Universidade Federal Rural do Semi-Árido
Pró-Reitoria de Pesquisa e Pós-Graduação
https://periodicos.ufersa.edu.br/index.php/caatinga

ISSN 0100-316X (impresso)
ISSN 1983-2125 (online)
http://dx.doi.org/10.1590/1983-21252022v35n216rc

PRODUCTION AND YIELD OF ONION UNDER DIFFERENT WATER AND NUTRITION MANAGEMENTS[1]

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ABSTRACT - The objective of this study was to evaluate the effect of different irrigation depths applied by drip system and nitrogen fertilization levels that promote higher yield and water use efficiency in onion (*Allium cepa* L.). The treatments consisted of five irrigation depths (50; 75; 100; 125; 150% of crop evapotranspiration), applied by drip system, combined with five nitrogen fertilization rates (0, 40, 80, 120 and 160 kg ha^{-1}), in a 5 x 5 factorial scheme, in a randomized block experimental design, with four replicates. Irrigation depths estimated at 120.2% and 77.81% of crop evapotranspiration promoted higher yield and water use efficiency for total yield of onion bulbs, respectively. Nitrogen dose of 160 kg ha^{-1} promoted maximum total yield and water use efficiency.

Keywords: *Allium cepa* L. Irrigation management. Ammonium sulfate. Crop evapotranspiration.

PRODUÇÃO E RENDIMENTO DA CEBOLA SOB DIFERENTES MANEJOS HÍDRICO E NUTRICIONAL

RESUMO – O objetivo do trabalho foi avaliar o efeito das diferentes lâminas de irrigação aplicadas por gotejamento e níveis de adubação nitrogenada que proporcionem maior produtividade e eficiência no uso da água às ceboleiras (*Allium cepa* L.). Os tratamentos consistiram em cinco lâminas de irrigação (50; 75; 100; 125; 150% da evapotranspiração da cultura), aplicadas por gotejamento, combinadas a cinco doses de adubação de nitrogênio (0, 40, 80, 120 e 160 kg ha^{-1}), perfazendo um esquema fatorial 5 x 5, em delineamento experimental de blocos casualizados, com quatro repetições. As lâminas de irrigação estimadas em 120,2% e 77,81% da evapotranspiração da cultura proporcionaram maior produtividade e eficiência no uso da água para produtividade total de bulbos de cebola, respectivamente. A dose de nitrogênio de 160 kg ha^{-1} proporcionou máxima produtividade total e eficiência no uso da água.

Palavras-chave: *Allium cepa* L.. Manejo de irrigação. Sulfato de amônio. Evapotranspiração da cultura.

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[1]Received for publication in 08/21/2020; accepted in 10/26/2021.
Paper extracted from the first author's master's thesis.
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INTRODUCTION

Onion was the third most produced vegetable in the world in 2018 (96.77 *x* 106 t), only behind potato (368.17 *x* 106 t) and tomato (182.26 *x* 106 t). In the national scenario, in 2018, onion appeared in the same place as the world ranking, with production of 1.55 *x* 106 t, while tomato production appeared in the first place with 4.11 *x* 106 t, followed by potato with 3.69 *x* 106 t (FAOSTAT, 2020).

The average national yield of onion crop was is on the order of 31.95 t ha^{-1}, while the average of the Northeast was 37.59 t ha^{-1}, in 2018, with Bahia and Pernambuco being the main producers of the region, reaching together 287,342 t, which is equivalent to 97% of the regional production (IBGE, 2020). It is necessary to increase onion yield considering mainly the concern with the rational use of natural resources, especially water, which associated with cultural practices such as fertilization can increase production per unit area (BAPTESTINI et al., 2018; WAKCHAURE et al., 2018; RIAZ et al., 2020).

There is interest in the availability of water volume and quality to meet the demands of multiple uses, thus avoiding possible conflicts, especially in arid and semi-arid regions, where water limitation is noticeable, so it is increasingly necessary to increase water use efficiency (TEMESGEN; AYANA; BEDADI, 2018; ABDELKHALIK et al., 2019; PIRI; NASERIN, 2020).

Increase in water use efficiency, in turn, can be obtained with the ideal water supply to onion crop, since in most properties it is difficult to determine adequate irrigation depths, causing water stress in plants. Thus, irrigation management based on agrometeorological stations can be an important tool, due to the ease of data acquisition and adequacy for the phenological stages of the crop (ROP; KIPKORIR; TARAGON, 2016; BHATTI; SHARMA; KAKAR, 2019).

In addition, to ensure a better application, one can be adopt irrigation systems that apply a smaller volume in a smaller wet area, such as the drip irrigation system, which has been indicated to the detriment of other systems, due to the efficiency in the application of water depths and greater adaptability to rugged topography (ROP; KIPKORIR; TARAGON, 2016; PIRI; NASERIN, 2020).

Along with the need to quantify the irrigation depth, through drip irrigation system, it is necessary to adjust the demand for nutrients, since the onion plant is demanding in terms of agricultural fertilizers, and the search for adequate doses can maximize yield, which depends on management conditions, phenological stages and edaphoclimatic conditions, especially for nitrogen, a nutrient that, when in deficit or nutritional imbalance, can lead to death of the plant (RIAZ et al., 2020).

Nitrogen is the second nutrient most extracted by onion crop, and the rational application of fertilizers is fundamental for plant metabolism, increasing yield, quality, and resistance to pests and diseases, favoring sustainability and reducing environmental risks (RODRIGUES et al., 2015; BACKES et al., 2018). Riaz et al. (2020) state that nitrogen fertilization should be performed considering quantity, formulation and splitting scheme, avoiding excesses and abiotic stresses.

In view of the above, the objective was to evaluate the effect of the different irrigation depths applied by drip system and nitrogen fertilization levels that promote higher yield and water use efficiency in onion plants.

MATERIAL AND METHODS

The experiment was conducted at the Federal University of Sergipe, Rural Campus, São Cristóvão – Sergipe, Brazil, with coordinates of 10°55'S and 37°11'W, at 18 meters of altitude, under open field conditions. According to Köppen's classification, the climate of the region is subtropical with dry summer (As'), with precipitation concentrated between April and September. Figure 1 shows the daily precipitation and mean temperature in the experimental area along the crop cycle.

The soil was classified as *ARGISSOLO VERMELHO AMARELO* (OXISOL) (SANTOS et al., 2018). Chemical (Table 1) and physical (Table 2) attributes were characterized at 0-20 cm depth, according to Teixeira et al. (2017).

The experimental area was cultivated during two cycles with maize crop, interspersed by the cultivation of *Canavalia ensiformis*, as green manure, and no fertilizers were used during previous crops.

Tillage consisted of plowing and harrowing, followed by the correction of soil pH through liming, increasing base saturation to 80%, incorporation of 20 t ha^{-1} of organic matter and application of 666.67 kg ha^{-1} of single superphosphate, according to recommendations for the use of correctives and fertilizers in the State of Sergipe (SOBRAL et al., 2007). After the initial preparation procedure, basal fertilization and incorporation, beds with dimensions of 1.20 m wide, 1.20 m long and 0.30 m high were shaped using a rotary plow.

The treatments consisted of five irrigation depths, corresponding to percentages of crop evapotranspiration (ETc) (50; 75; 100; 125; 150% of ETc) combined with five nitrogen doses (0, 40, 80, 120 and 160 kg ha^{-1}) equivalent to 0, 50, 100, 150 and 200% of the fertilization recommendation for the State of Sergipe (SOBRAL et al., 2007), using ammonium sulfate as source, arranged in a 5 x 5 factorial scheme, applied in onion plants under a randomized block design, with four replicates, from November 2018 to February 2019.

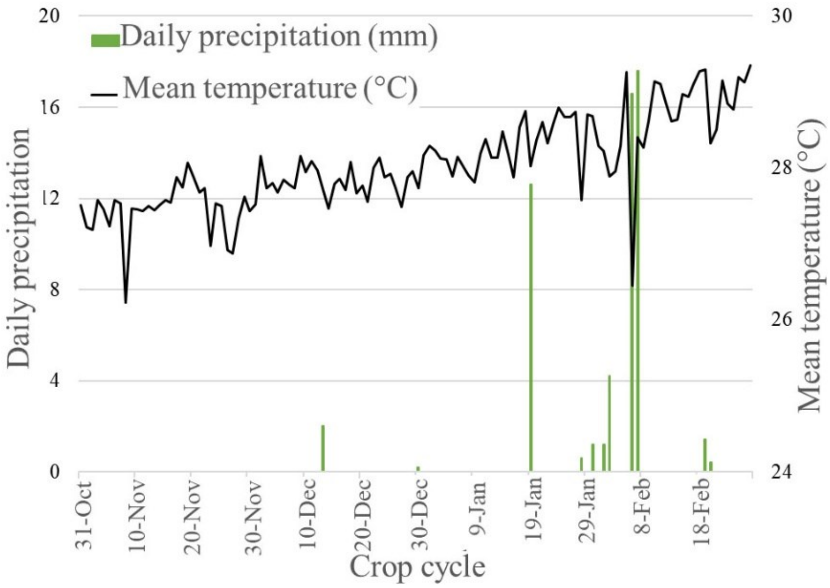

Figure 1. Precipitation and mean temperature during the experimental conduction

Table 1. Chemical characterization of the soil of the experimental area.

pH	OM	K	P	ESP	V	Ca^{2+}	Al^{3+}	Mg^{2+}	H + Al	SB	CEC	Na^{+}
H_2O	g kg^{-1}	%			cmol$_c$ dm^{-3}							
6.33	11.70	27.10	12.60	0.38	61.60	1.28	<0.08	0.93	1.43	2.29	3.72	0.014

OM: Organic Matter; ESP: Exchangeable Sodium Percentage; V: Base Saturation Index; SB: Sum of Exchangeable Bases; CEC: Cation Exchange Capacity.

Table 2. Physical characterization of the soil of the experimental area.

Textural class	Particle size			Bulk density
	Sand	Silt	Clay	
Loamy sand	81.4%	12.7%	5.9%	1.57 g cm^{-3}

The experimental plots had dimensions of 1.20 m long by 1.20 m wide, totaling an area of 1.44 m², at spacing of 0.10 m between rows and plants. The usable plot was formed by 25 plants of the central part of the plot, disregarding those at the ends of the rows.

The seedlings were formed in seed trays, using the cultivar 'Franciscana IPA 10', with predominantly purple color. Sowing was carried out at the rate of 80 seeds per meter of furrow, spaced apart by 0.15 m, with 1.20 m length and 5 mm depth. After 40 days, the seedlings were transplanted to the definitive beds.

The irrigation depths, for each treatment, were obtained through different times of operation of the lateral lines. ET_oCalculator® software, which was fed with meteorological parameters, obtained from an automatic weather station located near the experimental area, was used to obtain the daily reference evapotranspiration (ET_o). Subsequently, it was associated with the crop coefficients (Kc) 0.60, 0.80, 0.95 and 0.65, reaching 100% of ET_c, obtaining the evapotranspired depth. This time was obtained through calculation using Equation 1 (BERNARDO et al., 2019).

$$T = \frac{\mathrm{Li\,.\,Sp\,.\,Sr}}{\mathrm{q}} \qquad (1)$$

Where:
T = Irrigation time for each treatment, h;
Li = Irrigation depth for each treatment, mm;
Sp = Spacing between plants for each treatment, m;
Sr = Spacing between rows, m;
q = Average flow rate of drippers, L h^{-1}.

Irrigations were carried out using drip tubes with emitters spaced by 0.30 m, with flow rate of 1.8 L h^{-1} and operating pressure of 1.8 kgf cm^2. In each strip (bed), three drip tubes spaced apart by 0.30 m were installed, with daily irrigation interval. The drip lines were connected to the polyethylene manifold, with a valve at the beginning of each lateral line. The pressure was measured with an analog manometer and manually regulated by a gate valve.

The period between crop sowing and transplanting was 40 days, with no differentiation between the irrigation depths, with a total of 138 mm during seedling formation. From transplantation to harvest, which corresponded to the period of 79 days, irrigation depths of 172.6, 258.8, 345.1, 431.4 and 517.7 mm were applied by the drip system, and precipitation totaled 58 mm during the cycle. The accumulated irrigation depths, throughout the cultivation of onion plants, from the seed tray to the definitive site, including the total precipitation occurred in the cycle and the different treatments of water replacement as a function of crop evapotranspiration, can be observed in Figure 2.

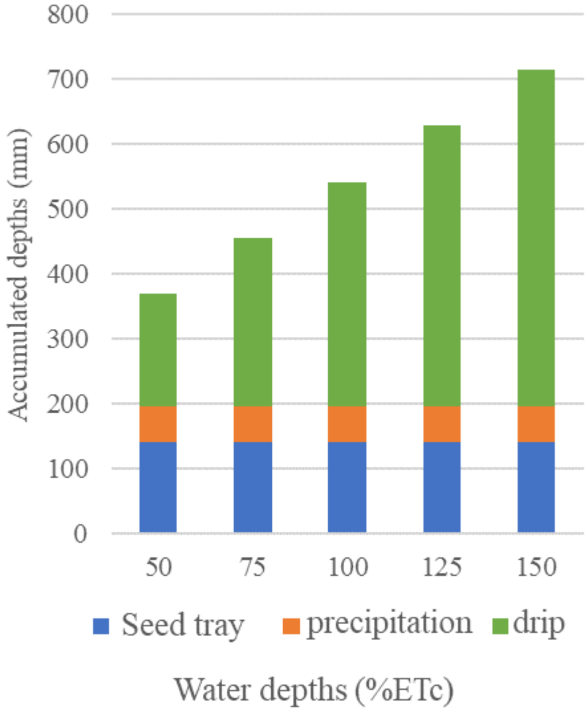

Figure 2. Accumulated water depth for each treatment along the experimental period.

Top-dressing fertilization for the nitrogen factor consisted of the following doses: 0, 40, 80, 120 and 160 kg ha^{-1}, corresponding to 0, 160, 380, 570 and 760 kg ha^{-1} (ammonium sulfate). For potassium (K_2O), the dose was 160 kg ha^{-1} (Potassium chloride, 266.67 kg ha^{-1}), split into two portions and applied broadcast at 10 and 45 days after transplantation.

Harvest was performed when, on average, 70% of the plants had their leaves fallen over, by harvesting 25 plants for evaluation, which were subsequently subjected to the curing process, followed by separation of the bulb from the roots and leaves.

Total bulb yield (TBY) was evaluated, considering the total production of the usable plot and its respective area, and estimating the yield per hectare, and the results were expressed in kg ha^{-1}. The water use efficiency for total bulb yield (WUE Total) was determined by the ratio between the values of total bulb yield (kg ha^{-1}) and the respective volumes of water supplied (mm) in each treatment.

The data were subjected to the normality test and subsequently to analysis of variance. Variables that were significantly affected at 1 and 5% probability levels by the treatments were analyzed by regression. The analyses were carried out using R statistical software (R CORE TEAM, 2019) with the ExpDes.pt package (FERREIRA; CAVALCANTI; NOGUEIRA, 2018).

RESULTS AND DISCUSSION

According to the analysis of variance (Table 3), there was a significant effect (P<0.01) on total bulb yield as a function of the irrigation depth factor and the fertilization dose factor. However, regarding the interaction between factors, no significant effect was observed (P<0.05).

According to the analysis of variance (Table 3), there was a significant effect (P<0.01) on water use efficiency for total yield as a function of the irrigation depths factor and the fertilization dose factor. However, regarding the interaction between factors, no significant effect was observed (P<0.05).

The maximum total yield of onion (Figure 3) was obtained by applying the estimated depth of 120.2% ETc, with a value on the order of 45.21 t ha^{-1}, which denotes the production potential of the crop when the appropriate irrigation management is adopted, since this value was higher than the Brazilian average in 2018, 31.9 t ha^{-1}, and the Northeast average, 37.59 t ha^{-1} (IBGE, 2020), which vary, however, with the location, cultural practices and cultivars.

Table 3. Summary of variance and regression analyses for total bulb yield (TBY) and water use efficiency for total bulb yield (WUE Total) of onion under different irrigation depths and nitrogen doses.

Sources of Variation	Degrees of Freedom	Sum of Squares	
		TBY (kg ha^{-1})	WUE Total (kg ha^{-1} mm^{-1})
Block	3	319.6**	1198**
Depth	4	4234.2**	10522**
N dose	4	7437.1**	27427**
Depth x N dose	16	445.3^{ns}	1467^{ns}
Residual	72	1454.3	5681
Overall mean	-	39.44	74.97
CV (%)	-	11.39	11.85
Depth	(4)	4234.2**	10522**
Linear	1	2779.89**	6906.88**
Quadratic	1	1402.68**	3071.54**
Deviation	1	13048^{ns}	10363^{ns}
N dose	(4)	7437.1**	27427**
Linear	1	7365.70**	27129.12**
Quadratic	1	58.1765^{ns}	233.28^{ns}
Deviation	1	12.36^{ns}	29.72^{ns}

^{ns}: not significant, *: significant at 5% probability level, **: significant at 1% probability level by F test, CV: Coefficient of variation.

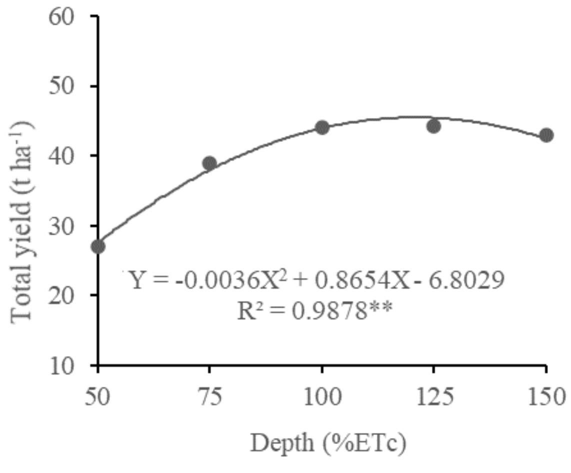

Figure 3. Means of total bulb yield of onion (t ha^{-1}), as a function of percentages of irrigation depths based on crop evapotranspiration.

Bispo et al. (2018) investigated the yield of 'IPA-11' onion under different drip irrigation managements in the city of Juazeiro-BA and obtained higher yield when applying a depth equivalent to 100% ETc, with a value on the order of 35.9 t ha^{-1}, lower than that achieved in the present study, which was 43.74 t ha^{-1}. Moreover, although other factors may be related, cultivars may have different water requirements, since the higher yield in this study was observed when a depth equivalent to 120.2% ETc was applied.

Baptestini et al. (2018) obtained maximum total yield of 60.7 t ha^{-1} when applying a depth equivalent to 150% ETc in the cultivation of 'Aquarius' onion, in the municipality of Viçosa-MG, emphasizing that the inflection point was not reached, differing from the present study, in which the peak production was obtained with application of a 120.2% ETc depth, which led to yield of 45.21 t ha^{-1}, hence confirming the hypothesis that water demand may vary with cultivar.

Temesgen, Ayana and Bedadi (2018) evaluated the effects of deficit irrigation at different stages of development on onion yield in Ethiopia and found that the 100% ETc depths promoted the best levels of total yield, which averaged 46.7 t ha^{-1}, while the application of 50% ETc led to an average of 37.8 t ha^{-1}, thus demonstrating the dependence of onion crop on water depths to increase yield. Therefore, it can be inferred that the production potential of onion crop is reduced in a situation of water stress, corroborating the present study, in which the increase in water depth from 50 to 120.2% resulted in an increase of 17.74 t ha^{-1} in yield.

Total bulb yield was affected by nitrogen fertilization doses, with 99% of variations explained by linear regression (Figure 4). Absence of nitrogen fertilization application led to the lowest average total bulb yield, 27.31 t ha^{-1}, while the highest fertilization dose, 160 kg ha^{-1}, promoted the highest total bulb yield, 51.58 t ha^{-1}.

Rodrigues et al. (2018) investigated onion yield as a function of nitrogen doses (0, 34, 67, 101, 134 and 168 kg ha^{-1}) distributed by fertigation in Mossoró-RN and concluded that the total bulb yield was described by a linear plateau regression model, in different cycles, and observed maximum yield of 28.93 t ha^{-1} in the first year, under 67.5 kg ha^{-1} of N, and 51.8 t ha^{-1} in the second year, under 113.66 kg ha^{-1} of N, different from what occurred in the present study, since the increase in the nitrogen dose promoted a linear increase in yield (Figure 4).

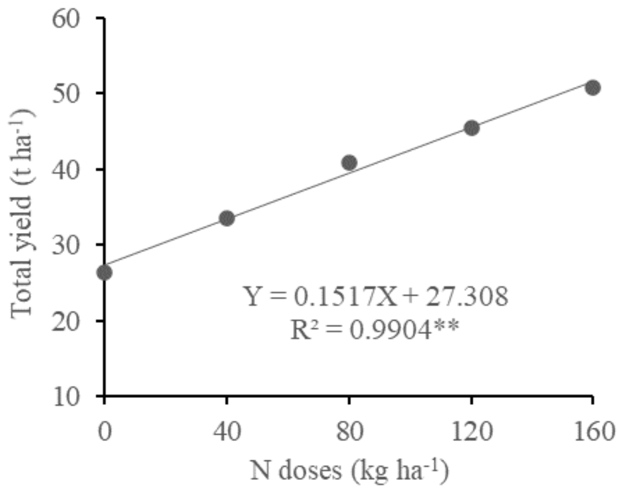

Figure 4. Total bulb yield of onion as a function of nitrogen fertilization doses.

Gonçalves et al. (2019) investigated the agronomic and qualitative performance of two onion cultivars subjected to dense cultivation system as a function of nitrogen fertilization, for the conditions of Mossoró-RN, and observed that total bulb yield was influenced by nitrogen doses (0, 45, 90, 135, 180, 225, 270 kg ha^{-1}), being described by a linear plateau regression model; the maximum total bulb yield was achieved with 92 kg ha^{-1} of nitrogen, and higher doses did not increase yield.

Gonçalves et al. (2019) attributed this behavior to excess nitrogen, which may have led to increase in respiration and decrease in photosynthetic yield. It can be inferred that for the present study yield could respond positively to an increase in nitrogen fertilization dose, because no plateau or inflection points were verified, so it is necessary to investigate higher nitrogen doses for the state of Sergipe.

Resende, Costa and Yuri (2016) studied yield and bulb classification of the onion cultivars 'Brisa IPA-12' and 'Vale Ouro IPA-11', subjected to five nitrogen doses (0; 60; 120, 180 and 240 kg ha^{-1}), and found that, regardless of the cultivar used, the doses caused an effect on bulb yield, which was represented by second-order polynomial regression model, with maximum estimated yield under application 183.2 kg ha^{-1}, which promoted 95.2 t ha^{-1}. This value is higher than the highest average achieved in the present study (51.13 t ha^{-1}), which can be explained by the technological level in cultivation and fertilization with higher doses.

Nitrogen is necessary for growth and development of onion crop, and its deficiency causes reduction of chlorophyll biosynthesis and, consequently, leaf area and bulbs, which are reserve organs, so it is necessary to supply N during the phenological stages (PIRI; NASERIN, 2020).

It was possible to note that water use efficiency for total bulb yield (Figure 5) was higher under application of 77.81% ETc, reaching 95.94 kg ha^{-1} mm^{-1}, showing a quadratic behavior. Some authors, such as Esmaeilzadeh, Asgharipour and Khoshnevisan (2020) and Sarma, Kotoky and Bora (2019), emphasize the need to quantify the total volume of water used in a given crop and report that in the onion production chain water consumption is equal to 154.62 and 192.00 m^3 t^{-1}, respectively.

Bispo et al. (2017) evaluated the performance of five onion cultivars under different soil water tensions, with depths applied by a drip system in the sub-middle region of São Francisco, and observed a decrease in water use efficiency from 107.5 to 25.13 kg ha^{-1} mm^{-1} as soil water tensions increased from 20 to 50 KPa, respectively. This is related to the drastic reduction in production observed with the increase in soil water tension, in general, which occurred in the present study, since there was quadratic behavior and the use of the 77.81% ETc depth promoted economically viable production, as it enabled greater WUE Total (Figure 5).

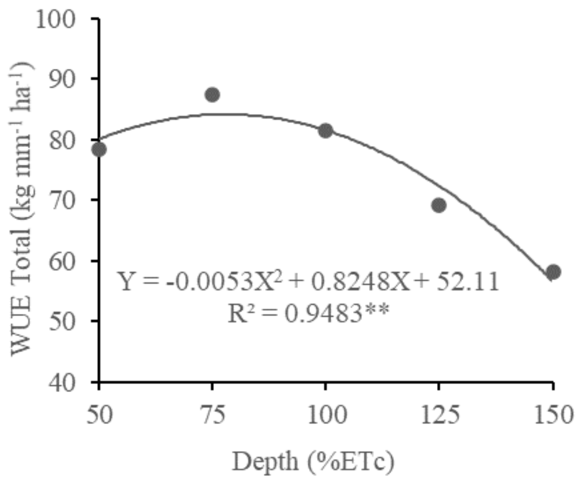

Figure 5. Water use efficiency for total bulb yield as a function of irrigation depth percentages based on crop evapotranspiration.

Rop, Kipkorir and Taragon (2016) evaluated the effects of deficit irrigation on the yield of onion in Kenya, under drip irrigation according to ETc percentages, which ranged from 50 to 100%, and found higher water use efficiency, on the order of 16.2 kg ha^{-1} mm^{-1}, with the depth equivalent to 50% ETc, 26.3% higher than that obtained with 100% ETc. Therefore, it highlights the need to evaluate the costs of increasing the amount of water relative to the increase in crop yield and point to the need for local studies for decision-making in water management, which may be different in different regions, according to water availability, and that water use efficiency should be a decisive factor in decision-making.

In this context, the recommendation of adequate efficiency, according to a study conducted by Rop, Kipkorir and Taragon (2016) was 80% ETc, corresponding to 15.8 kg ha^{-1} mm^{-1}, justified by the authors due to the decrease in the volume of water applied and the low variation in bulb diameter and yield, that is, in the maintenance of quality. It is worth pointing out that the value indicated by the authors is close to that estimated in this study, which was 77.81% ETc, reaching water use efficiency of 95.94 kg ha^{-1} mm^{-1}.

Mubarak and Hamdan (2018) indicate that water use efficiency had a directly proportional relationship with the increase of water depth in their investigation on the response of onion crop subjected to nitrogen levels and irrigation depths (100, 80 and 60% ETc), which is verified in the present study between the depths of 50% and 77.81%. The authors associate this behavior with the high sensitivity of the crop to water deficit mainly during the bulb development stage, as also confirmed in the investigation by Kifle et al. (2017), who concluded that water use efficiency in onion crop was optimized due to surge flow and alternate irrigation.

Abdelkhalik et al. (2019) cultivated onions under depths ranging from 50 to 100% ETc, applied by a drip system in the Mediterranean region, and observed a linear decrease in water use efficiency with the increase in irrigation depths, which ranged from 146.25 kg ha^{-1} mm^{-1} to 134.8 kg ha^{-1} mm^{-1}. Enchalew et al. (2016), producing onions under water deficit applied by drip irrigation in Ethiopia, using fractions (50, 60, 70, 80, 90 and 100%) of ETc, observed no significant difference in water use efficiency, diverging from the present study and pointing to the need for more related research.

There was significant linear effect of the different doses of nitrogen fertilization on the water use efficiency for total bulb yield (P<0.01), and it was not possible to determine the inflection point. It is possible to infer that the crop would respond to higher doses of nitrogen.

The increment of one unit in the dose of nitrogen fertilization (kg ha^{-1}) increases water use efficiency for total bulb yield by 0.291 kg ha^{-1} mm^{-1} (Figure 6), with maximum value of 98.271 kg ha^{-1} mm^{-1} under N application of 160 kg ha^{-1}.

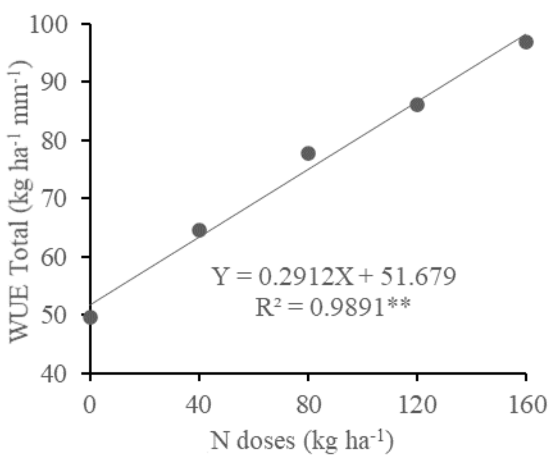

Figure 6. Water use efficiency for total bulb yield as a function of nitrogen fertilization doses.

Piri and Naserin (2020) found that the increase in nitrogen doses increased water use efficiency when the N doses (urea) of 30, 60, 90 and 120 kg ha^{-1} were applied, reporting that the crop can respond to higher doses, as in the present study.

Wakchaure et al. (2018) studied water productivity in onion crop subjected to deficit irrigation regimes and plant bio-regulators and stated that under water stress the plant suffers physiologically, mostly with stomatal closure, and that it can be overcome primarily with application of potassium nitrate and thiourea (nitrogen-rich compounds), helping to mitigate the effects of water stress in environments with water scarcity, a behavior consistent with the present study, so it is possible to infer that the nutritional condition of the plant can optimize water metabolism by plants.

Bhatti, Sharma and Kakar (2019) evaluated the effect of irrigation levels and nitrogen doses on water use efficiency and yield of onion and found the highest water use efficiency (130.6 kg ha^{-1} mm^{-1}) when the highest nitrogen dose was applied, while the lowest efficiency (91.3 kg ha^{-1} mm^{-1}) was observed at the lowest dose, corroborating the present study, in which the application of the highest nitrogen dose (160 kg ha^{-1}) resulted in the highest water use efficiency (98.271 kg ha^{-1} mm^{-1}).

Elnamas (2019) studied three methods of water application (precipitation, surface drip and subsurface drip) and nitrogen doses (0, 90 and 180 t ha^{-1}) on onion production, in two cycles, and found that the combination of surface drip irrigation and N dose of 90 t ha^{-1} promoted efficiency on the order of 88.24 and 93.44 kg ha^{-1} mm^{-1} in the first and second years, respectively, indicating that adapting the N dose to the irrigation method may favor water use efficiency. For the condition of the present study, the nitrogen dose that promotes maximum efficiency for the drip irrigation method was not obtained, so studies with higher doses need to be conducted.

The water use efficiency values found by Elnamas (2019) were higher when the dose of 90 kg ha^{-1} was applied. Doses of 0 and 180 kg ha^{-1} promoted lower values of water use efficiency, so it can be inferred that extreme values can cause stress and negatively affect this variable. Nitrogen excess can cause toxic effects on plants, as reported by Riaz et al. (2020), which was not observed in the present study.

CONCLUSIONS

Irrigation depths estimated at 120.2 and

77.81% ETc promoted higher yield and water use efficiency for onion bulbs, respectively.

Nitrogen dose of 160 t ha^{-1} and absence of fertilization resulted in the maximum and minimum total yield and water use efficiency, respectively.

No inflection point was obtained for these variables, so studies with higher nitrogen doses are required.

ACKNOWLEDGMENTS

The authors thank CAPES for the financial support. We extend our gratitude to the Federal University of Sergipe and the Graduate Program in Water Resources of the same institution.

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