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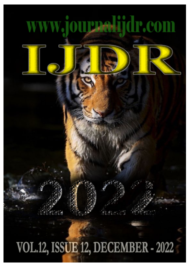

RESEARCH ARTICLE

OPEN ACCESS

ECONOMIC USE OF WATER IN THE CULTIVATION OF IRRIGATED CAUPI BEANS IN THE SEMI-ARID REGION OF BRAZIL

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ABSTRACT

Irrigation in agriculture allows to give conditions for plants to express their full production potential in the field, but scientific studies are needed to optimize the use of water in regions that are difficult to access, such as semi-arid regions. In view of this, the present work aimed to determine the economic irrigation depth for the cultivation of cowpea beans in the region of Sertão Alagoano. A creole bean variety commonly cultivated by farmers was used, which was subjected to five irrigation depths (30, 60, 90, 120 and 150% of the evapotranspiration of the culture, ETc). The experiment was developed at the Federal Institute of Alagoas/Campus Piranhas, during the months of February to May 2018. The crop was irrigated by drip, in which the costs of irrigation plus the costs of planting and cultural treatments were used to determine the economic level of water, through the analysis of grain yield. Agricultural yield differed statistically between the depths applied, according to F test ($p<0.05$). The caupi bean has a low response to irrigation, in which the economic irrigation depth is independent of the sale price of the grain and is close to the irrigation depth that provides maximum physical yield.

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INTRODUCTION

The cowpea (*Vigna unguiculata* (L.) Walp.), also known as green beans, is a food culture that has been part of the Brazilian diet since the mid 16th century (COSTA, 2020). In Brazil, culture has great socioeconomic importance, ensuring food and nutritional security of a large part of the Brazilian population, especially in the North and Northeast regions, where it is most cultivated and consumed (ARAÚJO, 2020). In addition, it is an important generator of jobs of economic occupation and formal work, supplying a production chain that extends from the family farmer and large agricultural enterprises, through several actors in the area of processing, from wholesale and retail trade to the consumer, in small and medium-sized cities and in large urban centers. The production of caupi beans in Brazil is 712.6 thousand Mg, with the contribution of 476.9 thousand Mg from the Northeast region, in which the State of Alagoas is responsible for 0.7%. Brazil has a planted area of 1,307.8 thousand ha of caupi beans in which the Northeast has 83.3% of this total with a yield of 438 kg ha^{-1}, while Alagoas has 6.3 thousand ha of planted area with yield of 562 kg ha^{-1} (CONAB, 2020). However, despite being the largest producer and consumer of cowpea beans in the country, the Northeast region has an average yield below 400 kg ha^{-1}, an index below the North and Midwest regions, other producers of the culture in the country (EMBRAPA ARROZ E FEIJÃO, 2020). This scenario is attributed to the traditional production system used by family farmers, the lack of technical assistance and the use of techniques and technologies that help in the optimization of the system, such as the use of irrigation. Despite its good adaptability to adverse conditions, in order for the crop to produce satisfactorily, water must be available in adequate quantity, this being one of the main factors that can interfere with its yield (AZEVEDO et al, 2011). Knowledge of the water need of the culture is of great importance for the proper management of it, as well as the understanding of the relationship between water consumption and yield (NASCIMENTO; PEDROSA & TAVARES-SOBRINHO, 2004). For this, it is necessary to know the atmospheric demand and the physical-water characteristics of the soil to then determine the economic irrigation depth for the crop.

Proper management of irrigation, through the use of the economical irrigation depth is the simplest way to ensure satisfactory yield results, in addition to optimizing the production system. The efficient use of water (EUW) is essential, especially in regions where there is a shortage of this resource, to ensure its conservation, contributing to sustainable development. Precisely in the region of the Sertão Alagoano, where the irrigated perimeters on the banks of the São Francisco River and the progress of the construction of the sertão canal arouses interest in studying this plant and the efficient use of water. The amount of precipitation in the region of the municipality of Piranhas-AL meets the water demand of the caupi bean crop, however, due to its irregular distribution, the crop goes through periods of water stress. Water is a non-renewable resource and its use in agriculture must be done in a rational way, since 70% of the use of fresh water in the world is made only in irrigated agriculture, which is an essential resource for the good development of crops. Thus, the need for the efficient use of water in agricultural production is further reinforced, providing greater profits for producers in the region. In addition, the cultivation of caupi beans is mainly produced by family farmers, a class that needs assistance and technical information to improve the production system. In view of the above, the objective of this work was to determine the economic irrigation depth for the cultivation of caupi beans in the region of the Sertão Alagoano.

MATERIAL AND METHODS

The research was conducted in the experimental area of the Federal Institute of Alagoas/Campus Piranhas from February to May 2018. The climate classification of the region by the Köppen method is of the BSh type, very hot climate, semi-arid, steppe type, with a rainy season centered on the months of March to July. The average annual rainfall in the region is 492. mm (SANTOS et. al, 2017). The soil of the area was classified as Luvissolo Crômico órtico by Fernandes (2010). The physical analysis was performed at the Irriation and Salinity Laboratory (LIS) of UFCG, with the following results: franco-argilous texture, density of 1.19 g cm^{-3}, porosity of 55% and humidity of 0.21 cm^3 cm^{-3}. The Field Capacity (CC) of the soil of the experimental area is 0.33 atm, the Permanent Weed Point (PMP) of 15 atm and Available Water Capacity (CAD) is 0.96 mm cm^{-1}. The experimental design used was in bands with four repetitions. The main treatments were irrigation depths (30, 60, 90, 120, 150% of the ETc). The plots in each block were composed of 4 rows of 5.0 m in length spaced at 0.80 m, resulting in a total area of 368 m^2, and the useful area was composed of the central 3 m of the two middle lines.
Planting was done in manually open grooves, in which 4 seeds were placed every 20 cm. The fertilization was carried out according to the recommendations of Melo et. al (2018), in which the doses of 20 kg ha^{-1} of P2O5 and K2O were used in the planting. At 15 days after sowing (DAS), the thinning was carried out, leaving the plant more vigorous and a final stand of 62,500 plants per hectare. Cover fertilization was carried out at 16 DAP, in which the doses of 20 kg ha^{-1} of P2O5 and K2O and 36 kg ha^{-1} of N were used. Cut and dry vegetable material was used for the dead cover on the soil surface, placed right after planting (at 21 DAP) in the quantity only to cover the soil, a layer of 3 to 5 cm. The control of spontaneous herbs was carried out with manual weeding according to the need. Irrigation was carried out via a drip system with a flow rate of 7.5 L h^{-1} m^{-1}, a nominal pressure of 10 mca and spacing between drippers of 20 cm. In the first twenty days all treatments were irrigated so that the crop did not suffer water deficit. From this period (21 DAP), the irrigation depths were differentiated according to the treatments and determined according to the evapotranspiration of the culture (ETc). The meteorological data for this ETc estimate were obtained at the automatic data acquisition station of the National Institute of Meteorology (INMET), located in Ifal/Piranhas near the experimental area.

ET_0 was calculated by the Penman-Monteith method:

$$ETo = \frac{0,408\ \Delta(R_n - G) + \left(\gamma \frac{900}{T+273}\right) u_2 (e_s - e)}{\Delta + [\gamma(1 + 0,34\ u_2)]} \quad (1)$$

Where: Δ is the slope of the saturated water vapor pressure versus air temperature curve (kPa $°C^{-1}$); Rn is the measured net radiation (MJ m^{-2} day^{-1}); G is the heat flux in the soil (MJ m^{-2} day^{-1}); γ is the psychometric coefficient; T is the average air temperature; u_2 is the average wind speed at 2 m height (m s^{-1}); e_s is the air vapor saturation pressure (kPa) and e is the air vapor vapor pressure (kPa). At the time of the harvest, the yield of the bean was determined by the average weight of the grains, in which the samples were placed in a drying greenhouse for 48 hours at 65 °C to correct the humidity to 13%. Through the grain yield data and ET_0, the efficiency in the use of water by the crop (USA) was determined in mm per ton:

$$EUA = \frac{W}{Pt} \quad (2)$$

On what: Pt - is agricultural yield (Mg ha^{-1}); W - is the irrigation depth used (mm). The function of culture response to irrigation depths was obtained by second-degree polynomial regression curves (FRIZZONE, 1993) with the independent variable according to Equation 3:

$$Y = b_0 + b_1 x - b_2 x^2 \quad (3)$$

On what: Y - is agricultural yield (kg ha^{-1}); x - is the total irrigation depth; and b0, b1 and b2 - are the coefficients of the equation. The equation used to estimate the irrigation depth that provides the maximum yield was deducted equal to zero the first derivative of the production function, according to Equations 4 and 5 (FRIZZONE, 1993):

$$Y' = b_1 - 2b_2 x \therefore b_1 - 2b_2 x = 0 \therefore -2b_2 x = -b_1 \quad (4)$$

$$X_{máx} = -\frac{b_1}{2b_2} \quad (5)$$

Where: X_{max} - It is the irrigation depth that provides the maximum agricultural yield (kg ha^{-1}). Subsequently, the maximum yield (Y_{max} in kg ha^{-1}) was estimated by substituting x for X_{max} in Equation 3. For the economic analysis of production, the price of the millimeter of water applied was calculated based on actual values, taking into account the use of drip irrigation systems (Table 1), considering 20 years of useful life of the hydraulic infrastructure and 4 years for the superficially managed irrigation system, this being the amortization period for the capital employed, considering three cycles of irrigated.
The sales prices of beans used for the calculation of remuneration were three standardized values due to the variation in quotation during the harvests, so that they can be used as comparisons in administrative decision-making (Table 2).

The irrigation depth of maximum economic efficiency was estimated by Equation 6 (FRIZZONE, 1993):

$$X_{ec} = \frac{P_x - P_y b_1}{2 P_y b_2} \quad (6)$$

On what: X_{ec} - is the N dose and irrigation depth that provides the optimal economic yield (kg ha^{-1}); P_x - is the average cost of mm of water (R$ mm^{-1}) and kg of (R$ kg^{-1}); P_y - is the selling price of kg of corn (R$ kg^{-1}); b1 and b2 - are the coefficients of the production function (Equation 3). Subsequently, the yield of maximum economic efficiency was estimated replacing x with X_{ec} in Equation 3. The agricultural contribution margin was estimated by Equation 7 (SILVA et. al, 2015):

$$MCA = P_y Y - \left(P_x L + C_{op}\right) \quad (7)$$

Where: MCA - is the agricultural contribution margin (R\$ ha^{-1}); Y - is the yield of beans (kg ha^{-1}); P_y - is the price of the kilogram of beans (R\$ kg^{-1}); P_x - is the cost of the millimeter of water for drip irrigation (R\$ mm^{-1}); L - is the total gross irrigation depth; C_{op} - is the operational cost of producing beans (R\$ ha^{-1}). The production results obtained through the agronomic variables were subjected to the analysis of variance by the Fisher test at the probabilities of 1 and 5%, and from which the production function of the crop was obtained to carry out the economic analysis.

RESULTS

Rainfall during the bean production cycle (22/02/2018 to 09/05/2018, 77 days) totaled 78.2 mm, and 26% (20.6 mm) of this rain occurred in only one day (23/02/2018), characterizing irregular distribution of rainfall during the cultivation period (Figure 1). However, this time of year does not correspond to the rainy season of the region. The total reference evapotranspiration (ET_0) in the cultivation cycle was 262.8 mm, with a minimum of 2.7 mm day^{-1} (13, 21 and 22/04; and 01/05 of 2018), a maximum of 6.8 mm day^{-1} (March 15, 2018) and an average of 4.6 mm day^{-1}. Lower ET_0 values are observed in the period in which there is the occurrence of rainfall, when there is high cloudiness and decrease in the intensity of solar radiation, the heating of the atmosphere and, consequently, in atmospheric water demand. Irrigation was fully applied throughout the 1st phase of crop development (February to March 2018) due to the low occurrence and irregularity of rainfall in most of this period to meet the water demand of plants (Figure 1), in which a 2.7 mm dia^{-1} irrigation depth was used to meet the water need of the crop (ETc).

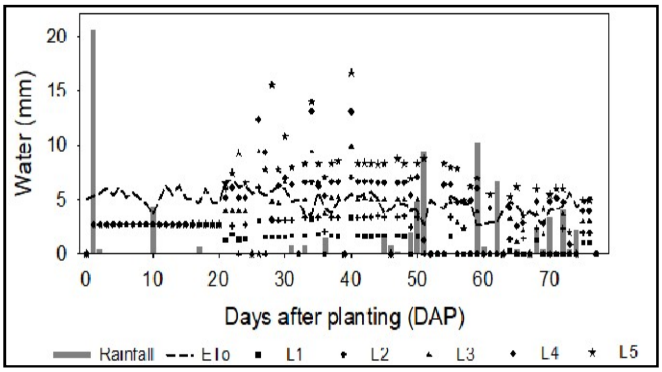

Figure 1. Daily values of rain, reference evapotranspiration (ET_0) and applied irrigation depths treatments (L1, L2, L3, L4 and L5) during the cultivation of caupi beans between fervereiro and May 2018, in the region of Piranhas-AL

The differentiated irrigation depths were started in the period between the end of the initial phase and the beginning of the crop growth phase (21 DAP). The average daily values of the irrigation depths applied were 1.6; 3.3; 4.6; 5.8 and 7.6 mm in L1, L2, L3, L4 and L5, respectively. In this geographical region it is important to pay attention to the use of drip irrigation, as lateral infiltration of the water can occur due to a saturated soil condition, since the soils are shallow and there is an impediment to drainage by the rock matrix. Throughout the initial phase of the crop (0-20 DAP), all treatments remained with the storage of water in the soil (ARM) equal to the available water capacity (CAD = 20 mm), due to the irrigation carried out in this period, so that the plants did not suffer stress in this period (Figure 2). From the growth phase, the ARM of L1, L2 and L3 was below the limit of easily available water (water fraction in the soil that can be easily absorbed by plants - AFD) in most days as a result of the irrigation, in which the water deficiency was of great intensity, especially in the phase when the crop was in maximum growth, requiring greater water consumption for its physiological In L4 and L5 treatments, the ARM remained close to CAD throughout the cultivation period, since they were irrigated with irrigation depths larger than ETc. During the differentiation of irrigation depths, there were some reductions in the ARM of these treatments due to pressure problems in the system, yet it was not enough to compromise the culture.

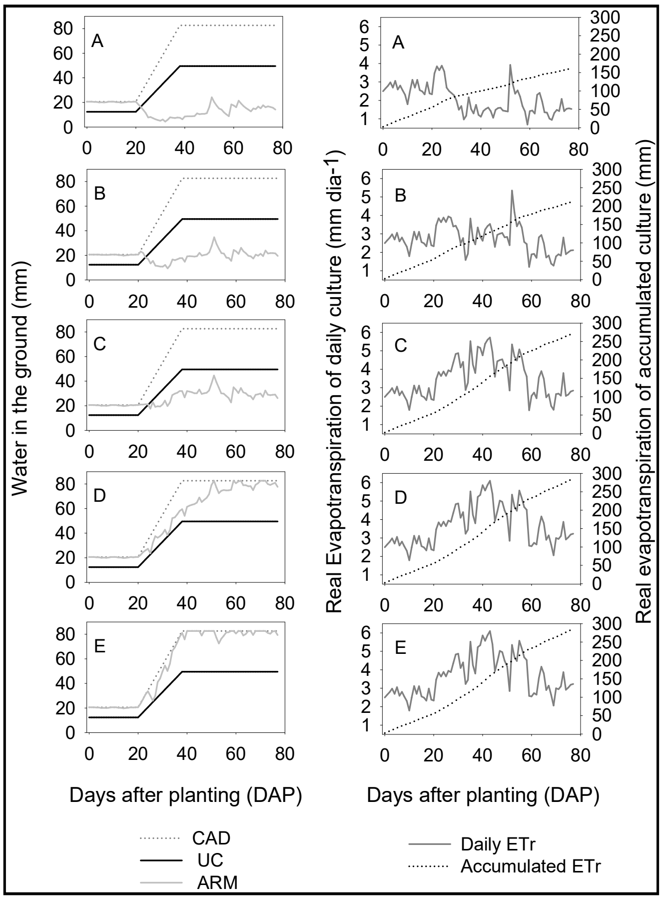

Figure 2. Daily values of CAD, AFD limit (UC-critical humidity), ARM and daily and accumulated actual evapotranspiration (ETr) of the crop for treatments with different irrigation depths (A-L1, B-L2, C-L3, D-L4 and E-L5) during the cultivation cycle of the cowpea between February and May 2018, in the Piranhas-AL.

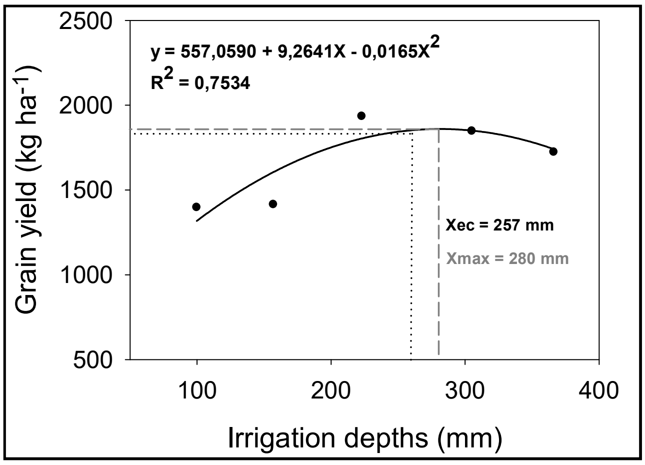

Figure 3. Agricultural yield of caupi beans due to different irrigation depths, in the Piranhas-AL region

The actual evapotranspiration of the culture varied between treatments with means of 1.9; 2.8; 3.8; 4.0 and 4.0 mm dia^{-1} and accumulation of 161.5; 210.7; 272.4; 286.0 and 286.0 mm day^{-1} for irrigation treatments with 30, 60, 90, 120 and 150% of Etc. The analysis of the variance of the variables: number of pods per plant

(NVP), number of grains per pod (NGV) and yield (kg ha^{-1}); is presented in Table 3. It is observed that there was a significant difference between irrigation depth treatments for the variables NVP and yield at 1% probability, with the coefficients of variation of 9.6 and 11.1%, respectively, indicating good accuracy with which the data were analyzed. The quadratic polynomial regression curve for agricultural yield of beans as a function of the irrigation depths in the cultivation cycle is found in Figure 3.

The agricultural yield of maximum economic efficiency with the minimum price of R$ 3.00 per kg of grain was 1,840.5 kg ha^{-1}, obtained with a 257 mm irrigation depth. For the average price of 4.67 R$ kg^{-1}, the maximum economic efficiency agricultural yield was 1,853.7kg ha^{-1} obtained with 266 mm. With the price of the bean of 6.33 R$ kg^{-1}, the maximum economic irrigation depth was 270 mm and generated agricultural yield of 1,855.4 kg ha^{-1}.

Table 1. Cost of the millimeter of water for drip irrigation in the corn crop

Descrição	R$ ha^{-1} $cycle^{-1}$	R$ mm^{-1}	%
Hydraulic infrastructure/Buildings (amortization in 20 years - 60 cycles)	40,60	0,12	5,0%
Irrigation system (amortization in 4 years - 12 cycles)	600,52	1,72	74,5%
Operating cost of irrigation per cycle	165,29	0,47	20,5%
Total cost of irrigation per cycle	806,41	2,30	100
Operation of the irrigation system for 3 production cycles per year			
Average irrigation depth per cycle: 350 mm	mm		

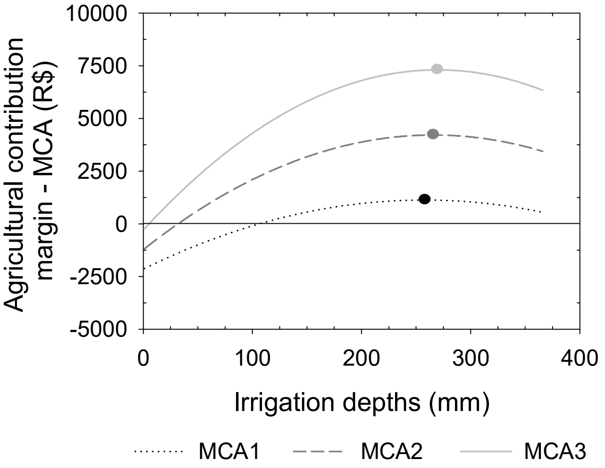

Figure 4. Margins of agricultural contribution for beans for prices of 3.00 R$ kg^{-1} (MCA1); 4.67 R$ kg^{-1} (MCA2); 6.33 R$ kg^{-1} (MCA3), in irrigated cultivation in the Piranhas-AL region

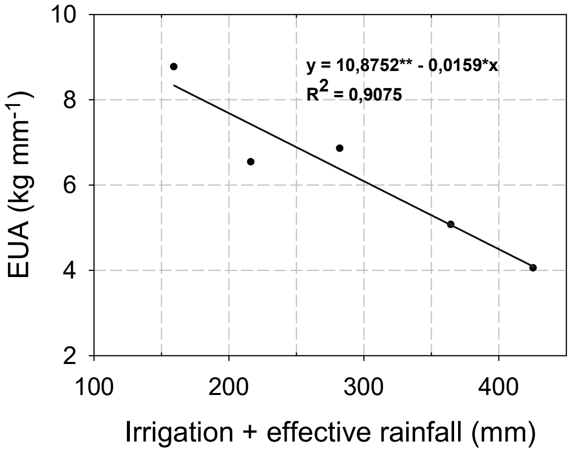

Figure 5. Efficiency in the use of water by caupi beans as a function of irrigation depths (30, 60, 90, 120 and 150% of ETc) plus effective precipitation in the municipality of Piranhas- AL

Agricultural yield between L1 and L5 ranged from 1,397.1 to 1,723.6 kg ha^{-1}. It can be observed that the regression curve presents a smooth behavior as the irrigation depths increase, due to the low response of the crop to water, because it is a Creole variety very adapted to the water scarcity conditions of the region.

Table 2. Quotation scenarios of the sack (60 kg) and kg of beans used in the economic analysis according to the sale prices of the Agrolink website, taking into account a margin of R$ 100.00 above and below the real price (consultation in February 2022)

R$ $sack^{-1}$	R$ kg^{-1}
180,00	3,00
280,00	4,67
380,00	6,33

Table 3. Summary of the analysis of variance by test F for productive evaluation carried out in the cultivation of caupi beans with NVP - number of pods per plant, NGV - number of grains per pod and PROD - grain yield (kg ha^{-1}) due to different water depths applied in the Piranhas-AL region

MIDDLE SQUARES			
Source of Variation	NVP	NGV	PROD
Block	$12{,}39^{ns}$	$57{,}32^{*}$	$27.861{,}61^{ns}$
Irrigation depths	$42{,}95^{**}$	$22{,}59^{ns}$	$243.766{,}26^{**}$
CV (%)	9,6	6,6	11,1
Overall Average	21,76	55,14	1.663,63

** significant ($p \leq 0{,}01$), * significant ($p \leq 0{,}05$) and ^{ns} not significant by the F test.

The economic irrigation depths for the different prices of the bean quotation result in agricultural yield close to each other, and similar to maximum physical agricultural yield. The agricultural contribution margin (MCA) becomes positive from the 107 mm irrigation depth for the price of the kg of the grain equal to R$ 3.00 (MCA1), as well as for the prices of R$ 4.67 (MCA2) and 6.33 (MCA3) with the irrigation depths of 32 and 6 mm, respectively (Figure 4). The maximum values of the MCA generated with the prices of beans equal to R$ 3.00; 4.67 and 6.33 kg^{-1} were R$ 4,786.95; 7,748.66 and 10,839.81 ha^{-1} obtained with the irrigation depths of 257, 267 and 270 mm, respectively (Figure 4). It is observed that the differences between the irrigation depths are very low, and that using the minimum economic irrigation depth of irrigation the MCA will be equivalent to the price variations of the kg of beans. It is also possible to observe that the irrigation depth that provide the maximum MCA values are equivalent to the irrigation depth that provide the yield of maximum economic efficiency for the sales price quotes of the beans studied. Thus, the yield of maximum economic efficiency, in practice, can be obtained with the economic irrigation depth of the minimum quotation. Regarding the efficiency in the use of water (EUA) by beans, it is observed that efficiency decreased with the increase of the irrigation depth, since this factor enters as a denominator of this relationship. Thus, the EUA reduced from 8.3 to 4.1 kg of grains per millimeter of water consumed in the depths with 30 and 150% of ETc, respectively (Figure 5), indicating that when irrigation approaches growing conditions without water deficiency, the EUA is smaller. That is, in the condition of water deficit the crop makes better use of the available water, which corroborates the conclusions of Frizzone (1993).

DISCUSSION

Rain events in the cultivation region are not enough to meet the water demand of the crop, and it is necessary to resort to the use of irrigation (SILVA et. al, 2019), to obtain better agronomic yields. Real crop evapotranspiration (ETr) is the amount of water transferred to the atmosphere by evaporation and perspiration, under the real conditions of atmospheric factors and soil moisture (MATZENAUER et. al, 2003). The evapotranspiration of the culture (ETc) suffers interference, in addition to the meteorological and soil variables, of the characteristics inherent to each culture, such as the type of metabolism and size of the leaves, and also, according to the phenology of the plant (SOUZA et. al, 2015). The ETc is adjusted according to the single crop coefficient (Kc) and configures the water demand of the crop according to its characteristics and the climate conditions of the cultivated region. In an irrigated condition, it is attributed that there is no water deficiency, since the water demand of the crop is supplied, thus, there is no stress for the plants (ARAÚJO et. al, 2021). In this sense, in an irrigated regime, the ETr corresponds to ETc. Similar results were found by Mota et. al (2020), who studied the effect of irrigation on three creole varieties of caupi beans and observed low increases in the crop to the increase in irrigation depths, with the maximum yield of 502 and 393 kg ha^{-1} for the Baiano and Caupi-preto varieties with 45 kPa of stress in the soil, From then on the crop showed a negative response; and the Beef Rib variety showed a response curve with a negative trend in all irrigation depth treatments applied. According to the law of decreasing yields, which corresponds to the analysis of response by the agronomic principle known as "the law of the minimum", described by Von Liebig (1840), "the yield of any crop is directed by any change in the quantity and quality of the scarce factor, the so-called minimum factor. In this sense, as the minimum factor is increased, yield is increased in proportion to the supply of that factor until another factor becomes minimum".

This law applies to all living beings; therefore, in this case, as soil moisture in treatments with larger depths was no longer the limiting factor of plant growth, crop yield would only increase under optimal conditions of nutrients, air temperature, light, CO2 and other plant production factors. The maximum physical yield of the crop, estimated by the production function, would be 1,857.4 kg ha^{-1}, obtained with a liquid irrigation depth of 281 mm (Figure 3). According to Silva et. al (2015), for yield above the maximum value, that is, with the crop in optimal conditions of soil moisture, it is necessary to resort to other agricultural practices, such as fertilization, pest and disease control, among others. A similar effect was found by Neves et. al (2021), who studied the economic viability of the bean as a function of irrigation and nitrogen fertilization and observed that with a physical irrigation depth of 448.9 mm and a maximum economic irrigation depth of 446.6 mm, the crop showed yield values equal to 4,89.7 and 4,858.76 kg ha^{-1}, respectively. Osti et. al (2019) studied the effect of growing irrigation depths on the cultivation of beans and observed an increase in net revenue from R$ -256,591.07 to R$ 379,406.71 with the irrigation depths of 295.14 and 635.69 mm, respectively, indicating an increase in the margin of agricultural contribution by the crop by increasing the amount of input applied. However, they did not test a larger irrigation depth to observe the fall of the response curve after reaching the inflection point. The calculation of the costs of inputs in agriculture in search of maximum return on capital covers several factors that are difficult to control, especially when it comes to environmental factors. Thus, works like this provide a basis for administrative decisions, as long as the conditions are similar to those of the place where the research was carried out. In addition, economic issues, such as prices of inputs and agricultural products, are subject to daily changes, being up to the judgment of the administrator to seek the best solution and choose the most advantageous alternative for the use of a certain input. The EUA is an essential variable for the irrigator to use as a reference measure in crop planning and decision-making, since it determines the unit yield as a function of the magnitude of the water depth you want to apply. Silva et al. (2018), studying irrigated corn with water levels between 40 and 160% of ETc, also observed a decrease in the EUA in the form of consumption, from 181.8 to 55.3 mm Mg^{-1}, as the irrigation depths in the Piranhas-AL region increased. The caupi beans have a low response to irrigation. The economical irrigation depth does not depend on the sale price and approaches the irrigation depth that provides maximum physical yield. The irrigation depth of maximum physical yield is around 280 mm (121% of ETc), and promotes an average grain yield of 1,857kg ha^{-1}. The irrigation depth of maximum economic efficiency is around 257 mm (111% of ETc), and promotes an average grain yield of 1,848kg ha^{-1}. The sale prices of the kg of grain equal to R$ 3.00, 4.67 and 6.33 result in average profitability of R$ 1,127.13, 4,213.26 and 7,304.41, respectively.

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