vegetative period directly influences gas exchanges and photochemical efficiency, leading to reduced plant growth and consequently decreased productivity [35]. In study conducted by Ávila et al. [36] even though water deficit no longer occurred from the beginning of flowering, productivity was lower in relation to irrigated treatment due to the reduction in grain mass and lower number of pods per plant. Thus, the importance of irrigated bean cultivation in regions where there is a potential risk of the plant to go through periods of water stress should be highlighted, since there are soils with low water retention capacity especially in the sowing period.

Conclusions

The water application variation (% ETc) promoted a significant difference for gas exchanges, except for the instantaneous water use efficiency.

Water stress causes a reduction in the potential and effective photochemical efficiency of common bean (Crioula variety).

The increase in the application of irrigation levels as a function of ETc significantly influenced the SPAD index.

Water application levels equal to 125% of ETc promoted a higher number of pods per plant and grain yield.

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