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Water-use efficiency and onion quality in future climate scenarios[1]

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ABSTRACT

Considering that changes in climatic parameters directly interfere in crop yields, this study aimed to evaluate the impact of changes in carbon dioxide concentrations, temperature and soil water availability on production, water-use efficiency and onion (*Allium cepa* L. cv. IPA 11) quality. Four levels of soil water availability (40, 60, 80 and 100 %) and two concentrations of atmospheric CO_2 (770 and 390 ppm) were evaluated in three experiments with different temperature regimes (18-24-30, 22-28-34 and 26-32-38 ºC), in Phytotron growth chambers. The water-use efficiency, bulb diameter and weight, shoot dry weight, pulp firmness, soluble solids content, pH and titratable acidity were also evaluated. The increase in temperature reduces the production, and a higher soil water availability increases the production of IPA 11 onion bulbs. The temperature regime of 18-24-30 ºC and the water availability of 76.72 % provide the best water-use efficiency for the onion crop.

KEYWORDS: *Allium cepa* L., water availability, carbon dioxide.

RESUMO

Eficiência no uso de água e qualidade de cebola em cenários climáticos futuros

Considerando-se que mudanças nos parâmetros climáticos interferem diretamente na produtividade das culturas, objetivou-se avaliar o impacto de mudanças nas concentrações de dióxido de carbono, temperatura e disponibilidade hídrica do solo na produção, eficiência do uso de água e qualidade de cebola (*Allium cepa* L. cv. IPA 11). Foram avaliados quatro níveis de disponibilidade de água no solo (40, 60, 80 e 100 %) e duas concentrações de CO_2 atmosférico (770 e 390 ppm), em três experimentos com diferentes regimes de temperatura (18-24-30, 22-28-34 e 26-32-38 ºC), em câmera de crescimento Fitotron. Também foram avaliados a eficiência do uso de água, diâmetro e peso dos bulbos, massa seca da parte aérea, firmeza da polpa, teor de sólidos solúveis, pH e acidez titulável. O aumento da temperatura reduz a produção, e maior disponibilidade de água no solo eleva a produção de bulbos de cebola IPA 11. O regime de temperatura de 18-24-30 ºC e a disponibilidade hídrica de 76,72 % proporcionam melhor eficiência no uso de água para a cultura da cebola.

PALAVRAS-CHAVE: *Allium cepa* L., disponibilidade hídrica, dióxido de carbono.

INTRODUCTION

The significant increase in greenhouse gases (GHG) has caused climatic changes such as increase in the air temperature and changes in the rainfall regime. The carbon dioxide (CO_2) concentration in the atmosphere has increased by 40 % since the pre-industrial period (IPCC 2013). Currently, the concentration of this gas is around 410 parts per million (ppm), with the expectation to exceed 700 ppm by the end of the century (NOAA 2019, IPCC 2013). As a result, the air temperature increased by 0.85 ºC, and the RCP 8.5 greenhouse gas emission scenarios point out to an increase of up to 4.8 ºC by 2100 (IPCC 2013).

Considering that agriculture is an activity highly dependent on climatic elements, strong adaptation policies should be developed to minimize global warming, to ensure the stable production of agricultural crops (Lee et al. 2016).

In the Brazilian Northeast, the sub-middle region of the São Francisco Valley stands out as one of the largest onion producers in the country, contributing for this vegetable to occupy the third

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place in economic importance for Brazil (Bandeira et al. 2013), with the Vale Ouro IPA-11 and Alfa São Francisco cultivars, with a yellow color, and Franciscana IPA-10, with a purple color, standing out. The largest producers of this crop in the Northeast are the States of Bahia (35.4 t ha^{-1}) and Pernambuco (31.7 t ha^{-1}) (IBGE 2020).

Climatic elements, such as temperature, radiation and rainfall, may act in the different stages of crop development, affecting their efficiency in the use of water and the nutrient absorption capacity, changing the cycle, the bulbs formation and quality, especially the acidity and the soluble solids. These parameters are important to determine the post-harvest quality, since a higher acidity is desirable for industrialization, by allowing a better dehydration, and high levels of soluble solids contribute to a better palatability of the onion (Bispo et al. 2018).

An important element of the environment for crop development is CO_2, whose high concentration can enhance the production of plants due to the higher photosynthetic rate and lower photorespiration and transpiration rates (Martinez et al. 2015). Associated with increases in temperature, the low water availability in the soil can promote a reduction in cell expansion and division, reducing the plant gas exchange and leaf area and resulting in lower growth and yield rates (Taiz et al. 2017). On the other hand, the excess of water, combined with high temperatures, favors the incidence of pathogens, compromising the bulbs production and quality (Marouelli et al. 2011).

The representation of future cultivation environments through experiments in controlled conditions may elucidate the influence of these climatic elements on the onion crop development in the field. With this, to prove the hypothesis that climate changes may interfere negatively in the world onion production, the present study aimed to evaluate the impact of the alteration of carbon dioxide concentrations, soil temperature and water availability in the production, water-use efficiency and quality of onion (*Allium cepa* L.) bulbs.

MATERIAL AND METHODS

The experiment was carried out in Phytotron growth chambers, with controlled temperature, relative humidity, carbon dioxide (CO_2) and light, at the Embrapa Semiárido, in Petrolina, Pernambuco State, Brazil (9º8’8.9”S, 40º18’33.6”W and altitude of 373 m), from July 2019 to Dec. 2020.

The experiment was designed in randomized blocks arranged in a 4 x 3 x 2 factorial scheme, with four levels of water availability in the soil (40, 60, 80 and 100 %); three temperature regimes (T1: 18-24-30 ºC, being 18 ºC from 8 p.m. to 6 a.m., 24 ºC from 6 a.m. to 10 a.m., 30 ºC from 10 a.m. to 3 p.m. and 24 ºC from 3 p.m. to 8 p.m.); T2: 22-28-34 ºC, being 22 ºC from 8 p.m. to 6 a.m., 28 ºC from 6 a.m. to 10 a.m., 34 ºC from 10 a.m. to 3 p.m. and 28 ºC from 3 p.m. to 8 p.m.; T3: 26-32-38 ºC, being 26 ºC from 8 p.m. to 6 a.m., 32 ºC from 6 a.m. to 10 a.m., 38 ºC from 10 a.m. to 3 p.m. and 26 ºC from 3 p.m. to 8 p.m.); and two CO_2 concentrations (770 and 390 ppm), with four replications. The values used to determine the temperatures were based on the minimum, average and maximum temperatures of the sub-medium São Francisco Valley region, which vary from 18 to 22 ºC, 25 to 27 ºC and 32 to 34 ºC for the minimum, average and maximum temperature, respectively.

Seeds of the IPA 11 cultivar were planted in pots with capacity of 3.5 L and kept in two growth chambers to differentiate the CO_2 concentrations from the environment. The soil was classified as Argissolo Vermelho-Amarelo (Santos et al. 2018) or Ultisol (USDA 2014), and the fertilization was carried out according to the results of the chemical analysis and recommendations by Mendes et al. (2008) for the onion crop.

For the irrigation management, weighing lysimeters were installed in all vessels to determine the amount of water to be applied per treatment. The lysimeters were equipped with load cells (model TSD, AEPH, 50 kg capacity) under a metallic base, with a device for collecting the excess of drained water. The load cells were connected to two multiplexers (AM16/32B) connected to a datalogger (CR1000), which performed a reading every 15 seconds, recording data every 10 minutes. All lysimeters were calibrated in order to obtain a signal reading curve (mV) from permanent wilting point to the soil field capacity. The irrigations were performed every two days, using the crop evapotranspiration data obtained by weighing the lysimeters, in order to restore the volume of water necessary to maintain the low water availability in the soil for each treatment.

For the evaluation of onion production, the plants were kept inside the growth chambers until they reached the ideal point for harvest, which was determined by the tipping of the plants, varying from 110 to 135 days after planting. After harvesting, the plants were submitted to the curing process, through exposure to light for three days, to decrease the humidity in the outer layers of the bulbs.

The water-use efficiency was calculated using the ratio of bulb production to the amount of water used in irrigation throughout the cycle.

With the aid of a caliper, the longitudinal and transverse diameter of the bulbs were measured, and, with the aid of an analytical scale, their weighing was carried out to obtain the crop production. Bulbs with a diameter between 35 to 90 mm were considered as commercial bulbs, and those with a transverse diameter of less than 35 mm were rejected.

The flesh firmness was obtained with the aid of a manual penetrometer from the longitudinal division of the bulb in two parts, and, in each of them, two readings were performed on the flesh, in opposite sides in the equatorial region, with the homogenized flesh obtained from processing through the use of a household shredder. After this procedure, the soluble solids (SS) (ºBrix) content was determined using a manual refractometer (model Pocket pal^{-1}). The pH was measured with a digital pHmeter. The titratable acidity (TA) (%) was determined by titrating 5 mL of homogenized flesh diluted in 50 mL of distilled water, in which three drops of 1 % phenolphthalein indicator were added, proceeding with a digital titration under constant shaking, with 0.1N NaOH solution, being the results expressed in g of citric acid per 100 mL of onion flesh.

The results for temperatures, carbon dioxide (CO_2) and low water availability in the soil were submitted to analysis of variance with the application of the F test ($p < 0.05$). Regression analysis was also carried out in the presence of a significant effect for the low water availability in the soil and interactions, taking into consideration the adjusted means with $R^2 > 50$ %, using the Sisvar software, version 5.3.

RESULTS AND DISCUSSION

The increase in air temperature reduced by 43.3 % the water-use efficiency (WUE) of plants maintained at a temperature regime of 26-32-38 ºC, with a higher bulb production (weight and diameter) in plants submitted to the regime of 18-24-30 ºC (Table 1). For the shoot dry weight, there was a variation in the observed values, with greater values under the temperature regime of 22-28-34 ºC, with a difference of 9.93 g, if compared to the temperature of 18-24-30 ºC, and 15.23 g for the temperature of 26-32-38 ºC (Table 1).

In addition, the results showed that the temperature regime of 22-28-34 ºC provided a higher value for the onion titratable acidity, reaching 1.73 %. However, for the soluble solids variable, the bulbs produced under a temperature range of 18-24-30 ºC reached 12.34 ºBrix. A similar behavior was observed for pH, which, under the same conditions, reached 5.71 ºBrix.

The most favorable temperature conditions for bulb firmness were observed in the regimes of 22-28-34 and 26-32-38 ºC, with values of 83.54 and 76.06 N, respectively. The onion plants grown in a lower temperature environment (18-24-30 ºC) showed the lowest value for this variable, reaching 44.78 N (Table 1).

Evaluating only the concentration and carbon dioxide, it was found that the increase of this gas to 770 ppm favored the WUE and the weight and diameter of the onion bulbs (Table 2), with the bulb weight presenting a difference of 29.7 g and diameter of 7.24 mm, when compared to bulbs grown in an environment with 390 ppm of CO_2. However, the bulbs developed in an environment enriched with

Table 1. Water-use efficiency (WUE), yield and postharvest parameters of onion bulbs (IPA 11 cultivar) grown under three temperature regimes.

Temperature regimes (ºC)	WUE (mg L^{-1})	Bulb weight (g)	Shoot dry weight (g)	Bulb diameter (mm)	Titratable acidity (%)	Soluble solids (ºBrix)	Firmness (N)	pH
18-24-30(1)	26.44 a	107.71 a	19.28 b	59.15 a	1.23 b	12.34 a	44.78 b	5.71 a
22-28-34(2)	16.70 b	68.73 b	29.21 a	49.92 b	1.73 a	10.03 c	76.06 a	5.36 c
26-32-38(3)	14.99 b	54.50 c	13.98 c	43.96 c	1.33 b	11.15 b	83.54 a	5.56 b

* For the same letters in the column, the means are not different, according to the Tukey test at 0.05 of probability. (1) 18 ºC from 8 p.m. to 6 a.m., 24 ºC from 6 a.m. to 10 a.m., 30 ºC from 10 a.m. to 3 p.m. and 24 ºC from 3 p.m. to 8 p.m. (2) 22 ºC from 8 p.m. to 6 a.m., 28 ºC from 6 a.m. to 10 a.m., 34 ºC from 10 a.m. to 3 p.m. and 28 ºC from 3 p.m. to 8 p.m. (3) 26 ºC from 8 p.m. to 6 a.m., 32 ºC from 6 a.m. to 10 a.m., 38 ºC from 10 a.m. to 3 p.m. and 26 ºC from 3 p.m. to 8 p.m.

Table 2. Water-use efficiency (WUE), production and postharvest parameters of onion bulbs (IPA 11 cultivar) grown under two CO_2 levels.

CO_2 levels (ppm)	WUE (mg L^{-1})	Bulb weight (g)	Shoot dry weight (g)	Bulb diameter (mm)	Titratable acidity (%)	Soluble solids (ºBrix)	Firmness (N)	pH
770	24.80 a	91.98 a	20.41 a	54.63 a	1.43 a	11.23 a	72.63 a	5.53 b
390	13.95 b	61.98 b	21.23 a	47.39 b	1.46 a	11.12 a	63.63 a	5.56 a

* For the same letters in the column, the means are not different, according to the Tukey test at 0.05 of probability.

CO_2 showed a lower pH (5.53). The increase in the CO_2 concentration did not affect the shoot dry weight, acidity, soluble solids content and firmness of the bulbs (Table 2).

In general, it may be observed that the increase in water availability in the soil had positive effects on the productive characteristics of the onion plants. There was a quadratic behavior for the variables bulb weight and shoot dry weight, which presented higher values with water availability of 108.6 and 89.4 %, resulting in maximum values of 108.9 and 24.5 g, respectively (Figure 1).

The bulb diameter and soluble solids (SS) also increased with the improvement of water availability in the soil, with an increase of 0.36 mm for bulb diameter and 0.0134 for soluble solids for each percentage unit of water availability added (Figure 1). For the shoot dry weight, an average increase of 12 g was observed, between 40 and 80 % of water availability. For 80 and 100 % of water availability, no significant change was observed for this variable (Figure 1). However, for acidity, an average reduction of 14 % was noticed, considering the water availability from 40 to 100 % (Figure 1).

The shoot dry weight showed higher values when subjected to 89.4 % of water availability (Figure 1). Lower values for water availability in the soil may have caused a series of physiological and metabolic changes, immediately resulting in a reduced growth and, consequently, a reduced shoot dry matter (Perdomo et al. 2017). The water deficit in the onion may alter the partition of assimilates between roots and shoots, with a great effect on the plant productivity, also decreasing the accumulation of shoot biomass. According to Perdomo et al. (2017), water is an important element in the development of plants, helping in various reactions, favoring the gas exchange and contributing to the translocation and assimilation of reserves and growth.

These results corroborate those found by Olalla et al. (2004), with a significant increase in the bulb size as the water depth increased in the growth and maturation stages. The low water availability in the soil induces the onion plant to stomatal closure (Menezes Júnior et al. 2014), and, when this occurs, both photosynthesis and the flow of nutrients from soil to roots are reduced (Taiz et al. 2017). Therefore, the occurrence of water deficits during cultivation, especially in the bulbification period, may hinder the normal development of plants, promote the formation of smaller bulbs and, consequently, reduce yield (Wordell Filho & Stadnik 2010).

Evaluating the interaction between temperature and CO_2 concentrations for bulb weight, diameter and water-use efficiency, the highest values were observed for plants kept in an environment with temperature regime of 18-24-30 ºC and 770 ppm CO_2 (Table 3). However, it was found that, in this temperature regime and at 390 ppm of CO_2, only the pH of the bulbs was higher than the others (Table 3).

The increase in temperature is associated with the acceleration of growth and phenology; however, its excessive increase generally reduces the biomass gain of the crop. In addition, very high temperatures cause a reduction in photosynthetic rates and decrease the net carbon gain of the plant (Dusenge et al. 2018). These results demonstrate that adjustments to the onion production system will be necessary, evaluating and validating agricultural practices that minimize the negative impacts of climate change on its production.

In addition to temperature, the carbon dioxide concentration also interfered with the size and weight of the bulbs (Table 2). The environment enriched with CO_2 showed the fertilizing effect of the gas, corroborating Daymond et al. (1997), who verified an increase in the size of the onion bulbs. The increase in the CO_2 concentration alters the physiological responses of C3 plants, stimulating the net CO_2 photosynthesis, which, consequently, may increase yield (Martinez et al. 2015).

Regarding the postharvest parameters, the pH varied between 5.35 and 5.78 and the soluble solids

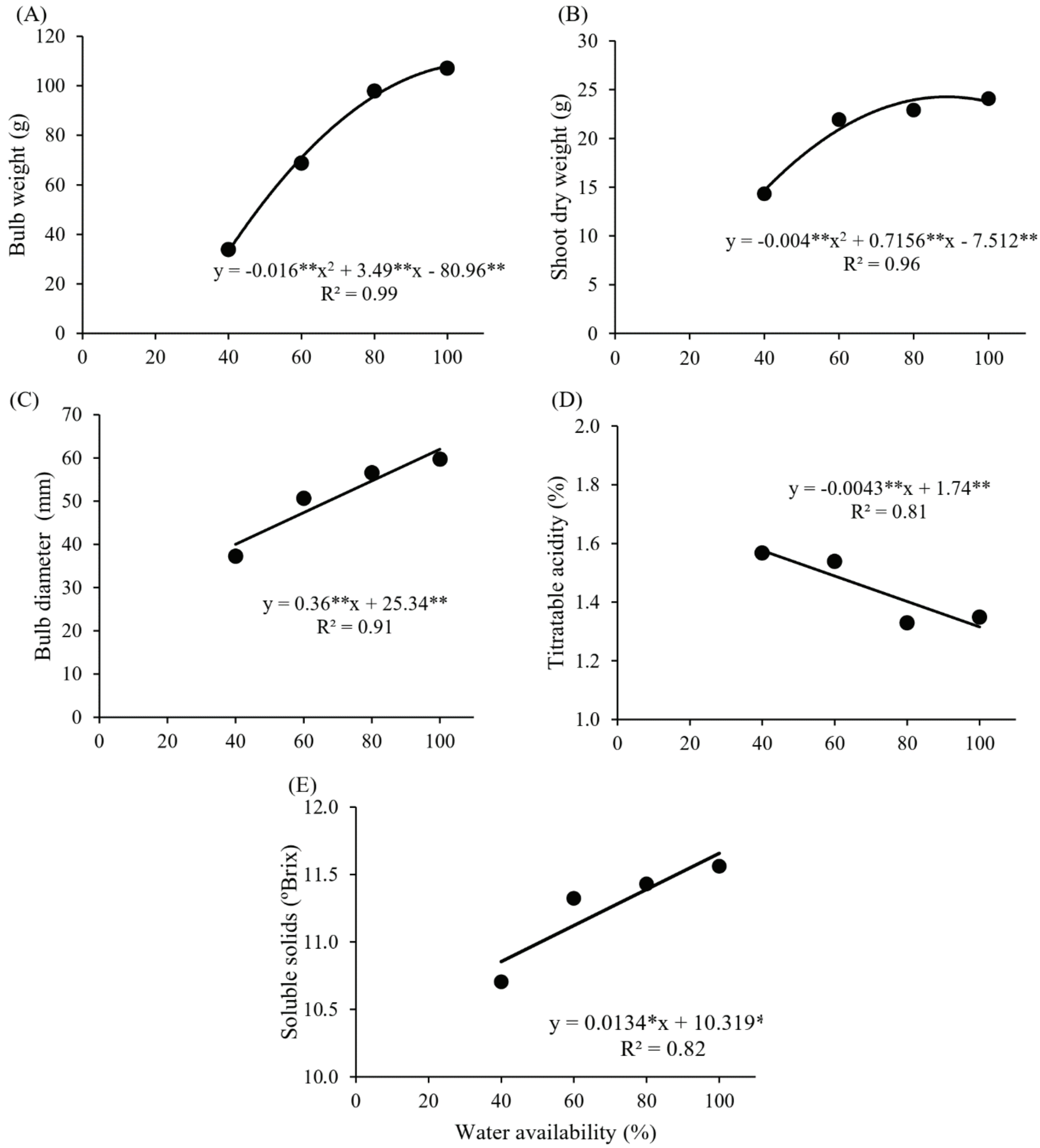

Figure 1. Productive and postharvest parameters of onion bulbs (IPA 11 cultivar) grown under different soil water availability levels. ** and *: regression coefficient significant at 0.01 and 0.05 of probability, respectively.

Table 3. Water-use efficiency (WUE), productive and postharvest parameters of onion bulbs (IPA 11 cultivar) grown under different temperature regimes and CO_2 concentrations.

Temperature regimes (ºC)	Bulb weight (g)		Bulb diameter (mm)		pH		WUE (mg L^{-1})	
	CO_2 (ppm)							
	770	390	770	390	770	390	770	390
18-24-30(1)	143.18 Aa	72.23 Ab	67.05 Aa	51.23 Ab	5.65 Ab	5.78 Aa	36.19 Aa	16.67 Ab
22-28-34(2)	71.25 Ba	66.21 Aa	50.93 Ba	48.90 Aa	5.36 Ca	5.35 Ca	19.74 Ba	12.65ABb
26-32-38(3)	61.51 Ba	47.49 Bb	45.90 Ca	42.02 Bb	5.57 Ba	5.56 Ba	18.46 Ba	11.52 Bb

* For the same uppercase letters in the column and lowercase letters in the row, the means are not different according to the Tukey test at 0.05 of probability. (1) 18 ºC from 8 p.m. to 6 a.m., 24 ºC from 6 a.m. to 10 a.m., 30 ºC from 10 a.m. to 3 p.m. and 24 ºC from 3 p.m. to 8 p.m. (2) 22 ºC from 8 p.m. to 6 a.m., 28 ºC from 6 a.m. to 10 a.m., 34 ºC from 10 a.m. to 3 p.m. and 28 ºC from 3 p.m. to 8 p.m. (3) 26 ºC from 8 p.m. to 6 a.m., 32 ºC from 6 a.m. to 10 a.m., 38 ºC from 10 a.m. to 3 p.m. and 26 ºC from 3 p.m. to 8 p.m.

content between 10.03 and 12.34 (Table 1) with the change in the air temperature. Resende et al. (2010) also found differences for these parameters and concluded that the pH and SS values are influenced by the cultivar x environment interaction. In addition, a high content of soluble solids is a parameter required for a good bulb storage quality, because it is necessary to guarantee reserves for the consumption of substrates that occur in the respiratory metabolism due to catabolic reactions of senescence (Muniz et al. 2012).

The bulbs firmness was influenced by the temperature regimes, and, for those of 22-28-34 and 26-32-38 ºC, the values of 83.54 and 76.06 N were found, respectively, showing firmer bulbs than at the temperature range of 18-24-30 ºC, which obtained less firmness, with a value of 44.78 N (Table 1). Aragão et al. (2014) obtained bulb firmness values between 66.10 and 75.95 N, studying IPA 11 onion bulbs stored at room temperature, which are higher than the ones found in the temperature regime of 18-24-30 ºC in the present study.

The production and quality of vegetables are directly influenced by high temperatures and exposure to high CO_2 levels (Bisbis et al. 2018). However, in the present study, the increase in the CO_2 concentration did not affect the shoot dry weight, titratable acidity, soluble solids content and firmness of the bulbs, and the bulbs developed in an environment enriched with CO_2 (770 ppm) showed a lower pH, with a value of 5.53 (Table 2). Variations in temperature may affect the crop photosynthesis, as observed by Lee et al. (2016) in kimchi Cabbage leaves. These specific mechanisms by which high air temperatures affect the net photosynthetic rate are caused by increased photorespiration in plants submitted to elevated temperatures (Lee et al. 2016, Lee et al. 2018). An increase in global temperatures may be expected to have a significant impact on postharvest quality, influencing important quality parameters such as sugar synthesis, organic acids, antioxidant compounds and firmness.

Figure 2 confirms the positive effect of the temperature regime of 18-24-30 ºC on the weight of the onion bulbs. With 100 % of water availability, the average weight of the bulbs were 155, 103 and 60 g, respectively for the regimes of 18-24-30, 22-28-34 and 26-32-38 ºC. For the regime of 18-24-30 ºC, it was observed that the weight gain of the bulbs increased, with a maximum point at the water availability of 101 %, resulting in a maximum value of 159 g. However, for the regimes of 22-28-34 and 26-32-38 ºC, increases of 40 and 60 % were respectively observed for bulb weight, in relation to 100 % of water availability in the soil, with increases of 1.18 and 0.391 g, respectively, for each unit of water availability percentage added.

For bulb diameter, there was no significant difference for the plants maintained at the regimes of 22-28-34 and 26-32-38 ºC, with 40 and 60 % of soil water availability. However, for the regime of 18-24-30 ºC, the bulbs developed more when applying a water availability of 97.1 % and with a diameter of 72.70 mm. For the regime of 22-28-34 ºC, the behavior was linear, and the largest bulbs were registered when applying an irrigation level of 100 %. However, at the regime of 26-32-38 ºC, the maximum point for water availability was 80.45 %, resulting in a maximum value of 47.7 g (Figure 3).

The best water-use efficiency (WUE) for the onion crop was observed for the regime of 18-24-30 ºC, with a maximum point of 76.72 % for soil water availability, with 34.52 mg L^{-1}. For the WUE, there was no significant difference for plants maintained at 22-28-34 and 26-32-38 ºC, with 40 and 60 % of soil water availability, respectively (Figure 4).

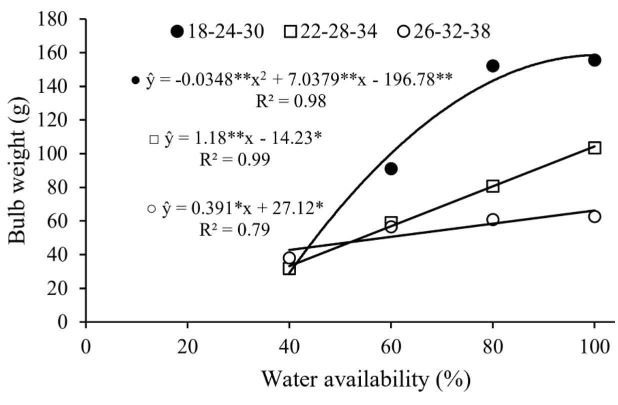

Figure 2. Bulb weight for onion (IPA 11 cultivar) grown under different temperature regimes and soil water availability. **, *: significant regression coefficient at 0.01 and 0.05 of probability, respectively. Temperature regimes: 18-24-30 ºC (18 ºC from 8 p.m. to 6 a.m., 24 ºC from 6 a.m. to 10 a.m., 30 ºC from 10 a.m. to 3 p.m. and 24 ºC from 3 p.m. to 8 p.m.); 22-28-34 ºC (22 ºC from 8 p.m. to 6 a.m., 28 ºC from 6 a.m. to 10 a.m., 34 ºC from 10 a.m. to 3 p.m. and 28 ºC from 3 p.m. to 8 p.m.); 26-32-38 ºC (26 ºC from 8 p.m. to 6 a.m., 32 ºC from 6 a.m. to 10 a.m., 38 ºC from 10 a.m. to 3 p.m. and 26 ºC from 3 p.m. to 8 p.m.).

It is noteworthy that, at the temperature regime of 18-24-30 ºC, the greatest water-use efficiency was observed with the application of 76.72 % of the water availability in the soil (Figure 4), demonstrating that, in this regime, the plants were more effective in maintaining a cooler leaf canopy, modulating the stomata opening and water usage. At higher temperature regimes, there is a higher water consumption by transpiration to keep the leaf temperature low (Wakchaure et al. 2018). This value is highlighted, since water restriction is one of the main obstacles to future climate scenarios. Thus, saving 23.28 % of water in irrigation could reduce production costs and contribute to water sustainability. From this result, there is a need for a review of water management for onion cultivation, as a measure of adaptation to climate change.

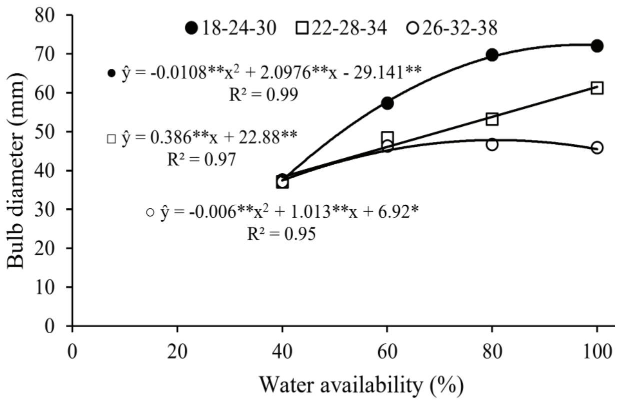

Figure 3. Diameter for onion bulbs (IPA 11 cultivar) grown under different temperature regimes and soil water availability levels. **, *: regression coefficient significant at 0.01 and 0.05 of probability, respectively. Temperature regimes: 18-24-30 ºC (18 ºC from 8 p.m. to 6 a.m., 24 ºC from 6 a.m. to 10 a.m., 30 ºC from 10 a.m. to 3 p.m. and 24 ºC from 3 p.m. to 8 p.m.); 22-28-34 ºC (22 ºC from 8 p.m. to 6 a.m., 28 ºC from 6 a.m. to 10 a.m., 34 ºC from 10 a.m. to 3 p.m. and 28 ºC from 3 p.m. to 8 p.m.); 26-32-38 ºC (26 ºC from 8 p.m. to 6 a.m., 32 ºC from 6 a.m. to 10 a.m., 38 ºC from 10 a.m. to 3 p.m. and 26 ºC from 3 p.m. to 8 p.m.).

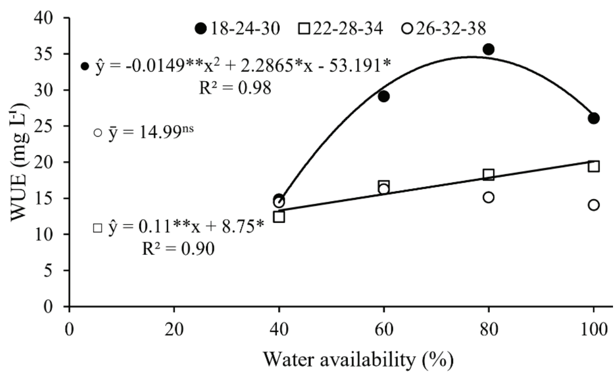

Figure 4. Water-use efficiency (WUE) for onion bulbs (IPA 11 cultivar) grown under different temperature regimes and levels of water availability in the soil. **, *: regression coefficient at 0.01 and 0.05 of probability, respectively. Temperature regimes: 18-24-30 ºC (18 ºC from 8 p.m. to 6 a.m., 24 ºC from 6 a.m. to 10 a.m., 30 ºC from 10 a.m. to 3 p.m. and 24 ºC from 3 p.m. to 8 p.m.); 22-28-34 ºC (22 ºC from 8 p.m. to 6 a.m., 28 ºC from 6 a.m. to 10 a.m., 34 ºC from 10 a.m. to 3 p.m. and 28 ºC from 3 p.m. to 8 p.m.); 26-32-38 ºC (26 ºC from 8 p.m. to 6 a.m., 32 ºC from 6 a.m. to 10 a.m., 38 ºC from 10 a.m. to 3 p.m. and 26 ºC from 3 p.m. to 8 p.m.).

Growth and production are considered determining factors, and the first to suffer the consequences of increased temperatures and water restrictions (Taiz et al. 2017). Under these conditions, onion plants, which are already sensitive to water deficiency, need good water availability in the soil for their good development. Therefore, the water deficit, combined with high temperatures, may be equally harmful, reducing growth and, consequently, the production and quality of bulbs (Marouelli et al. 2011).

The determination of the efficient use of water for the rational management of irrigation will require interdisciplinary studies on temperature, amount of carbon dioxide and water availability in the soil to determine the choice of the appropriate management, taking into consideration the WUE, the production and the final quality of the bulb (Bandeira et al. 2013). Thus, efforts will be necessary to increase the resilience of the onion production system in the face of increased temperature, amount of carbon dioxide and water restriction, in addition to promoting the sustainable use of water resources.

This will only be possible through investment in research that fosters technological development for the adaptation of onion cultivation in the face of climate change. Thus, the proper management of irrigation and temperature control becomes of main importance, since it may be adjusted to the momentary conditions of the onion crop.

CONCLUSIONS

1. The increase in temperature may reduce the production of IPA 11 onion cultivar;

2. A higher soil water availability leads to a higher production of this cultivar;
3. The temperature regime of 18-24-30 ºC and the water availability of 76.72 % provide the best water-use efficiency for the onion crop;
4. Considering weight, bulb diameter and water-use efficiency, the highest values were observed for plants kept in an environment with a temperature regime of 18-24-30 ºC and 770 ppm of CO_2;
5. Bulbs produced at temperatures of 18-24-30 ºC reach higher values of soluble solids content and pH;
6. The most favorable temperature conditions for bulb firmness were observed at the temperature regimes of 22-28-34 and 26-32-38 ºC, while the regime of 22-28-34 ºC resulted in a higher acidity for the onion bulbs.

REFERENCES

ARAGÃO, C. A.; ASSIS, J. S.; SANTOS, A. E. O. Influência da altura de corte da folhagem e do tipo de cura na qualidade pós-colheita de cebola. *Revista Sodebras*, v. 9, n. 105, p. 42-45, 2014.

BANDEIRA, G. R. L.; QUEIROZ, S. O. P.; ARAGÃO, C. A.; COSTA, N. D.; SANTOS, C. A. F. Desempenho agronômico de cultivares de cebola sob diferentes manejos de irrigação no submédio São Francisco. *Irriga*, v. 18, n. 1, p. 73-84, 2013.

BISBIS, M. B.; GRUDA, N.; BLANKE, M. Potential impacts of climate change on vegetable production and product quality: a review. *Journal of Cleaner Production*, v. 170, n. 1, p. 1602-1620, 2018.

BISPO, R. C.; OLIVEIRA, G. M.; QUEIROZ, S. O. P.; SANTOS, I. M. S.; PESSOA, E. S. Produtividade da cebola sob diferentes manejos de irrigação. *Irriga*, v. 23, n. 2, p. 262-272, 2018.

DAYMOND, A. J.; WHEELER, T. R.; HADLEY, P.; ELLIS, R. H.; MORISON, J. I. L. The growth, development and yield of onion (*Allium cepa* L.) in response to temperature and CO_2. *Journal of Horticultural Science*, v. 72, n. 1, p. 135-145, 1997.

DUSENGE, E. M.; DUARTE, A. G.; WAY, D. A. Plant carbon metabolism and climate change: elevated CO_2 and temperature impacts on photosynthesis, photorespiration and respiration. *New Phytologist*, v. 221, n. 1, p. 1-18, 2018.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA (IBGE). *Sistema IBGE de recuperação automática*: Sidra. 2020. Available at: https://www.sidra.ibge.gov.br. Access on: July 19, 2022.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC). *Climate change 2013*: the physical science basis. Cambridge: Cambridge University Press, 2013.

LEE, S. G.; KIM, S. K.; LEE, H. J.; CHOI, C. S.; PARK, S. T. Impacts of climate change on the growth, morphological and physiological responses, and yield of Kimchi cabbage leaves. *Horticulture, Environment, and Biotechnology*, v. 57, n. 1, p. 470-477, 2016.

LEE, S. G.; KIM, S. K.; LEE, H. J.; LEE, H. S.; LEE, J. H. Impact of moderate and extreme climate change scenarios on growth, morphological features, photosynthesis, and fruit production of hot pepper. *Ecology and Evolution*, v. 8, n. 1, p. 197-206, 2018.

MAROUELLI, W. A.; VIDIGAL, S. M.; COSTA, E. L. Irrigação e fertirrigação na cultura da cebola. *In*: SOUSA, V. F.; MAROUELLI, W. A.; COELHO, E. F.; PINTO, J. M.; COELHO FILHO, M. A. (ed.). *Irrigação e fertirrigação em fruteiras e hortaliças*. Brasília, DF: Embrapa Informação Tecnológica, 2011. p. 585-608.

MARTINEZ, C. A.; OLIVEIRA, E. A. D. de.; MELLO, T. R. P.; ALZATE-MARIN, A. L. Respostas das plantas ao incremento atmosférico de dióxido de carbono e da temperatura. *Revista Brasileira de Geografia Física*, v. 8, special issue, p. 635-650, 2015.

MENDES, M. A. S.; FARIA, C. M. B.; SILVA, D. J.; RESENDE, G. M.; OLIVEIRA NETO, M. B.; SILVA, M. S. L. *Nutrição mineral e adubação da cultura da cebola no submédio do Vale do São Francisco*. Petrolina: Embrapa Semiárido, 2008. (Circular técnica, 86).

MENEZES JÚNIOR, F. O.; GONÇALVES, P. A.; VIEIRA NETO, J. Produtividade da cebola em cultivo mínimo no sistema convencional e orgânico com biofertilizantes. *Horticultura Brasileira*, v. 32, n. 4, p. 475-481, 2014.

MUNIZ, L. B.; MORETTI, C. L.; MATTOS, L. M.; CARVALHO, P. G. B. de; MELO, C. O. Caracterização física e química de duas cultivares de cebola armazenadas sob refrigeração. *Revista de Ciências Agrárias*, v. 35, n. 1, p. 261-273, 2012.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (NOAA). *Trends in atmospheric carbon dioxide*. 2022. Available at: https://www.esrl.noaa.gov/gmd/ccgg/trends/. Access on: July 19, 2022.

OLALLA, F. M. S.; DOMINGUEZ-PADILLA, A.; LOPEZ, R. Production and quality of the onion crop (*Allium cepa* L.) cultivated under controlled deficit irrigation conditions in a semi-arid climate. *Agricultural Water Management*, v. 68, n. 1, p. 77-89, 2004.

PERDOMO, J. A.; CONESA, M. À.; MEDRANO, H.; RIBAS-CARBÓ, M.; GALMÉS, J. Rubisco and rubisco activase play an important role in the biochemical limitations of photosynthesis in rice, wheat, and maize under high temperature and water deficit. *Frontiers in Plant Science*, v. 8, e490, 2017.

RESENDE, J. T. V. D.; MARCHESE, A.; CAMARGO, L. K. P.; MARODIN, J. C.; CAMARGO, C. K.; MORALES, R. G. F. Produtividade e qualidade pós-colheita de cultivares de cebola em sistemas de cultivo orgânico e convencional. *Bragantia*, v. 69, n. 2, p. 305-311, 2010.

SANTOS, H. G.; JACOMINE, P. K. T.; ANJOS, L. H. C.; OLIVEIRA, V. Á.; LUMBRERAS, J. F.; COELHO, M. R.; ALMEIDA, J. A.; ARAÚJO FILHO, J. C.; OLIVEIRA, J. B.; CUNHA, T. J. F. *Sistema brasileiro de classificação de solos*. 5. ed. Brasília, DF: Embrapa, 2018.

TAIZ, L.; ZEIGER, E.; MOLLER, I. M.; MURPHY, A. *Fisiologia e desenvolvimento vegetal*. 6. ed. Porto Alegre: Artmed, 2017.

UNITED STATES DEPARTMENT OF AGRICULTURE (USDA). Soil Survey Staff. *Keys to soil taxonomy*. 12. ed. Washington, DC: USDA, 2014.

WAKCHAURE, G. C.; MINHAS, P. S.; MEENA, K. K.; SINGH, N. P.; HEGEDE, P. M.; SORTY, A. M. Growth, bulb yield, water productivity and quality of onion (*Allium cepa* L.) as affected by deficit irrigation regimes and exogenous application of plant bio-regulators. *Agricultural Water Management*, v. 199, n. 3, p. 1-10, 2018.

WORDELL FILHO, J. A.; STADNIK, M. J. Efeito de fosfitos de potássio e de manganês sobre o míldio da cebola. *Agropecuária Catarinense*, v. 23, n. 1, p. 84-87, 2010.