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Economic indicators for cowpea cultivation under different irrigation depths[1]

Indicadores econômicos para o feijão-caupi cultivado sob diferentes lâminas de irrigação

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HIGHLIGHTS:

Irrigation positively influences gross revenue and profitability index.
Cowpea yield was negatively affected by the occurrence of extreme weather events.
Deficit irrigation of up to a depth of 50% of water demand provides water sustainability and production profitability.

ABSTRACT: Cowpeas are of high socioeconomic importance in the North and Northeast regions of Brazil, whereby the search for alternatives that offer increased productivity with financial returns has become an important challenge. Thus, the objective of this study was to estimate and evaluate the economic indicators of cowpea production in 2015 and 2016 when applying drip irrigation to different depths. Irrigation treatments were based on crop evapotranspiration (ETc). The experiment was laid in a randomized complete blocks design with four treatments (0, 25, 50, and 100% ETc) and six replications. For economic analysis, the results were extrapolated to an area of one hectare. Productivity in 2015 was lower than that in 2016; however, in all treatments, it was always higher when plants were grown under adequate water supply. In both years, the total operating costs were higher under irrigation than under rainfed conditions. The 100% ETc treatment resulted in a greater number of cowpea bags (60 kg) produced and a higher gross revenue than the rainfed treatment by 17 bags ha^{-1}, equivalent to 1,020 kg ha^{-1} (gross revenue US$ 711.48) and 16 bags ha^{-1}, equivalent to 960 kg ha^{-1} (gross revenue US$ 867.12), in 2015 and 2016, respectively. Water deficit limited cowpea yield in both years but made cultivation economically unfeasible only in 2015.

Key words: *Vigna unguiculata*, dripping irrigation, profitability, Northeastern Pará

RESUMO: O feijão-caupi apresenta grande importância socioeconômica nas regiões Norte e Nordeste do Brasil, sendo que a busca por alternativas que ofereçam aumento de produtividade com retorno financeiro tem se tornado um importante desafio. Assim, o objetivo deste trabalho foi estimar e avaliar os indicadores econômicos da produção de feijão-caupi nos anos de 2015 e 2016 quando da aplicação de irrigação por gotejamento em diferentes lâminas. Os tratamentos de irrigação foram baseados na evapotranspiração da cultura (ETc). O experimento foi instalado em blocos ao acaso com quatro tratamentos (0, 25, 50 e 100% da ETc) e seis repetições. Para análise econômica, os resultados foram extrapolados para uma área de um hectare. A produtividade em 2015 foi inferior à de 2016; porém, em todos os tratamentos, a produtividade foi sempre maior quando as plantas foram cultivadas sob irrigação adequada. Em ambos os anos, os custos operacionais totais foram maiores sob irrigação do que sob condições de sequeiro. O tratamento 100% ETc resultou em maior número de sacas de feijão-caupi (60 kg) produzidas e receita bruta superior ao tratamento de sequeiro em 17 sacas ha^{-1}, equivalente a 1.020 kg ha^{-1} (receita bruta US$ 711,48) e 16 sacas ha^{-1}, equivalente a 960 kg ha^{-1} (receita bruta US$ 867,12), em 2015 e 2016, respectivamente. A deficiência hídrica limitou a produtividade do feijão-caupi nos dois anos, mas inviabilizou economicamente o cultivo apenas em 2015.

Palavras-chave: *Vigna unguiculata*, irrigação por gotejamento, rentabilidade, nordeste do Pará

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Introduction

Cowpea (*Vigna unguiculata* (L) Walp.) is cultivated mostly in northern and northeastern Brazil, where, specifically, northeastern Pará is one of the main producers of this legume (Vieira et al., 2020). In this region, cowpeas are grown only in the dry season (Pinto et al., 2021), with the growing season comprising the end of the rainy season with a low water supply for the crop (Souza et al., 2020a). Consequently, the average productivity of the crop in the State of Pará is only 821 kg ha^{-1} (Souza et al., 2020b). Such productivity is below crop potential and likely associated with the prevalent limited water availability, as despite being considered tolerant to water deficit, cowpeas tend to show higher yields with a higher water supply, especially during the reproductive phase (Farias et al., 2017).

The environmental impacts resulting from traditional irrigation have given greater focus to efficient irrigation management as an effective means to ensure an adequate water supply for the crop without disregard for economic aspects via a shallower depth of water application to warrant profit (Fito & Van Hulle, 2021).

Micro-irrigation methods, such as drip irrigation, allow the precise application of small amounts of water directly to the root zone and, when associated with fertigation, increase crop productivity and ensure greater water use efficiency, nutrient supply, soil fertility, environmental sustainability, and profit (Surendran & Chandran, 2022). Thus, for example, Shinde et al. (2021) recommend drip over microsprinkler irrigation, as it saves approximately 32% more water than the latter, which is critical in places where water availability is low.

Economic indicators, such as gross revenue, operating profit, profitability index, equilibrium price, and equilibrium productivity, are valuable tools for a more efficient economic analysis, as they allow determining whether the use of irrigation is profitable for crops such as cowpeas through estimates of production costs and implementation of this system (Barbosa et al., 2014).

Although there are some studies on the economic performance of irrigated cowpeas, as for example, in Maranhão (Castro Júnior et al., 2015), crop water demand depends on the edaphoclimatic conditions of each region. Therefore, it is necessary to study economic performance at each location of interest. Thus, the objective of this study was to estimate and evaluate the economic indicators of cowpea production using a drip irrigation system at different depths, in the municipality of Castanhal, Pará State.

Material and Methods

In this study, we used data on cowpea production from 2015 to 2016. The experiment was conducted at the Experimental Farm of the Federal Rural University of Amazonia-UFRA (1° 19' 24.48" S, 47° 57' 38.20" W; 41 m elevation), in the northeast region of the state of Pará, in the municipality of Castanhal.

According to the classification by Köppen, the local climate is characterized as Am, that is, a tropical climate with an average annual temperature of approximately 26 °C, maximum and minimum air temperatures of 28 and 22 °C respectively, and an annual rainfall above 2,000 mm (Alvares et al., 2013). During the experiment in 2015, the average air temperature was 28 °C (±0.51) ranging from a minimum of 26.25 °C to a maximum of 28.69 °C and total rainfall of 30 mm. In turn, during the experiment in 2016, the average air temperature was 27.1 °C (±0.53) with a minimum of 25.94 °C and a maximum of 28.18 °C and a total rainfall of 153 mm.

The soils at the site are classified as Oxisols (United States, 2014), which corresponds to the Latossolo Amarelo class in the Brazilian Soil Classification System (EMBRAPA, 2018), with a sandy loam texture with 4% clay. The soil was conventionally prepared and fertilized according to chemical analysis (Table 1), using 300 kg ha^{-1} (NPK, 10-20-20) and 210 kg ha^{-1} (NPK, 9-18-15), following recommendations by EMBRAPA Amazônia Oriental.

The cowpea cultivar used was BR3-Tracuateua, and was sown in an area of approximately 0.5 ha. The spacing adopted was 0.5 m between rows and 0.1 m between plants for a population density of 200,000 plants ha^{-1}. The experiment was laid in a complete randomized block design with four treatments, namely, 0, 25, 50, and 100% of crop daily evapotranspiration (ETc), and six replicates. Treatments were applied at the beginning of the reproductive phase (i.e., approximately 36 days after sowing, DAS).

Cowpea developmental stages were observed using the scale of Gepts and Fernández, as described by Farias et al. (2017), based on daily monitoring of three 1 m rows each with 10 plants in each treatment. Developmental stages were as follows: V0 (germination), V1 (cotyledons above the soil), V2 (expanded cotyledon leaves) V3 (1st trifoliate leaf open), V4 (3rd trifoliate leaf open), R5 (1st flower bud), R6 (anthesis of 1st flower), R7 (1st pod), R8 (grain filling), and R9 (physiological maturity).

Drip irrigation was applied at a flow rate of 1.03 L h^{-1} and an application efficiency of 81%. Management was based on crop evapotranspiration (ETc) calculated by reference evapotranspiration (ETo) as estimated by Penman-Monteith (Allen et al., 1998) and using the crop coefficient (Kc) obtained by Bastos et al. (2008).

Table 1. Chemical and physical characteristics of Oxisols (Latossolo Amarelo), referring to the soil from the 2015 and 2016 experiments

Characteristics	Samples (0-20 cm)	
	2015	2016
pH (H_2O)	4.9	3.7
N (%)	0.05	0
P (mg.dm^{-3})	2	20
K^+ (mg dm^{-3})	26	30
Na^+ (mg dm^{-3})	9	2
Ca^{2+} (cmolc dm^{-3})	0.5	1
Mg (cmolc dm^{-3})	0.2	0.2
Al^+ (cmolc dm^{-3})	0.8	0.6
Sand (g kg^{-1})	835	835
Silt (g kg^{-1})	125	125
Clay (g kg^{-1})	40	40
Soil bulk density (g cm^{-3})	1.56	1.56
Field capacity (FC) (m^3 m^{-3})	0.20	0.20
Permanent wilting point (PWP) (m^3 m^{-3})	0.11	0.11
Easily available water (EAW)*	0.17	0.17

*Obtained at an effective root depth of 25 cm and a sensitivity factor of 0.4

A 3-m high micrometeorological tower equipped with sensors for ambient temperature and air relative humidity was installed at the center of the planting area (Thermo-hygrometer, Vaisala, HMP45a), rainfall (Rain Gauge, Campbell Sci., TB4), and soil moisture (TDR, Campbell Sci., CS616) connected to a data recorder (Campbell Sci. CR10x), with readings made continuously at 10 s intervals and averages recorded every 10 min.

Yield was evaluated at 65 DAS in 2015 and 68 DAS in 2016, when 90% of the plants reached the R9 phenological stage. At the time, the pods and grains of the plants in the three central lines in each experimental plot were harvested and counted. Harvesting was performed in two planting rows previously separated in each treatment, from where plants in three 1-m^2 subplots were collected, represented by 2 m rows. Sampled pods were dried for 72 hours and subsequently weighed to estimate yield in each treatment. They were then subjected to regression analysis as a function of the level of water deficit (DEF), with the generated equations checked based on the F test at 5% significance using the statistical program Assistat.

For economic analysis, treatments were considered commercial crops, and all values were estimated for 1 ha. The total operating cost (TOC) proposed by Martin et al. (1998) was used to calculate production costs. TOC comprises technical assistance expenses, interest, and effective operating cost (EOC), which includes expenses related to inputs, services, and depreciation.

Costs were determined through the following items: 1) services, with average number of men per day defined for the execution of each task, multiplied by the average amount paid in the region; 2) materials, calculated by multiplying the quantity of each material used by the corresponding unitarian price; and 3) technical assistance, taking into account a 3% rate of EOC expenditure.

The cost of irrigation was generated in R$ mm^{-1} by adding the cost of the irrigation project plus the energy consumption for the application of water, and then converted to US$ according to the dollar exchange rate in 2016 (US$1 = R$3.49). In this study, the values of the motor pump plus the necessary hydraulic pipes, a depreciation of 20 years, and a maintenance cost of the system at a rate of 1% (CONAB, 2010) were considered. To calculate the cost of electricity, the time at which the irrigation system was turned on for each treatment and the price of the B2 tariff for rural properties, also in dollars according to the 2016 exchange rate, were considered (US$ 0.1201 KW h^{-1}) according to Eq. (1), as suggested by Pereira et al. (2018).

$$CE = V_{kWh} \times T \times \frac{736Pot}{1000\eta} \quad (1)$$

where:

CE - energy cost (US$);
V_{kWh} - kWh value (US$);
T - total operation time of the irrigation system (h), variable for each treatment
Pot - power of the motorcycle pump set (cv); and,
η - performance of the motor pump set (decimal).

For the economic evaluation of the treatments, the following indicators were calculated based on the methodology proposed by Martin et al. (1998):

$$GR = QP \times PPU \quad (2)$$

where:

GR - gross revenue;
QP - number of bags of 60 kg produced; and,
PPU - price per unit (average price received).

$$OP = GR - TOC \quad (3)$$

where:

OP - operating profit;
GR - gross revenue; and,
TOC - total operating cost.

$$PI = \left(\frac{OP}{GR}\right) \times 100 \quad (4)$$

where:

PI - profitability index;
OP - operating profit; and,
GR - Gross revenue.

$$EPro = \frac{TOC}{APOTP} \quad (5)$$

where:

EPro - equilibrium productivity;
TOC - total operating cost; and,
APOTP - average productivity obtained by the producer.

$$EP = \frac{TOC}{APRTP} \quad (6)$$

where:

EP - equilibrium price;
TOC - total operating cost; and,
APRTP - average price received by the producer.

Crop productivity in each treatment was converted into commercially available 60-kg bags. Input and service prices were updated for 2015 and 2016, and the sale value of a bag was US$ 42.44 and US$ 56.99, for each year, respectively (CONAB, 2019), according to the dollar exchange rate in 2016 (US$1 = R$3.49).

Results and Discussion

The 2015 experiment was influenced by the climatic phenomenon, El Niño (Grimm & Aceituno, 2015) with a highly significant reduction in rain throughout the cropping cycle. Further, total rainfall during the 2015 cowpea cropping cycle was approximately 19.6% lower than that registered in the 2016 campaign. In 2015, mean air temperature during the experimental period was 28.0 °C, with a relative humidity of

74.7% and a total rainfall of only 30 mm due to the lower cloud cover. In turn, in the experiment of 2016, mean temperature was 27.3 °C, with total rainfall of 153 mm and a mean relative humidity of 73.8%.

The absence of rainfall during the vegetative phase and the occurrence of 30 mm in the reproductive phase in 2015 were the result of El Niño, unlike in 2016, when a total of 141 mm was recorded in the vegetative phase and only 12 mm during the reproductive phase (Figure 1).

As the experiment was conducted during the same period of the year (September to November) in both cases, the meteorological conditions during the two experimental years were similar, except for rainfall, which significantly reduced crop water supply in 2015 (Figure 1 and Table 2).

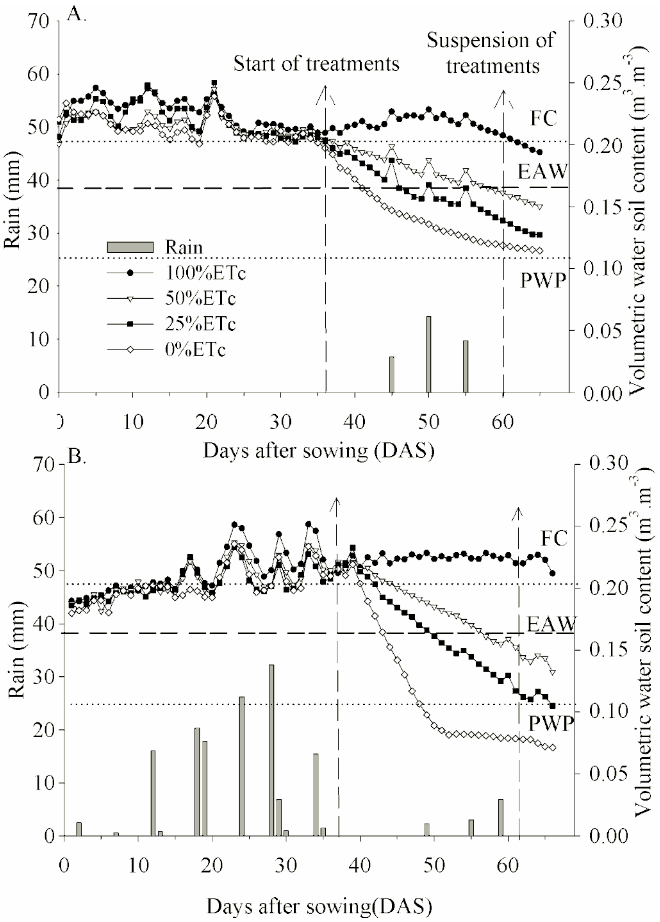

Figure 1. Rainfall, volumetric soil water content, field capacity (FC), easily available water (EAW), permanent wilting point (PWP), and period in which treatments began in the experiments of 2015 (A) and 2016 (B)

For the cultivar used in this region, the total water consumption is approximately 267.7 ± 10.2 mm (Farias et al., 2017) and it can be noted that in both years, cowpea underwent increasing cumulative deficits from 50% ETc treatment, and the observed reduction in yield was attributed to this deficit (Souza et al., 2020a).

Yield increased with increasing irrigation depth with a significant mathematical fit ($p > 0.05$) to the polynomial model in response to accumulated water deficit (DEF). Water depth at 100% replacement of ETc represented the highest yield (Table 2). According to Souza et al. (2020a), water depths below 260 mm during the crop cycle limit yield to values lower than 1,000 kg ha^{-1} for the cultivar adopted in the region. However, the use of irrigation to supply as little as 50% of the water demand during the reproductive phase of cowpea is enough to allow for a significant increase in all yield components and final yield. However, the results presented by the authors did not address economic efficiency.

The positive effect described above is due to the greater availability of water to the crop, which allows adequate plant growth, enabling greater carbon assimilation resulting from stomatal opening and, consequently, the realization of photosynthetic processes, thus allowing greater crop production (Silva et al., 2017).

The water deficit associated with high temperature tends to decrease crop transpiration due to the reduction in stomatal conductance, interfering with latent heat dissipation and causing an increase in leaf temperature, which in turn compromises the productive capacity of cowpea plants, and ultimately reduces plant yield (Souza et al., 2020b).

Studies conducted by Ferreira et al. (2021) with cowpeas showed that under conditions of water deficit, leaf temperature is higher than that observed under ideal water supply, as heat dissipation from the plant body is impaired. In a study on the influence of water deficit on cowpea yield, Souza et al. (2020a) demonstrated that the more severe the water deficit, the lower the crop yield, which is reduced by 41 to 72%.

In this study, input costs contributed the most to total production costs in both years, corresponding to 63.83% for irrigation treatments and 59% for the rainfed treatment; thus, together, expenditures on fertilizers, seeds, and irrigation contributed the most to TOC, contributing approximately

Table 2. Total water depth (from irrigation and rain), yield, and accumulated water deficit (DEF) during the reproductive stage in the cowpea cycle under different irrigation treatments. ETc is crop evapotranspiration; c, b, and a coefficients of the polynomial equation

Years	Treatments	Rain (mm)	Irrigation (mm)	Yield (kg ha^{-1})	DEF (mm)	Regression analysis coefficients (second order polynomial) $c + bx + ax^2$	R^2
2015	100%ETc	30.5	113.5	1474.1	0	$-1{,}204.34 + 11.12^{*}x - 0.01^{*}x^2$	0.998
	50%ETc		56.7	1098.0	30.2		
	25%ETc		28.4	943.9	57.7		
	0%ETc		0	468.3	112.5		
2016	100%ETc	12.2	113.8	1597.1	0	$-3{,}195.11 + 23.20^{*}x - 0.03^{*}x^2$	0.999
	50%ETc		56.9	1295.3	33.1		
	25%ETc		28.4	1069.8	59.0		
	0%ETc		0	684.3	94.5		

* Significant at $p \leq 0.05$ by F test

51% of TOC in the irrigation treatments and 44% of TOC in the treatment without irrigation.

Costs varied depending on irrigation depth; however, they were similar. In 2015, TOC values ranged from US$ 65.90 to US$ 69.91, depending on management (Table 3). Similarly, in 2016, TOC values for irrigated treatments were also higher than those for rainfed treatments, ranging from US$ 61.89 to US$ 65.90. TDC corresponded to an average of 13.3%, 12.9%, and 12.6% of TOC, and 12.6%, 12.1%, and 11.9% of TOC, under 100%, 50% and 25% ETc, respectively (Table 3).

The values for TDC and TOC in 2016 were lower than those in 2015, presumably owing to the low rainfall registered in 2015, which was 123 mm lower than that in 2016 (Table 2), and contributed to a significantly higher crop water demand. The increase in the amount of water supplied to the crop reportedly causes an increase in the cost of electricity resulting from a longer irrigation time, which in turn increases total production costs (Kahramanoğlu et al., 2020).

In the two years analyzed herein, the 100% ETc treatment showed a higher yield than any other treatment (Table 4). Furthermore, comparing 100% ETc with 0% ETc in 2015, yield was higher by approximately 17 bags ha^{-1} (1,020 kg ha^{-1}), which also contributed to a higher gross revenue of approximately US$ 711.48. Similarly, in 2016, the 100% ETc treatment showed a yield which was 16 bags ha^{-1} (960 kg ha^{-1}) greater than that of the 0% ETc treatment, and a gross revenue exceeding US$ 867.12 (Table 4).

These results corroborate reports by Ramos et al. (2014) and Souza et al. (2020a), who found that the use of irrigation for bean and cowpeas resulted in productivity gains, whereas water deficit caused a decrease in gain. The effects of a water deficit vary according to the intensity, phase, and stage of crop development, with flowering and pod formation being the most sensitive (Brito et al., 2016). A water shortage causes a decrease in the number of pods and increased abortion of flowers and eggs, resulting in lower grain production (Silva et al., 2020).

A positive operating profit was observed in all irrigation treatments tested, compared to the treatment without irrigation in 2015, because of plant damage caused by water deficit under rainfed conditions (US$ -121.41). Conversely, in the same year, the 100% ETc treatment showed the highest profit (US$ 516.30). Similarly, in 2016, the highest profit (US$ 995.13) was attained under the 100% ETc treatment, and the lowest (US$ 197.36) was recorded for the rainfed treatment (Table 5).

According to Grimm & Aceituno (2015), one of the most severe El Niño events in recent years occurred in 2015. The occurrence of this extreme event compromised cowpea productivity, especially in the treatment without irrigation, because soil wetting caused by rainfall events is much more efficient than that caused by drip irrigation. The low plant yield resulted in a smaller number of bags produced per unit area and, consequently, a lower profit due to a gross revenue which was lower than TOC.

The profitability index (PI) was positive for all treatments in 2016 despite a lower productivity in the rainfed treatment (Table 5). In contrast, in 2015, PI was positive only for the irrigation treatments, whereas the rainfed treatment did not show any profitability (-36.65%). When the two years of experimentation are compared, in 2016, the 100% ETc treatment obtained a PI approximately 16.08% higher than that obtained in 2015, resulting in a higher OP of US$ 478.83 more than in 2015 owing to the higher yields obtained, which resulted in a higher value for PI (Table 5).

According to Table 6, for the adopted prices of US$ 42.44 and US$ 56.99 per a 60-kg bag of cowpea, all treatments showed equilibrium yields below the average values obtained by the crop (Table 4) in 2015 and 2016, respectively. Only the 0%ETc (2015) treatment showed a loss, in which case, EPro was approximately three bags (180 kg ha^{-1}) greater than the amount produced by cowpeas (eight bags or 480 kg ha^{-1}), as the EPro corresponds to the number of bags that must be produced to cover all costs. In 2016, cowpea produced approximately 11 bags (660 kg ha^{-1}) without irrigation, indicating that the crop produced three bags (180 kg ha^{-1}) more than necessary to cover the costs.

Among the treatments tested, that which replenished water fully (100%ETc), produced approximately 13 (780 kg ha^{-1}) and 18 (1,080 kg ha^{-1}) bags over the amount necessary to cover

Table 3. Total water depth cost (TDC) and total operating cost (TOC), in US$, for the cowpea cropping cycle, depending on irrigation depth

Treatments	TDC (US$)		TOC (US$)	
	2015	2016	2015	2016
100%ETc	69.97	65.78	526.48	522.06
50%ETc	67.37	62.94	523.74	519.07
25%ETc	66.05	61.81	522.35	517.88
0%ETc	-	-	452.72	452.72

ETc - crop evapotranspiration

Table 4. Yield and gross revenue obtained from cowpea as a function of irrigation depth

Treatments	Yield				Gross revenue (US$)	
	(bags ha^{-1})		(kg ha^{-1})			
	2015	2016	2015	2016	2015	2016
100%ETc	25	27	1,500	1,620	1042.78	1517.20
50%ETc	18	22	1,080	1,320	776.73	1230.49
25%ETc	16	18	960	1,080	667.72	1015.35
0%ETc	8	11	480	660	331.30	650.08

ETc is crop evapotranspiration

Table 5. Operating profit (OP) and profitability index (PI) obtained from the cowpea crop, as a function of different irrigation depths

Treatments	OP (US$)		PI (%)	
	2015	2016	2015	2016
100%ETc	516.30	995.13	49.51	65.59
50%ETc	252.98	711.42	32.57	57.82
25%ETc	145.37	497.46	21.77	48.99
0%ETc	-121.42	197.36	-36.65	30.36

ETc – crop evapotranspiration

Table 6. Equilibrium productivity (EPro) and equilibrium price (EP) of the cowpea crop as a function irrigation depth

Treatments	EPro				EP (US$ $bags^{-1}$)	
	(bags ha^{-1})		(kg ha^{-1})			
	2015	2016	2015	2016	2015	2016
100%ETc	12	9	720	540	21.43	19.61
50%ETc	12	9	720	540	28.62	24.04
25%ETc	12	9	720	540	33.20	27.58
0%ETc	11	8	660	480	58.00	39.69

ETc – Crop evapotranspiration

the costs of irrigated cowpea production in 2015 and 2016, respectively. Therefore, in addition to covering the costs, there is still an estimated profit related to the production of this number of bags, which was higher by approximately five bags (300 kg ha^{-1}) in 2016, relative to 2015 (Table 6).

Regarding the equilibrium price (EP), although the 0% ETc treatment did not have a cost associated with the irrigation system, it showed the highest average cost of production when compared to the other treatments, both in 2015 and 2016 (Table 6), because, as irrigation depth increased, the cost of producing a bag of 60 kg decreased, as TOC became diluted by the number of bags produced.

In 2015, the cost of producing one bag of cowpea under the rainfed treatment (US$ 58.00) was US$ 15.55 higher than the selling price (US$ 42.44), whereby, it would have caused economic loss to the producer. In contrast, in 2016, although this cost was also high for the same treatment (US$ 39.69), sale price still allowed the producer to profit, because the bag of cowpea was sold at a higher price (US$ 56.99) than the production cost, generating a profit of approximately US$ 17.30 per bag.

In general, the high EP for rainfed crops, such as that obtained in 2015, is due to the low number of bags produced. Although irrigated cultivation entails higher costs, it also renders greater yields, thus allowing sale revenue to exceed the cost, consequently reducing the average cost of production (Gerlach et al., 2013).

Although the 100% ETc treatment showed the maximum productivity increase compared to any other treatment, it also used a greater amount of irrigation water. If it is proved profitable, the supply of water below maximum crop demand can contribute to the economy of this resource, as concerns regarding the sustainable use of water in agriculture are on the raise due to the population growth and the higher demand for food (Fito & Van Hule, 2021).

According to Souza et al. (2019), an irrigation depth equivalent to 50% of the crop water demand in the reproductive phase resulted in a similar WUE (4.31 kg ha^{-1} mm^{-1}) to that obtained with an irrigation depth of 100% of the crop water demand (4.63 kg ha^{-1} mm^{-1}), which suggests the possibility of using this irrigation depth in periods or regions where water is a limiting factor, or in response to concerns about saving water resources in agriculture.

Studies conducted by Osti et al. (2019) using different irrigation depths due to the profitability of corn and beans, showed that it is possible to achieve economic and environmental balance through limited irrigation. Thus, for example, Zwirtes et al. (2015) studied the productive and economic performance of sorghum subjected to limited irrigation and observed that despite the reduction in plant grain yield, the increase in economic return was linear.

In the study reported herein, despite an important reduction in the number of bags produced, when compared to the 100% ETc treatment, six bags ha^{-1} (360 kg ha^{-1}) and five bags ha^{-1} (300 kg ha^{-1}) above EPro were still produced under the 50% ETc treatment in 2015 and 2016, respectively, thus contributing to a considerable PI in both years. As previously observed (Souza et al. (2019), this result shows that, although maximum productivity might not be attained, irrigating to replenish only 50% of ETc can be an attractive alternative for the producer, as it reduces both CTL and TOC, renders a satisfactory productivity level, effectively covers production costs, and allows for greater savings of irrigation water.

Conclusions

1. The year 2016 showed the highest values for gross revenue and profitability index, and a lower equilibrium productivity and cost for the production of one bag of 60 kg of cowpea, compared to the agricultural year 2015.

2. In general, the use of irrigation water for crop production pays off economically with increasing financial returns. As the greater irrigation depth, the 100% ETc treatment showed the highest profitability rates in both years of study.

3. From the point of view of the rational use of water, irrigating cowpea to replenish 50% of ETc can be adopted by the producer as an economic alternative, as in both years, this treatment resulted in a lower total water depth cost (TDC) and total operating cost (TOC), concomitant with a satisfactory level of crop productivity, and considerable water savings.

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