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EFFECTS OF WATER REGIMES AND IRRIGATION FREQUENCIES ON COWPEA GROWTH

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KEYWORDS

Vigna unguiculata L., irrigation management, semiarid.

ABSTRACT

Cowpea (*Vigna unguiculata* L.) is a key crop in Brazil's Northeast due to its adaptability to semi-arid conditions. This study evaluated the effects of different water regimes and irrigation frequencies on cowpea cultivation under a semi-arid climate. The experiment was conducted at the experimental area of IFCE – Campus Iguatu-CE, using a randomized block design with 20 treatments and four replications, arranged in a 5 × 4 factorial scheme. The treatments consisted of five water regimes (R1 – 50%, R2 – 75%, R3 – 100%, R4 – 125%, and R5 – 150% of crop evapotranspiration, ETc) and four irrigation frequencies (F1 – daily, F2 – every two days, F3 – every three days, and F4 – every four days). Irrigation was applied via a drip system. The variables evaluated included the number of pods per plant, number of grains per pod, pod length, pod mass, grain yield, and water use efficiency. Results indicated that daily irrigation led to the highest grain yield (381.94 kg ha^{-1}) and water use efficiency (1.43 kg ha^{-1} mm^{-1}). The most efficient water regime was 407.11 mm (113.7% of ETc), which had a significant isolated effect on pod number, pod mass, and the number of grains per pod.

INTRODUCTION

Cowpea (*Vigna unguiculata* L.), also known as black-eyed pea, is a vital agricultural crop in Brazil’s Northeast. Its adaptability to semi-arid conditions makes it a preferred choice among farmers in the region. Cowpea is one of the most important crops for food and nutritional security, serving as a primary source of protein for millions in developing countries (Santos et al., 2017). It is also highly resilient to adverse climatic conditions, such as those found in Brazil's semi-arid regions (Melo et al., 2022).

Brazil has become one of the three largest cowpea-producing countries in the world (Pessoa et al., 2023). In recent years, the demand for cowpea production has expanded beyond dry grains to include grains and green pods, increasing its overall importance, and shifting its traditional role as a primarily dry grain crop (Almeida et al., 2019).

In Brazil, cowpea production reaches 631.4 thousand tons, with major contributions from the states of Bahia, Ceará, Tocantins, Piauí, Mato Grosso, and Pernambuco (CONAB, 2022). Proper water management in irrigation is essential for the development of sustainable irrigated agriculture, aiming not only to increase yield and productivity but also to ensure efficient water use. Therefore, research is needed across different regions and cultivars to assess crop responses and determine appropriate irrigation depths tailored to local growing conditions (Ferreira et al., 2021a).

The adoption of efficient irrigation management technologies is essential to increase crop productivity, reduce production costs, and improve the income of rural producers. Growing water scarcity has significantly impacted irrigated agriculture, encouraging farmers to adopt more efficient and rational water use practices

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(Lakhiar et al., 2024). Although cowpea is well adapted to a wide range of soil and climatic conditions, its productivity can be limited under inadequate management, as the crop is sensitive to both water deficits and excesses. Cowpea responds variably to irrigation, particularly in terms of grain yield and its components (Ramos et al., 2014).

Irrigation frequency refers to the time interval, in days, between successive irrigation events. It must be carefully planned to meet crop water requirements without causing stress due to excess or deficit (Okasha et al., 2015). This interval is a critical management decision influenced by several factors, including the efficiency of the irrigation system, the soil's physical and hydraulic properties, and the crop's developmental stage. Proper planning of irrigation frequency ensures water availability for optimal plant growth and productivity.

Given the importance of cowpea cultivation and proper irrigation management in agricultural production systems, this study aimed to evaluate the effects of different water regimes and irrigation frequencies on cowpeas grown for green pod production under semi-arid climatic conditions.

MATERIAL AND METHODS

The region's climate is classified as BSh' (hot semi-arid) according to the Köppen climate classification. The average annual temperature is 28 °C, ranging from a minimum of 22.4 °C to a maximum of 33.5 °C. Potential evapotranspiration (ETP) exceeds rainfall, with an annual average of 1,902.5 ± 117.8 mm, and the highest rates occurring between August and January (INMET, 2019). The historical average annual rainfall is 996.6 ± 300.0 mm, concentrated primarily between December and May, with approximately 43% of the total rainfall recorded between March and April (INMET, 2019). Figure 1 presents the variation in rainfall, evapotranspiration, relative humidity, and average temperature over the days after planting (DAP), reflecting the meteorological conditions during the experimental period.

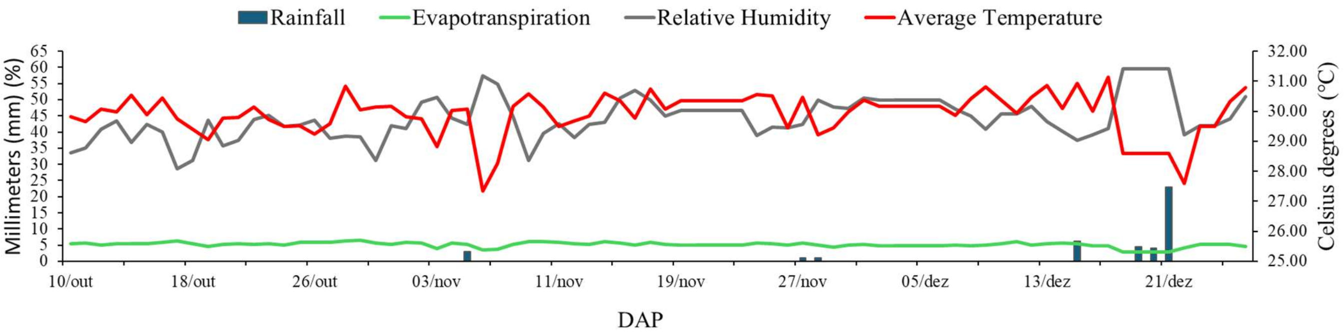

FIGURE 1. Climatic variables throughout the cowpea crop cycle, Iguatu, Ceará-Brazil, 2024.

The experiment was carried out in the state of Ceará, located in the Northeast region of Brazil (Figure 2). The experimental site is situated at the Federal Institute of Education, Science and Technology of Ceará (IFCE), in the south-central region of the state. The aerial image below shows the specific location where the experiment was conducted.

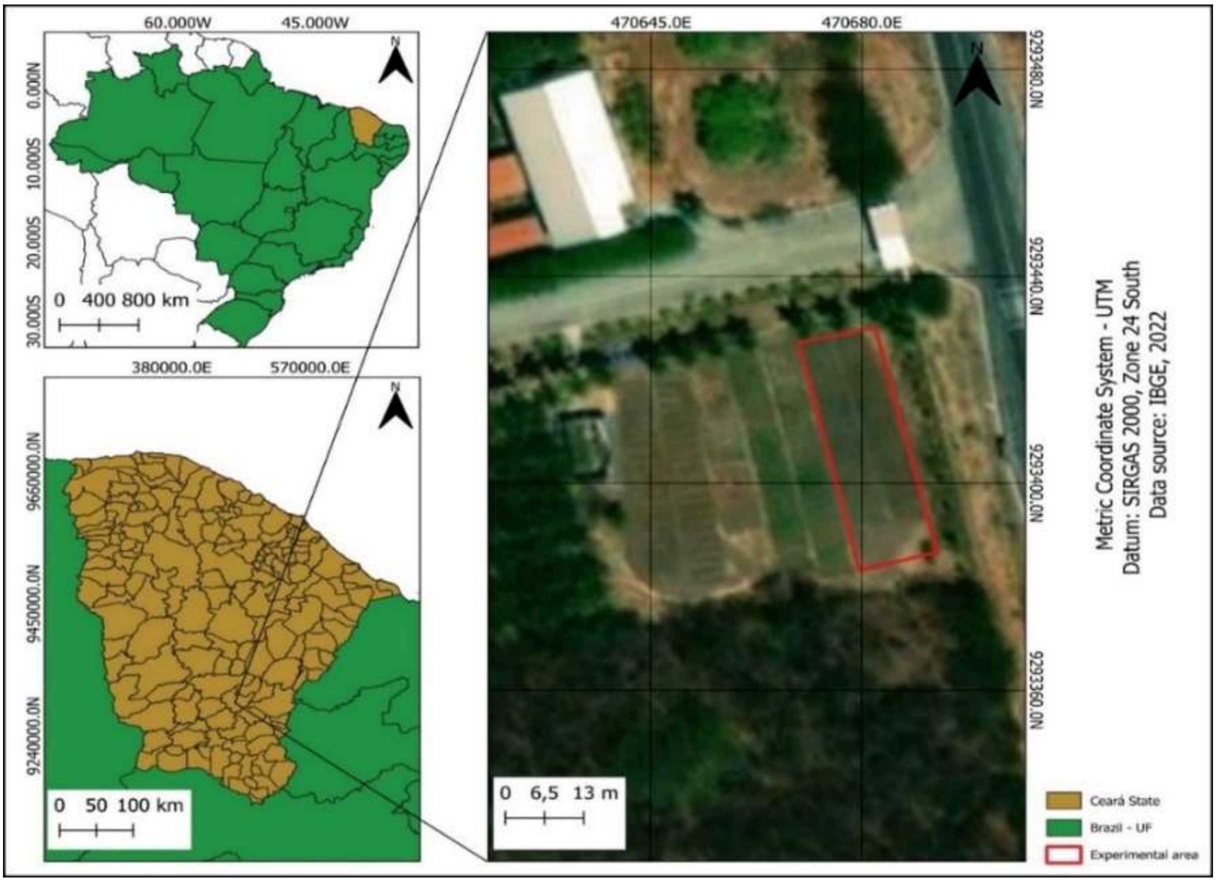

FIGURE 2. Experimental area, Iguatu, Ceará-Brazil, 2024.

The soil at the experimental site is classified as eutrophic Red-Yellow Argisol with a sandy loam texture. Its physical and chemical properties, presented in Tables 1 and 2, respectively, were determined before planting through soil sampling at a 0.0–0.20 m depth layer using a Dutch auger.

TABLE 1. Physical properties of the soil 0.0–0.20 m depth layer in the experimental area. Iguatu, Ceará-Brazil.

Property	Depth layer (0.0-0.2 m)
Coarse sand (g kg^{-1})	388
Fine sand (g kg^{-1})	354
Silt (g kg^{-1})	204
Clay (g kg^{-1})	54
Textural class	Sandy-Loam
Soil bulk density (g cm^{3})	1.5

Source: Laboratory of Soils, Water, and Plant Tissue of the IFCE - *Campus* at Limoeiro, 2017.

TABLE 2. Chemical properties of the soil 0.0–0.20 m depth layer in the experimental area. Iguatu, Ceará-Brazil[1].

pH	EC	Chemical property					
(H_2O)		Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	$H^{+} + Al^{3+}$	Al^{3+}
	(dS m^{-1})	(mmol$_c$ dm^{-3})					
7.1	0.52	35.9	9.1	3.72	1.06	ND	ND
SB	CEC	BS	ESP	C	OM	$P_{available}$	
(mmol$_c$ dm^{-3})		(%)		(g kg^{-1})		(mg dm^{-3})	
49.8	49.8	100	2	8.12	14	72	

[1]pH – hydrogen potential, EC – electrical conductivity of soil saturation extract; ND –non-detectable; SB – the sum of bases; CEC – cation exchange capacity; BS – base saturation; ESP – exchangeable sodium percentage; C – organic carbon; OM – organic matter; $P_{available}$ – available phosphorus.

To establish the crop, the area was prepared by deep plowing followed by two cross-harrowings. The soil was then manually cleaned and leveled using a hoe and harrow to remove crop residues that could interfere with treatment application or hinder the installation of the irrigation system. Cowpea was sown manually, placing three seeds per hole, with a spacing of 0.20 m between plants and 1.0 m between rows. After emergence, thinning was performed to leave two plants per hole.

Irrigation was applied using a surface drip system, consisting of one lateral line per plant row, each 5 meters long. Drip irrigation is recognized for its high water-use efficiency and uniformity of distribution (Andrade et al., 2021). Each lateral line was composed of a 16 mm diameter flexible polyethylene drip tape with integrated self-compensating emitters spaced 0.20 m apart, delivering 1.6 L h^{-1} per emitter at an operating pressure of 100 kPa.

The experiment followed a randomized block design with twenty treatments and four replications. Treatments were arranged in a 5 × 4 factorial scheme, consisting of five water regimes (R1 – 50%, R2 – 75%, R3 – 100%, R4 – 125%, and R5 – 150% of crop evapotranspiration, ETc) and four irrigation frequencies (F1 – daily, F2 – every two days, F3 – every three days, and F4 – every four days). ETc was estimated using reference evapotranspiration (ETo) calculated by the FAO Penman-Monteith method (FAO-56; Allen, 1998), based on climatic data from an INMET automatic weather station located within the IFCE Campus Iguatu-CE. Crop coefficient (Kc) values were adopted from Souza et al. (2005).

Nutrient application rates were determined based on the soil analysis of the experimental area (Table 2) and the recommendations by Ribeiro et al. (1999) for bean crops. Nitrogen and potassium were applied via fertigation 7 days after sowing, using urea as the nitrogen source and potassium chloride for potassium (Table 3). Basal fertilization included phosphorus and micronutrients, with 194.4 g of single superphosphate and 25 g of FTE BR12 applied per planting row as sources of phosphorus and micronutrients, respectively.

TABLE 3. Fertigation scheduling[1].

Application	Date (DAP)	%N	%P	Urea (g row^{-1})	KCl (g row^{-1})
1	7	13.3	11.2	14.8	1.9
2	14	13.3	19.1	14.8	3.2
3	21	13.3	17.8	14.8	3.0
4	28	12	16.1	13.3	2.7
5	35	12	13.7	13.3	2.3
6	42	12	10.9	13.3	1.8
7	49		7.5		1.3

[1]DAP – days after planting, %N – nitrogen percentage, %P –potassium percentage, KCl – potassium chloride.

Harvesting began 52 days after planting (DAP) when the pods reached the appropriate stage for green grain harvest. Pods were collected and packaged according to treatment for variable evaluation. Harvesting was repeated three additional times—at 62, 69, and 78 DAP.

The variables analyzed were: the number of pods per plant, pod mass per plant, pod length, number of grains per pod, grain mass, grain yield, and water use efficiency. The numbers of pods and grains per pod (units) were determined by manual counting. Pod and grain mass (g $plant^{-1}$) were measured using a precision scale. Pod length (cm) was assessed using a ruler, measuring from one end to the other on five representative pods per plant. Grain yield (kg ha^{-1}) was estimated based on grain mass data.

All variables were subjected to analysis of variance (ANOVA) using the F-test at 1% and 5% probability levels, followed by regression analysis. Statistical analyses were performed using ASSISTAT® software (version 7.6 beta) developed by the Federal University of Campina Grande, and Microsoft Excel® (version 2019).

RESULTS AND DISCUSSION

Among the variables evaluated, a significant interaction between water regimes and irrigation frequencies (WR × Freq) was observed at the 1% probability level for grain mass (GM), grain yield (GY), and water use efficiency (WUE). The variables number of pods per plant (NP), number of grains per pod (NGP), and pod mass (PM) were significantly influenced only by the water regimes. Pod length (PL) was not significantly affected by any of the treatments, as shown in Table 4.

TABLE 4. Summary of analysis of variance (ANOVA) for the number of pods per plant (NP), number of grains per pod (NGP), pod length (PL), pod mass (PM), grain yield (GY), and water use efficiency (WUE). IFCE, *Campus* at Iguatu, 2024.

VS	DF	Mean square					
		NP	NGP	PL	PM	GY	WUE
Water regime (WR)	4	236.40156**	8.35646*	8.50618ns	16351.80072*	141.94936*	1.07755**
Irrigation Frequency (Freq)	3	130.54583ns	3.94730ns	7.93763ns	12547.59407ns	206.63173 *	0.17738*
WR x Freq	12	73.93906ns	2.49080ns	7.15159ns	6753.56272ns	9.79428**	0.00837**
Block	3	461.22083**	24.92751**	39.17113**	38512.61945**	238.91982**	0.25164**
Residue	57	58.42478	3.29199	4.91047	5255.28974	2240.72	0.05814
Total	79	-	-	-	-	-	-
CV (%)		37.58	19.65	15.18	44.51	25.72	25.94

** significant at 1%; * significant at 5% by the F-test; (ns) non-significant by the F-test; VS – Variation source; DF – Degree of freedom

Number of pods

Figure 3 shows the relationship between water regimes and the number of pods, which followed a quadratic trend with a high coefficient of determination ($R^2 = 0.88$), indicating a good fit of the model to the data.

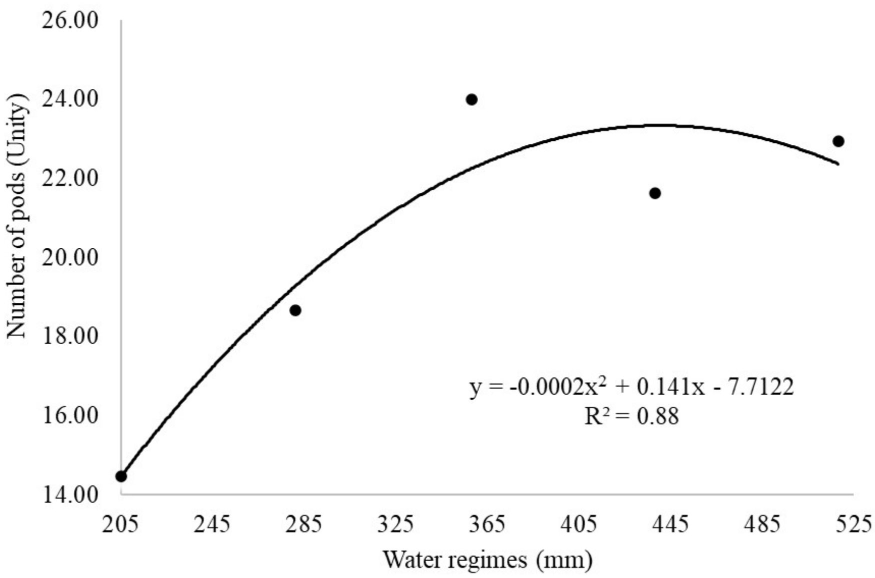

FIGURE 3. Number of pods per cowpea plant as a function of the water regimes and irrigation frequencies tested, Iguatu, Ceará-Brazil, 2024.

The number of pods increased with rising water regimes, reaching an estimated maximum of 351 mm, equivalent to 98% of ETc. Beyond this point, pod production declined, indicating that excess water can negatively affect yield. Hara et al. (2022), evaluating six levels of water replacement (20, 40, 60, 80, and 100% of field capacity), reported a linear increase in the number of pods per plant with increased water supply. Similarly, Souza et al. (2014) found that the number of pods was the variable most affected by water deficit, directly limiting production. Consistent with these findings, Azevedo et al. (2011) observed the lowest pod counts in treatments subjected to both water excess and deficit. These results collectively highlight the importance of maintaining irrigation within an optimal range to maximize yield and prevent productivity losses due to under- or over-irrigation.

Number of grains per pod

Figure 4 illustrates the response of the number of grains per pod in cowpeas to different water regimes, showing a linear increasing trend. The highest value was observed at 150% of ETc (518 mm), with an estimated average of 10 grains per pod.

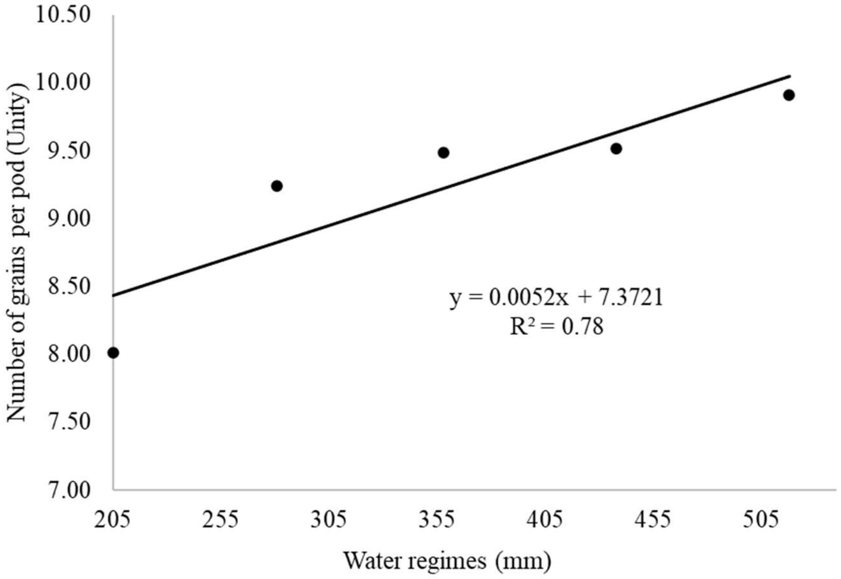

FIGURE 4. Number of grains per pod in cowpea plants as a function of the water regimes and irrigation frequencies tested, Iguatu, Ceará-Brazil, 2024.

This behavior suggests that water availability plays a crucial role in cowpea productivity, as increased water regimes promote greater pod development. Silva et al. (2018) reported similar findings and observed maximum production at 150% of ETc. Supporting this trend, Coelho et al. (2023) demonstrated that water limitation significantly reduces the agronomic performance of common beans, regardless of the cultivar, with productivity losses of up to 31%.

Pod mass

Figure 5 illustrates the effect of different water regimes on pod mass. Initially, increasing the water regime led to a rise in pod mass, reaching a maximum estimated productivity of 182.84 g m^{-2} with a water application of 455.77 mm, corresponding to 127% of the crop's ETc.

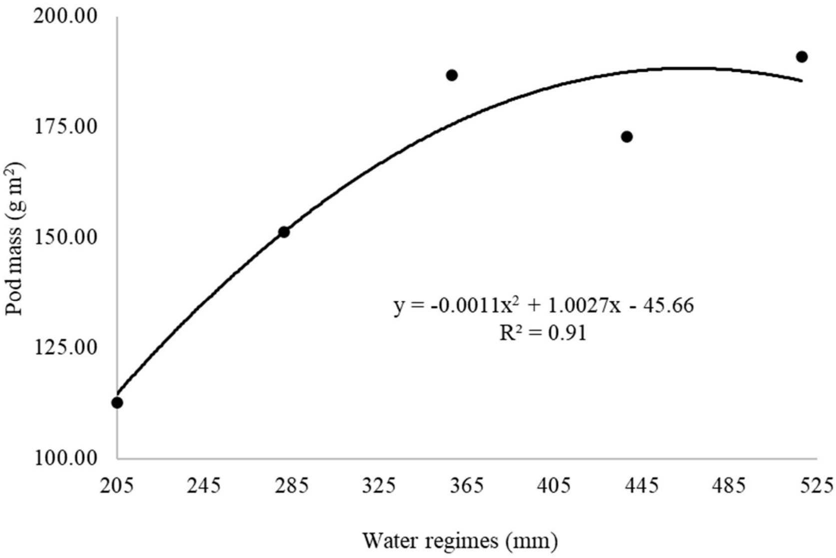

FIGURE 5. Pod mass in cowpea plants as a function of the water regimes and irrigation frequencies tested, Iguatu, Ceará, 2024.

Silva et al. (2019) reported maximum pod mass yield for cowpea plants at an estimated water application of 112.6% of ETc, corroborating the results observed in the present study. In contrast, Guimarães et al. (2020), working with the BRS Novaera cultivar under different irrigation levels, found no significant differences in response to the applied water depths.

Grain yield

As shown in Figure 6, a quadratic polynomial model provided the best fit for the grain yield response to water regimes across all evaluated irrigation frequencies.

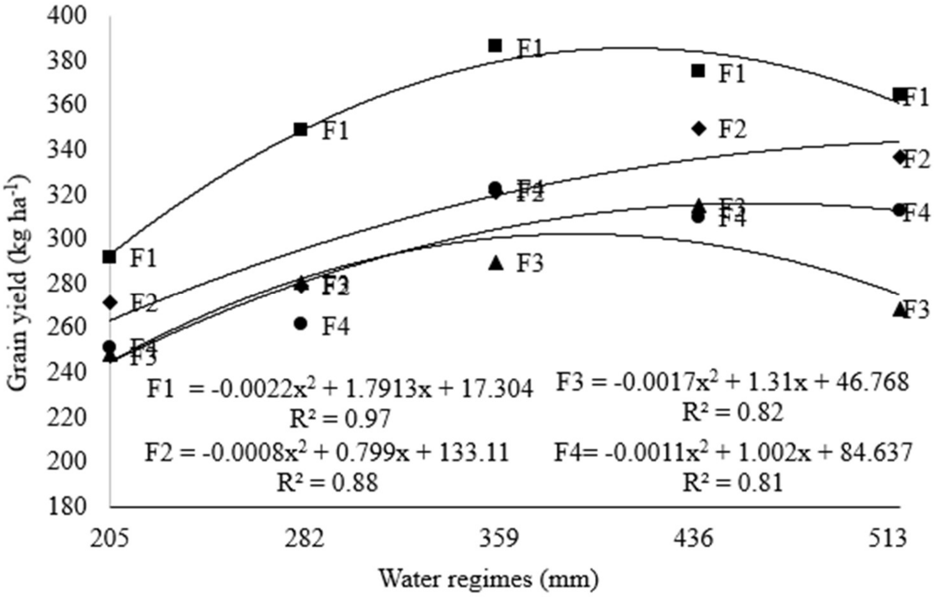

FIGURE 6. Cowpea grain yield as a function of water regimes and irrigation frequencies in Iguatu, Ceará-Brazil, 2024.
*F1 – Daily irrigation; F2 – Every two days; F3 – Every three days; F4 – Every four days.

Daily irrigation (F1) resulted in the highest grain yield (GY) among all frequencies, reaching 381.94 kg ha^{-1} at a water application of 407.11 mm, equivalent to 113.7% of ETc. In comparison, under F2, 499.38 mm of water—22.7% more—was required to achieve a lower yield of 332.61 kg ha^{-1}. For F3, water application decreased to 385.29 mm (5.36% less than F1), yet GY also declined, reaching 299.14 kg ha^{-1}. Under F4, the maximum GY was 312.82 kg ha^{-1}, requiring an 11.87% increase relative to F1.

These results indicate that the most efficient water regime for cowpea productivity was 113.7% of ETc under daily irrigation. This finding suggests a need to adjust the crop coefficient (Kc) values currently used for irrigation management in the study region and underscores the importance of continued research on crop water requirements under varying local conditions.

Lower productivity under reduced water regimes can be attributed to soil moisture scarcity, which triggers stomatal closure as a strategy to limit water loss through transpiration and maintain cell turgor. However, this adaptation also reduces CO_2 assimilation, as both processes share the same pathway (Costa et al., 2020). Stomatal regulation of transpiration is a key drought-avoidance mechanism employed by many plant species (Ferreira et al., 2021b). Similarly, Ezin et al. (2021) reported significant reductions in cowpea yield and yield components under water deficit conditions.

Conversely, excessive soil moisture can impair biological nitrogen fixation in cowpeas due to reduced root zone oxygenation, which inhibits the activity of nitrogen-fixing bacteria. This decreases nitrogen availability, adversely affecting plant development and grain yield (Iseki et al., 2021). These observations highlight the importance of precise water management to mitigate the negative effects of both water deficit and excess, ensuring stable and efficient cowpea production.

Daily irrigation enhances productivity by maintaining soil moisture near field capacity, which favors stomatal opening and improves water absorption. When soil moisture is near field capacity, the free energy of water is higher, facilitating uptake by plant roots. This behavior is supported by physiological studies such as Wube et al. (2020), who found that higher irrigation frequencies, like daily irrigation, maintain adequate moisture in the root zone, improving plant water status, turgor pressure, and overall physiological performance.

In contrast, longer irrigation intervals cause water to be more tightly retained by soil particles, reducing its free energy, and making it less available to roots. This limits water uptake decreases stomatal conductance, and impairs transpiration and photosynthesis, ultimately reducing crop productivity.

Water use efficiency

Figure 7 shows the behavior of water use efficiency (WUE) as a function of the water regimes and irrigation frequencies applied to cowpeas. A decreasing linear model best represented the observed trend.

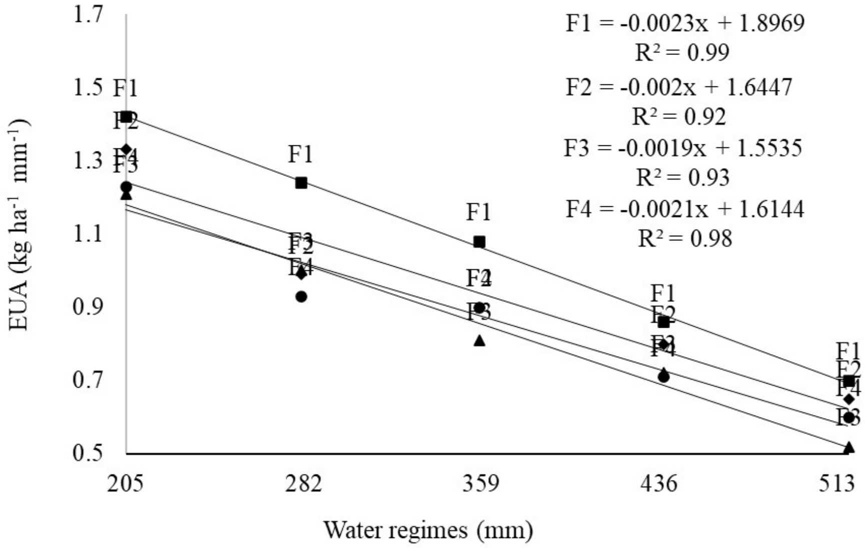

FIGURE 7. Water use efficiency (WUE) in cowpea plants as a function of the water regimes and irrigation frequencies, Iguatu, Ceará-Brazil, 2024. *F1 – Daily irrigation; F2 – Every two days; F3 – Every three days; F4 – Every four days.

The highest water use efficiency (WUE) estimate was 1.43 kg ha^{-1} mm^{-1}, obtained under daily irrigation (F1) with the lowest applied water regime of 205 mm (50% ETc). A similar pattern was observed across the other frequencies, where WUE decreased as the water regime increased. Compared to F1, WUE was reduced by 13.98%, 18.88%, and 17.48% in F2, F3, and F4, respectively.

Pimenta et al. (2023) also reported a linear decrease in WUE with increasing irrigation depths in different cowpea cultivars. For each 1% increase in water replacement, WUE dropped by 0.48, 0.49, and 0.24 kg m^{-3} for BRS Rouxinol, BRS Tumucumaque, and BRS Itaim, respectively.

Daily irrigation not only led to higher productivity but also resulted in better water use efficiency, proving to be a useful strategy for optimizing water application in semi-arid regions where water availability is often limited.

CONCLUSIONS

Water regimes independently influenced the number of pods and pod mass, both of which exhibited a quadratic response to increasing water levels. In contrast, the number of grains per pod followed a linear increasing trend. The interaction between water regimes and irrigation frequencies, along with the observed patterns for cowpea productivity and water use efficiency (WUE), highlighted the benefits of daily irrigation, which consistently resulted in higher values for these variables across all treatments. The water regime of 407.11 mm, equivalent to 113.7% of ETc, yielded the highest productivity at 381.94 kg ha^{-1}. However, WUE declined as the applied water volume increased.

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