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PRODUTIVIDADE DO USO DE ÁGUA E FERTILIZANTE NO CULTIVO DA CENOURA FERTIRRIGADA

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1 RESUMO

Visando à otimização no manejo dos fatores de produção, um experimento foi realizado com o objetivo de avaliar o efeito de lâminas de irrigação e doses de fertilizantes sobre a produtividade do uso da água e fertilizantes no cultivo de cenoura fertirrigada. Conduzido na área experimental da UFAL, Arapiraca, adotou-se o delineamento de blocos casualizados, num esquema fatorial 6x4, com três repetições. Os tratamentos foram seis lâminas de irrigação: L_1: 210,5; L_2: 315,7; L_3: 421,0; L_4: 526,2; L_5: 631,5 e L_6: 736,7 mm e quatro doses de fertilizantes: F_1: 226,9; F_2: 340,3; F_3: 453,8 e F_4: 567,2 kg ha^{-1}, aplicados via fertirrigação. Ao final do ciclo, foram coletadas quatro raízes de cenoura/parcela para estimar a produtividade. A combinação de lâmina de irrigação e dose de fertilizantes que obteve maior produtividade do uso de água (24,3 kg m^{-3}) foi de 293,46 mm e 553,74 kg ha^{-1}, respectivamente. A máxima produtividade do uso de fertilizantes (345,36 kg kg^{-1}) foi obtida aplicando-se a dose de 226,89 kg ha^{-1} de fertilizantes e lâmina de irrigação de 517,50 mm. As produtividades do uso da água e de fertilizantes aumentaram à medida que houve redução nas lâminas de irrigação e doses de fertilizantes, respectivamente.

Palavras-chave: *Daucus carota*, lâmina de irrigação, nutrição mineral, eficiência produtiva.

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PRODUCTIVITY OF WATER AND FERTILIZER USE IN FERTIGATED CARROT CULTIVATION

2 ABSTRACT

Aiming at the optimization of the management of production factors, an experiment was carried out to evaluate the effect of irrigation depths and fertilizer doses on the productivity of water and fertilizer use in fertigated carrot cultivation. The experiment conducted in the experimental area of UFAL, Arapiraca, presented a randomized block design, in a 6x4 factorial scheme, three replications. The treatments were six irrigation depths: L1: 210.5; L2: 315.7; L3: 421.0; L4: 526.2; L5: 631.5; and L6: 736.7 mm and four doses of fertilizer: F1: 226.9; F2: 340.3; F3: 453.8; and F4: 567,2 kg ha^{-1} applied via fertigation. At the end of each cycle, four carrot/parcel roots were collected to estimate productivity. The combination of irrigation depth and fertilizer dose that obtained the highest water productivity (24.3 kg m^{-3}) was 293.46 mm and 553.74 kg ha^{-1}, respectively. The maximum fertilizer productivity (345.36 kg^{-1}) was obtained by applying 226.89 kg ha^{-1} of fertilizer and an irrigation depth of 517.50 mm. The productivities of water and fertilizer use increased as irrigation depths and fertilizer doses were reduced, respectively.

Keywords: *Daucus carota*, irrigation depth, mineral nutrition, production efficiency.

3 INTRODUCTION

The carrot (*Daucus carota* L.) is a tuberous root that occupies a prominent place among agricultural products grown in Brazil. The production estimates for this tuberous crop exceed 700,000 tons per year (CARVALHO *et al*., 2019). It is a vegetable with high economic value, in addition to being an important source of vitamin A and potassium in the human diet (KIEŁKOWSKA *et al*., 2019).

Daucus carota L. is cultivated on a large scale in the Central-West, Southeast, South and Northeast Regions of Brazil (CARVALHO *et al*., 2017). The Agreste region of the state of Alagoas has favorable edaphoclimatic conditions for the production of vegetable crops, such as constant heat, high luminosity and low relative humidity. (SILVA *et al*., 2018). However, the irregularity of water availability associated with the long-term dry season makes it necessary to use irrigation to achieve satisfactory productivity (SILVA *et al*., 2017).

Water plays a fundamental role in plant growth, as each gram of organic matter produced during photosynthesis by a plant requires approximately 500 g of absorbed water (TAIZ; ZEIGER, 2017). Furthermore, most of the absorbed water, approximately 97%, is lost through evapotranspiration to balance internal temperatures and allow the optimal action of enzymes in plant metabolism (LACERDA *et al*., 2017).

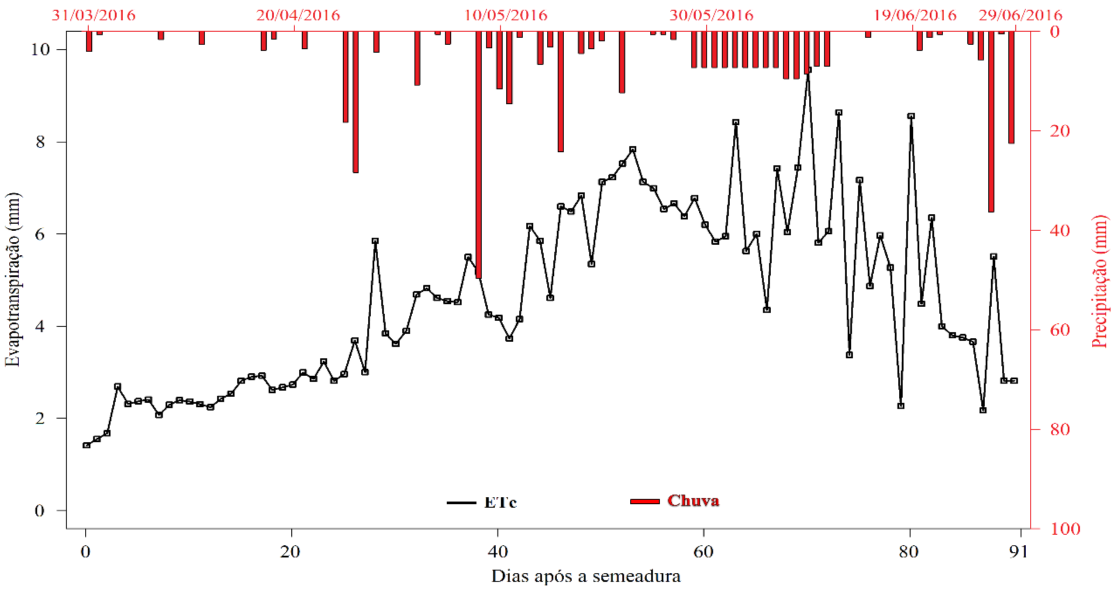
Water stress and low soil nutrient availability generally limit crop growth and production potential in agroecosystems, as most crops are sensitive to water and nutrient deficits at different critical stages (MIRANDA *et al*., 2019). Conversely, applying excess water can increase production costs and fertilizer leaching. Therefore, increasing water use productivity in agriculture is a key approach for reducing water losses in irrigated systems. In agricultural systems, water and fertilizer use productivity can be defined as the relationship between physical productivity and the amount of water or fertilizer used in agricultural production (ALI; TALUKDER, 2008).

The objective of this study was to evaluate the effects of irrigation depth and fertilizer dose on the productivity of water and fertilizer use in fertigated carrot cultivation.

4 MATERIALS AND METHODS

The work was developed at the experimental unit of the Irriga Group of the Arapiraca Campus of the Federal University of Alagoas (UFAL) from March to July 2016. This experimental unit is located in the Agreste Alagoano mesoregion, at coordinates of 9° 45' 09" S (latitude) and 36° 39' 40" W (longitude), at an altitude of 325 m. This region is a transition between the Zona da Mata and the Sertão A lagoonal region. Its climate is tropical 'As' with a summer dry season according to the Köppen classification criterion (1948). According to Xavier and Dornellas (2010), the rainy season begins in May and lasts until the first half of August, with an average precipitation of 854 mm year $^{-1}$, with May to July being the rainiest months and September to December the driest months. The soil in the experimental area was classified as a dystrophic yellow red latosol (EMBRAPA, 2018), with a medium to clayey texture. The precipitation (mm) and evapotranspiration (mm) data obtained during the experiment are presented in Figure 1.

Figure 1. Precipitation (mm) and evapotranspiration (mm) during the carrot cycle (March–July 2016).



Source: Silva *et al*. (2018)

The physical-hydric characteristics of the soil included coarse sand (24.3%), fine sand (29.0%), silt (30.2%), clay (16.6%), apparent density (1.48 kg dm^{-3}), field capacity (7.8%) and wilting point (4.05%), whereas its fertility was characterized by organic matter (0.57%), pH (5.3), P (7 mg dm^{-3}), K^+ (10 mg dm^{-3}), Ca^{2+} (0.7 cmolc kg^{-1}), Mg^{2+} (0.5 cmolc kg^{-1}), Na^+ (0.09 cmolc kg^{-1}) and H^+ + Al+ (3.5 cmolc kg^{-1}).

The preparation of the area consisted of plowing and harrowing to a depth of 0.20 m. Then, 24 beds were raised, each with dimensions of 3 × 1 × 0.25 m in length, width and height, respectively, representing three plots with dimensions of 1 m^2. The beds were spaced 0.5 m apart. The cultivar “Brasília” was planted via direct seeding, with a spacing of 0.25 m between rows and 0.10 m between plants, equivalent to a population of 400,000 plants ha $^{-1}$. A drip irrigation system was installed with drip tapes with a diameter of 16 mm (ISO 09261) and self-compensating emitters with a flow rate of 2.1 L h $^{-1}$, with a daily frequency.

A randomized block design (RBD) was adopted in a 6x4 factorial scheme, with three replications, totaling 72 experimental plots. The treatments were represented by six irrigation depths: L_1 (50% ETc): 210.5; L_2 (75% ETc): 315.7; L_3 (100% ETc): 421.0; L_4 (125% ETc): 526.2; L_5 (150% ETc): 631.5; and L_6 (175% ETc): 736.7 mm correlated with four fertilizer doses, equivalent to F_1 (50% of recommendation): 226.9; F_2 (75% of recommendation): 340.3; F_3 (100% of recommendation): 453.8; and F_4 (125% of recommendation): 567.2 kg ha $^{-1}$.

Irrigation management was carried out on the basis of crop evapotranspiration (ETc), which was obtained daily via drainage lysimeters, according to Silva *et al.* (2018). Fertilizers were applied according to the quantity defined for each treatment (IPA, 2008) and distributed to the plants via irrigation water starting 30 days after sowing (30 DAS), when the plants had four fully developed leaves. The fertilizer sources used were urea (45% N), monoammonium phosphate (MAP; 12% N and 60% P), and white potassium chloride (60% K) (Table 1).

Table 1. Nutritional recommendation (kg ha^{-1}), fertilizer sources used and total fertilizers applied (kg ha^{-1}) for each treatment.

Nutritional recommendation (kg ha $^{-1}$)			
Nitrogen (N)	Phosphorus (P)		Potassium (K)
80	120		60
Fertilizer sources used			
Urea	MAP		KCl
45% N	12% N	60% of P	60% of K
153.8 kg ha $^{-1}$ of urea	200 kg ha $^{-1}$ of MAP		100 kg ha $^{-1}$ of KCl
Total applied for 100% of the recommendation (kg ha $^{-1}$)			
	453.8 kg ha $^{-1}$		
F1 (50% recommendation)	F2 (75% recommendation)	F3 (100% recommendation)	F4 (125% recommendation)
226.9 kg ha $^{-1}$	340.3 kg ha $^{-1}$	453.8 kg ha $^{-1}$	567.2 kg ha $^{-1}$

Source: IPA (2008)

The quantity of nutrients to be applied as top dressing was divided by the period of the experiment to be analyzed, with fertigation being carried out daily.

At the end of the carrot growing season, four central carrots from each plot were evaluated to estimate yield (kg ha $^{-1}$). The effects of the blades and fertilizer rates were analyzed via polynomial regression. Water use productivity (WUP) (kg m^3) was determined by the relationship between productivity and depth, according to Equation (1).

$$PUA = \frac{P}{L} \quad (1)$$

where PUA is the water use productivity, kg m ^{3}; P is the productivity, t ha $^{-1}$; and L is the applied depth, m ^{3} ha $^{-1}$.

Fertilizer use productivity (PUF) (kg kg $^{-1}$) was determined by the relationship between productivity and fertilizer dose, according to Equation 2.

$$PUF = \frac{P}{F} \quad (2)$$

where PUF is the fertilizer utilization productivity, kg kg $^{-1}$; P is the productivity, t ha $^{-1}$; and F is the amount of fertilizers applied, kg ha $^{-1}$.

5 RESULTS AND DISCUSSION

Table 2 shows the average carrot productivity according to water depth and fertilizer dose. The irrigation depths and fertilizer doses applied varied between 210.40 and 736.38 mm and between 226.89 and 567.22 kg ha $^{-1}$, respectively. The water requirement of carrots in the agricultural region during the total cycle is 421.00 mm (SILVA *et al*., 2018).

Table 2. Average carrot productivity (t ha $^{-1}$) as a function of irrigation depth and fertilizer dose.

Blade (mm)		**Fertilizers (kg ha^{-1})**			
		F1	**F2**	**F3**	**F4**
		226.89	**340.33**	**453.78**	**567.22**
L1 (50% ETc)	210.4	20.6	44.5	50.6	42.5
L2 (75% ETc)	315.6	71.7	73.2	83.6	74.8
L3 (100% ETc)	420.79	85.4	96.4	115.4	112.9
L4 (125% ETc)	525.98	86.6	68.8	87.1	79.3
L5 (150% ETc)	631.85	70.1	68.0	68.9	76.6
L6 (175% ETc)	736.38	60.8	46.9	73.4	59.5

Source: Silva (2020)

The depth and fertilizer dose had significant effects on the water use productivity and fertilizer use productivity of carrots at the 0.1% probability level, indicating that both factors interfered with carrot development (Table 3).

Table 3. Water use productivity (WUP) and fertilizer use productivity (FUP) of carrots as a function of irrigation depth and fertilizer dose.

Source of variation	GL	Mean squares	
		PUA	PUF
Irrigation blades (L)	5	531.44**	42526.27**
Fertilizer doses (F)	3	65.84**	81079.81**
LXF	15	21.64**	4373.35**
Block	2	1.48	424.99ns
Residue	46	0.81	134.66
Total	71		
CV (%)		5.30	5.86

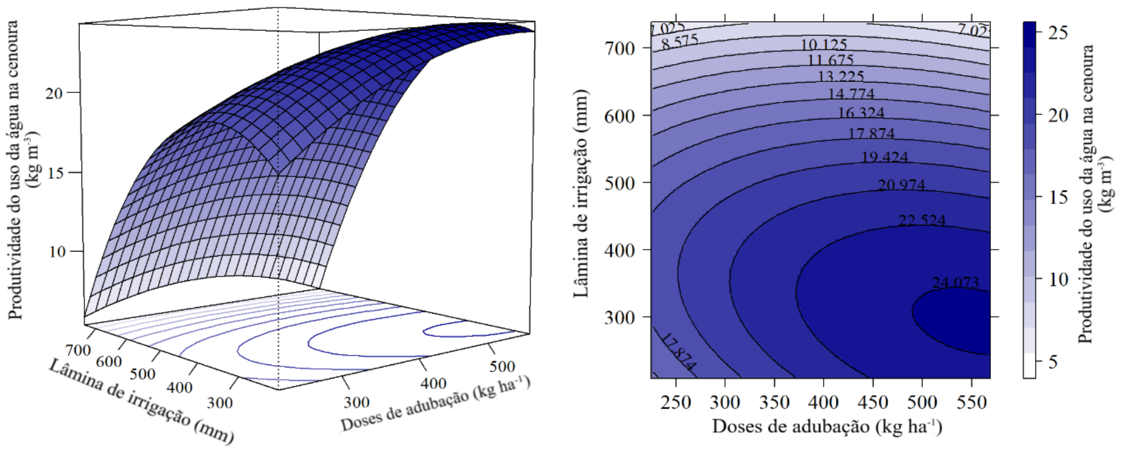
probability level, ns - not significant according to the F test. CV = Coefficient of variation. **Source:** Authors (2022)

In addition to the productive aspects, knowledge of water use productivity in irrigated agriculture is essential, as it allows us to determine which treatment provides the greatest water utilization by the plant, as well as the economic viability of the activity (MEZZOMO *et al*., 2020). Under the effects of different irrigation depths and fertilizer doses, the quadratic model with a significant interaction was the one that best fit the average PUA dataset (Equation 3).

$$PUA = - 9.34 + 0.08113*L + 0.07848*F - 0.0000956*L^2 - 0.00005889*F^2 - 0.00004519*L*F \quad (3)$$

The combination of irrigation depth and fertilizer rate that yields the highest water productivity for carrot crops is 293.46 mm of water and 553.74 kg of fertilizer. These values provide a water productivity of 24.3 kg m $^{-3}$ (kg of carrot produced per m³ of water applied), equivalent to the use of 41 liters of water to produce 1 kg of carrot (Figure 2A).

Figure 2. A: Response surface for water use productivity (WUP) (kg m $^{3)}$ as a function of irrigation depth (mm) and fertilizer dose (kg ha $^{-1}$), and B: Isoquants that delimit regions of water and fertilizer combinations that result in the same WUP.



Source: Authors (2022)

When water depths greater than the maximum determined depth are applied, plant water productivity decreases. Isoquants represent combinations of fertilizer rates and irrigation depths that result in the same water productivity (Figure 2B). These combinations show that the higher the water productivity is, the fewer combinations there are until a single combination is obtained, corresponding to the maximum physical yield, which is 24.3 kg m^{-3} in this case.

In this study, the highest PUA was obtained at the lowest applied depths. As the amount of water used increased, there was a significant reduction in PUA. According to Taiz *et al*. (2017), when water stress occurs, water use productivity can increase due to a decrease in stomatal conductance, which affects the photosynthetic rate more intensely than the leaf transpiration rate does, and when stress becomes severe, dehydration of mesophyll cells inhibits photosynthesis. This compromises mesophyll metabolism and water productivity. The PUA aims to maximize water utilization, achieving maximum production potential while using the least amount of water possible.

Water productivity varied between 6.03 and 24.30 kg m^{-3}, meaning that 166 and 41 liters of water would be required to produce 1 kg of carrot, respectively. These results are similar to those reported by Cunha *et al*. (2016), who evaluated the agronomic characteristics of carrot cultivars subjected to different irrigation depths and reported values between 11 and 19.92 kg m^{-3}. These same authors reported that to produce 1 kg of carrot root, volumes ranging from 50 to 88 liters of water are needed.

The quadratic model was the one that best adjusted for this variable (PUA) analyzed; these results corroborate those found by Lima Júnior *et al*. (2012), who, when cultivating carrots in Lavras-MG, verified a quadratic effect of the productivity of water use as a function of different water contents in the soil.

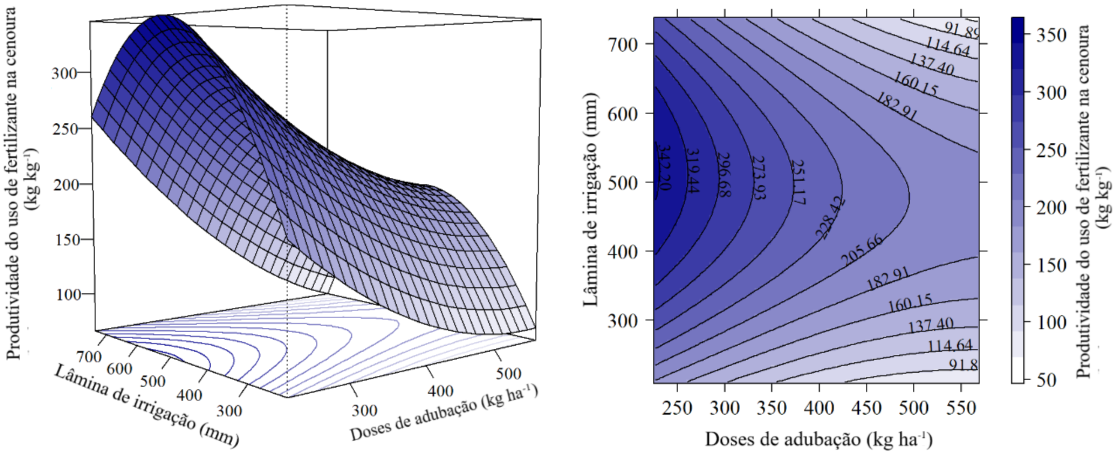
When choosing the best irrigation depth to apply, one should consider not only the depth that provides the highest production and best water use. It is necessary to simultaneously analyze other factors, such as energy availability and water consumption, and some water productivity indicators, which express benefits derived from water consumption by crops and can be used to assess the impact of agricultural strategies under water scarcity conditions. An analysis of these factors provides a more appropriate view of where water can be saved (FRIZZONE *et al*., 2014).

For the productivity of fertilizer use, the quadratic model with a significant interaction also best fit the average data set (Equation (4)).

$$PUF = 46.588 + 1.9339*L - 0.9764*F - 0.00176*L^{2} + 0.000981*F^{2} - 0.000508*L*F \qquad (4)$$

The combination of fertilizer dose and irrigation depth in which greater productivity is obtained from the use of fertilizers for carrot crops is 226.89 kg of fertilizer and 517.50 mm of water, resulting in a productivity of 345.36 kg kg^{-1} (kg of carrots per kg^{-1} of fertilizer) (Figure 3A). The greater the amount of fertilizer used, the lower the productivity of the use of this input and the greater the combinations of fertilizers and water that result in the same PUF (Figure 3B).

Figure 3. A: Response surface for the productivity of fertilizer use (PUF) (kg kg $^{-1}$) as a function of irrigation depth (mm) and fertilizer dose (kg ha $^{-1}$), and B: Isoquants that delimit regions of water and fertilizer combinations that result in the same PUF.



Source: Silva (2020)

Although potassium, nitrogen and phosphorus are among the four nutrients most absorbed by carrot crops and directly participate in the efficient use of water, opening and closing of stomata and growth, as the amount of these nutrients in the soil increases, the plant reduces its use and consequently its productivity (TAIZ *et al*., 2017), and this effect may be caused by losses through leaching and volatilization (LORENSINI *et al*., 2012).

6 CONCLUSION

The productivity of water and fertilizer use increased as the irrigation depth and fertilizer level decreased.

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