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Water consumption of *Beta vulgaris* L. cultivated in greenhouse under fertigation and types of foundation fertilization

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Abstract

The cultivation of table beet is being largely done in greenhouse. It is among 15 most cultivated crops in Brazil. The quantification of water consumption is relevant to meet water demand at different stages of crop development. Thus, the objective of this study was to evaluate the daily water consumption of table beet cv. Early Wonder in greenhouse under fertigation and different types of fertilization. The experiment was conducted in a greenhouse of Federal University of Campina Grande. Treatments consisted of five doses of nitrogen applied by fertigation (0, 0.7, 1.4, 2.1 and 2.8g per pot) and three types of crop establishment fertilization (earthworm humus; earthworm humus +NPK, and soil without fertilization as control), arranged in a 5 x 3 factor design with four repetitions. A digital hygrometer was used to measure temperature and relative humidity of the air. The reference evapotranspiration was estimated as recommended by Hargreaves and Samani. To meet the water requirement of crop, irrigation must be managed according to its developmental stage. The highest daily water consumption in these growing conditions was obtained in the third stage of development, at which the evapotranspiration of the crop exceeded the reference evapotranspiration. Fertilization with earthworm humus in greenhouse beet cultivation increased the efficiency of water use and can be used instead of chemical fertilization to meet the nutritional needs of the crop. The nitrogen dose of 2.8 g per pot, corresponding to 6.22 g of urea per plant, was the one that provided the highest water content in beet cultivation in greenhouse.

Keywords: Coefficient of cultivation, Efficient use of water, Evapotranspiration, Biomass.

Abbreviations: A_Types of Fertilization; Al_aluminum; Ca_Calcium; CTC_capacity exchange cations, DAT_Days after transplanting; ETpc_potential evapotranspiration of a crop; ET_0_reference evapotranspiration; EUW_ Efficient use of water; FBAP_Fresh biomass of aerial part; F_Fertigation; FRB_Fresh root biomass; H_Hydrogen; K_potassium; Kc_crop coefficient; Na_sodium; Mg_ Magnesium; M_Saturation percentage by aluminum; MFPA_mass of fresh matter in the area; MSPA_mass root matter of the plant; MFT_phytomass Total fresh; N_nitrogen; NPK_nitrogen, phosphorus and potassium; O.M_Organic matter; P_phosphorus; pH_ hydrogen potential; Ra:_extraterrestrial radiation; RH_mean relative; SB_Sum of bases; Tmax_maximum temperature; Tmin_minimum temperature; Tmd_mean daily temperature; V_percentage of saturation per base; WCAP_ water content in aerial part ; WCR_ water content in root ; α_empirical parameter; β_exponential empirical parameter.

Introduction

The Beet (*Beta vulgaris* L.) is a biennial herbaceous plant belonging to the family Chenopodiaceae, originating in temperate regions of Europe and North Africa. The tuberous root has the globular form, sweet taste and purple color (Filgueira, 2008; Oliveira Neto et al., 2011). In Brazil, the beet cultivation is exclusively for table purpose, being used in salads. The cultivar Early Wonder is the most cultivated in the country, responsible for approximately 250,000 t in year^{-1}, generating income for more than 500,000 people per year (Filgueira, 2008; Tivelli et al., 2011).

In Brazil, the beet growing in a controlled environment in the last years has gained great prominence, being one of the 15 most cultivated plants in greenhouse, as a way to overcome environmental inclement weather (Tivelli et al., 2011). Tullio et al. (2013) stated that beet production in greenhouse favors harvesting in times when there is less supply of the product in the market due to the difficulty of production in places or times, whose climatic conditions are unfavorable to open-air cultivation. In this way, the cultivation of beet in protected environment meets the needs of the off-season and consumers every day more demanding in products of quality.

There is little information in the literature regarding the nutritional requirement, especially regarding the management by means of the fertirrigation in the cultivation of table beet (Silva et al., 2015). Coelho et al. (2014) stated that fertigation consists of one of the main forms of split fertilization, consisting of the application of water-soluble fertilizers in the irrigation system along the cycle and during the management of water in the crop.

Silva et al. (2014) studied fertigation management of vegetables in greenhouse and reported that fertirrigation is

widely used mainly in in the major producing centers of Brazil. However, it is necessary to pay attention to the phases of greater nutritional requirement of the crops and to associate with irrigation management.
Topak et al. (2011) reported that the major problem in increasing crop productivity, especially in vegetables, is related to the management of irrigated fertilization. This needs taking into account the correct choice of irrigation system and fertilizers, especially in species like beet that extract large quantities of soil nutrients and have greater sensitivity to water deficit.
In this context, to establish the water requirement of a crop, the determination of crop evapotranspiration (ET_c), which represents the amount of water lost by evapotranspiration, is of paramount importance (Allen et al., 1997).
Doorenbos and Kassam (1979) stated that the potential evapotranspiration of a crop (ET_{pc}) is the ratio between the reference evapotranspiration (ET_0) and the crop coefficient (kc). Thus, determination of water consumption of crops depends on the knowledge of the evapotranspiration reference, which is closely related to the climatic conditions of the place of its installation, as well as the physiological and morphological characteristics evidenced by its crop coefficient (Oliveira Neto et al., 2011).
The knowledge of the evapotranspiration and the crop coefficients of each stage of development of the crop allow estimation of the water consumption and fertilization by the water and nutrients absorption by the plants. These factors have great importance as they maximize the production and minimize the costs (Paiva et al., 2017).
When water consumption and nutrient requirements of crops are known, it is possible to manage adequate irrigation and fertilization to meet water and nutrient requirements, matching crop growth phases. Given the relevance of the thematic, this study aimed to evaluate the daily water consumption of table beet cv. Early Wonder cultivated in greenhouse under fertigation and types fertilization.

Results and Discussion

Water consumption of beet over a crop cycle

The variation of the crop evapotranspiration (ET_c) and reference evapotranspiration (ET_0) values of beet obtained during the 90 days after transplanting (DAT), which is observed in Fig.1 along with the water consumption. The average evapotranspiration of the crop for the studied period was 3.5 mm day^{-1}, while for the reference evapotranspiration it was 4.3 mm day^{-1}. The highest ET_c value was 6.0 mm day $^{-1}$, while ET_0 was 5.4 mm day $^{-1}$. Regarding the minimum evapotranspiration values, the lowest ET_c was 0.7 mm day $^{-1}$ and the ET_0 was 2.9 mm day $^{-1}$.
Oliveira Neto et al. (2011) studied evapotranspiration and beet crop coefficients under different dead cover plans and observed a maximum water consumption of 4.0 mm day^{-1}. Silva et al. (2014) found that the higher water consumption of 2.3 mm day^{-1} in the intermediate phase of vegetative development was observed in the treatment with lower level of salinity using the same cultivar in this study. The difference between the water consumption obtained by these authors and the present study may be related to the climate of the study region and different irrigation and fertilization management adopted.
The duration of each developmental stage of the crop coefficient and the water consumption, for 90 day period after the beet transplant are presented in Table 1.
We verified that the stage of vegetative development of half culture (III) provided the highest water consumption, even though it lasted less than 5 days compared to development (II). The lower water consumption of 41.9 mm was observed in the final phase of the culture. However, the total consumption of 310.8 mm was observed during the experimental period.
Paiva et al. (2017) studying the growth of table beet under different irrigation slides and obtained better results with 100% of crop evapotranspiration, corresponding to 77.9 mm, 45 days after transplanting. Howver, Silva et al. (2014) verified a higher water demand of 89.5 mm with the actual evapotranspiration of the crop, 51 days after transplanting cv. Early Wonder.
80 days after transplanting the seedlings, Oliveira Neto et al. (2011) obtained the maximum water consumption for the Early Wonder cv., corresponding to 119.62 mm. The lower values of water consumption observed by these authors can be attributed to the lower cycle of cultivation to determine water consumption.

Water content, fresh biomass and water use efficiency

The summary of analysis of variance for water content in aerial part (WCAP), root water content (WCR), fresh shoot biomass (FBAP), fresh root biomass (FRB) and efficient water use (EUW) of beet plants grown under different types of fertilization and nitrogen fertigation at 90 DAT are shown in Table 2.
There were effects of fertilization types for all variables at probability levels of 0.01 (F-test). For the fertigation factor, there was a significant effect for variables such as water in the aerial part, water content in the root and fresh biomass of the aerial part, at the 1 and 5% probability level (Table 2). There was no significant effect for the interaction between the types of fertilization (A) and nitrogen (F) doses in the beet crop at 90 DAT (Table 2).
The water content in aerial part in the beet was higher in the earthworm humus treatment when compared to the earthworm humus + NPK treatment and the control treatment. There was a better response to the application of the organic fertilizer, since it is adequate for the nutritional demands of the plants, besides improving the soil structure and the water content in the plant (Fig. 2A).
According to Pereira et al. (2013), the mineral nutrition of plants reflects improvements in soil structure through the addition of organic fertilizers in the soil, which is considered the key to their fertility. In addition, it helps the formation of lumps, maintains humidity and temperature balanced, decreases unnecessary energy expenditure by the plant under high temperatures. This fact can contribute significantly to the better productive performances of the agricultural species, especially when considering the species with high extraction of nutrients of the soil like the beet.

Table 1. Duration of vegetative developmental stages and water consumption of the crop for the period and conduction of experiment.

Stages of vegetative development		Duration of phases (Days)	Coefficient of culture (Kc)	Water consumption (mm)
I	Initial	25	0.50	48.2
II	Development	30	0.75	91.3
III	Half culture	25	1.10	129.4
IV	finale	10	0.90	41.9
Utter	-	90	0.80	310.8

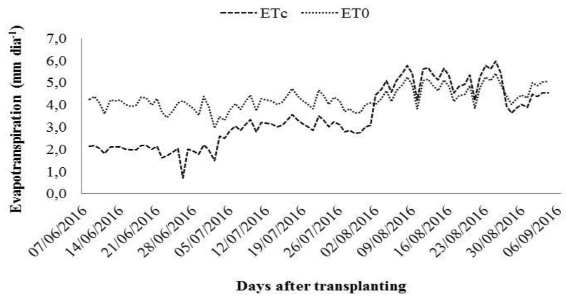

Fig 1. Cultivation evapotranspiration (ET_c) and evapotranspiration reference (ET_0) accumulated during the period of conduction of the experiment.

Table 2. Summary of the analysis of variance for the variables water content in aerial part (WCAP), water content in root (WCR), Fresh biomass of aerial part (FBAP), Fresh root biomass (FRB) and Efficient use of water (EUW) of beet plants under different types of basal fertilization and N doses applied via fertigation at 90 days after transplanting.

Sources of Variation	G.L.	WCAP (%)	WCR (%)	FBAP (g)	FRB (g)	EUW (g L^{-1})
Types of Fertilization (A)	2	49.34^{**}	99.65^{**}	26.52^{**}	109.27^{**}	16.67^{**}
Fertigation (F)	4	91.29^{**}	78.67^{**}	6.57^{*}	5.61^{ns}	0.63^{ns}
Interaction (A x F)	8	9.23^{ns}	7.60^{ns}	2.18^{ns}	1.32^{ns}	0.02^{ns}
Residue	30	6.93	17.43	2.17	3.05	0.26
General Media	-	86.94	87.97	8.65	7.75	2.20
Coefficient of variation (%)	-	3.03	7.75	17.03	22.53	23.22

Note. * And ** significant at 5 and 1% probability, respectively, ns not significant.

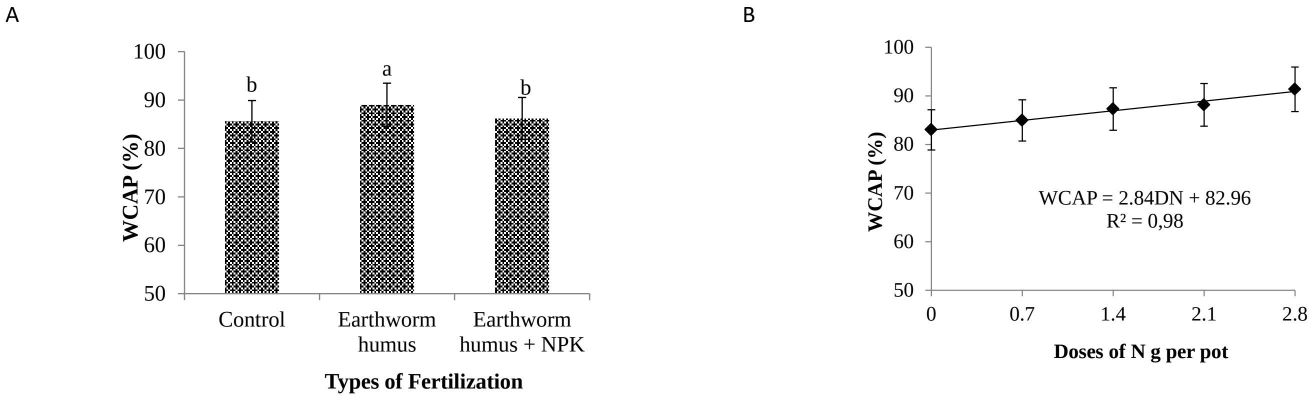

Fig 2. Water content in aerial part according to the types of fertilization: control - A0, earthworm humus - A1, earthworm humus + NPK - A2 (A) and nitrogen doses: 0.0, 0.7, 1.4, 2.1 and 2.8 g pot^{-1} (B) of the beet at 90 days after transplanting.

Table 3. Physical and chemical characteristics of the soil, at the 0.0 – 0.2 m depth and also the earthworm humus used in the experiment.

Soil								
pH	M.O	P	K	Na	Ca	Mg	Al	H
	(%)	mg/100g	---------------------------------- mmol$_c$ dm^{-3} -----------------------------					
5.9	0.65	1.43	0.14	0.07	1.9	0.66	0.2	1.88
	Density		Sand		Silt		Clay	
	(g cm^{-3})		-------------------------------- (%)------------------------------					
	1.39		74.7		16.11		9.19	

Earthworm humus											
pH	M.O	P	K	Na	Ca	Mg	Al	SB	CTC	V	M
	- gkg^{-1}-	--- mgdm^{-3} ---		------------------ Cmol$_c$ dm^{-3} ------------------						----%----	
6.95	73.13	469.31	656	0.98	13.25	1.05	0	18.96	20.79	91.24	0

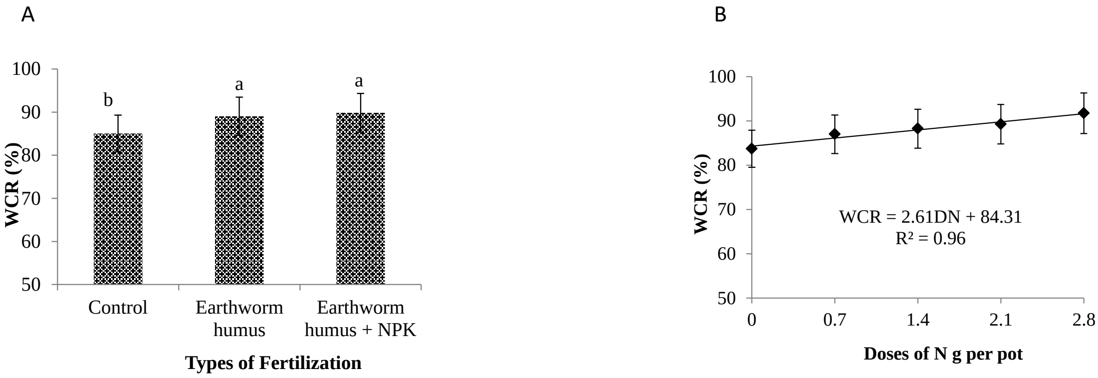

Fig 3. The water content in root according to the types of fertilization: control - A0, earthworm humus - A1, earthworm humus + NPK - A2 (A) and nitrogen doses: 0, 0.7, 1.4, 2.1 and 2.8 g pot^{-1} (B) of the beet at 90 days after transplanting.

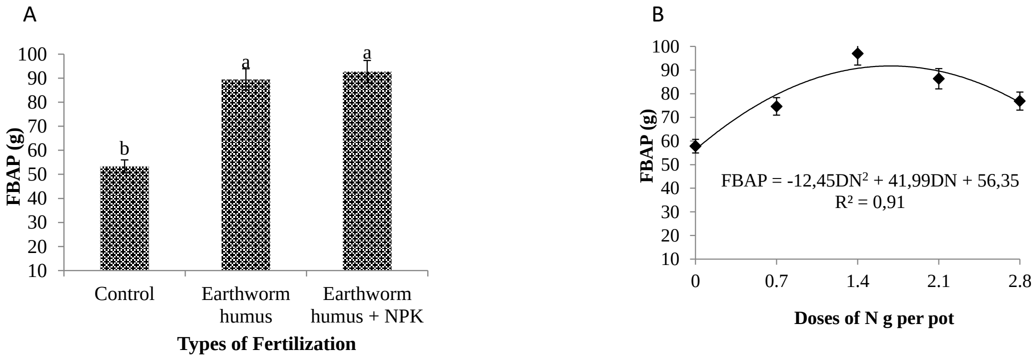

Fig 4. Fresh biomass of aerial part according to the types of fertilization: control - A0, earthworm humus - A1, earthworm humus + NPK - A2 (A) and nitrogen doses: 0, 0.7, 1.4, 2.1 and 2.8 g pot^{-1} (B) of the beet at 90 days after transplanting.

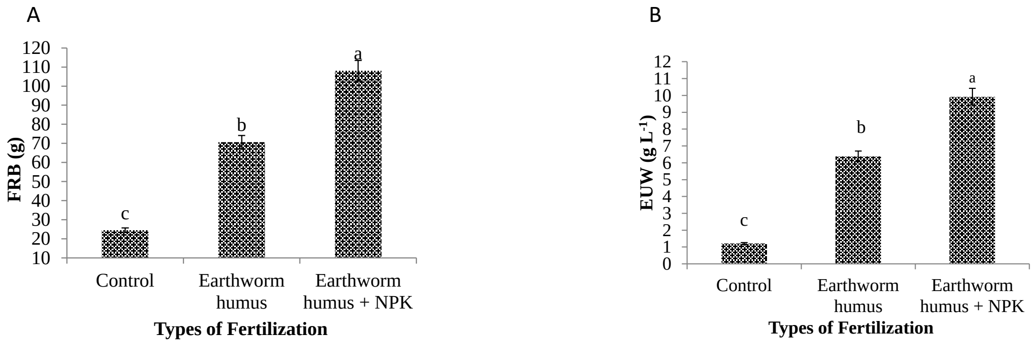

Fig 5. Fresh root biomass according to the types of fertilization: control - A0, earthworm humus - A1, earthworm humus + NPK - A2 (5A) and efficient use of water in function nitrogen doses: 0, 0.7, 1.4, 2.1 and 2.8 g pot^{-1} (5B) of the beet at 90 days after transplanting .

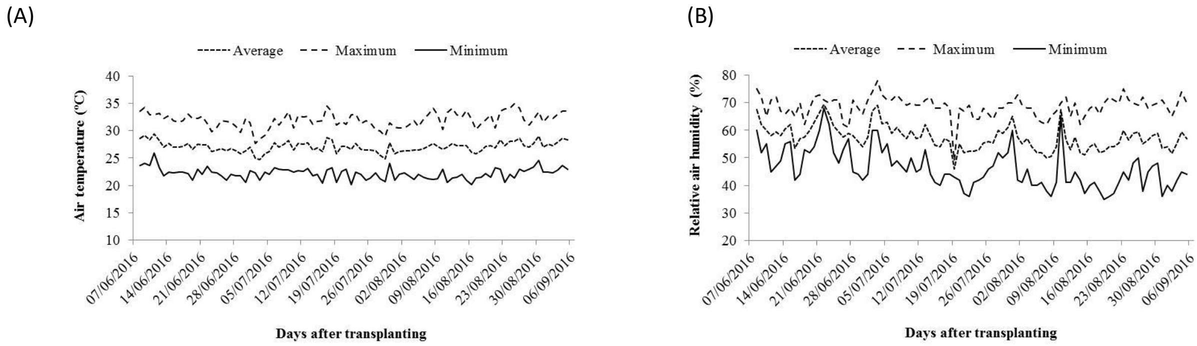

Fig 6. Temperature (A) and relative air humidity (B), average, maximum and minimum daily, observed during the period of conduction of the experiment.

The increase in the nitrogen applied by fertigation increased the water content in the aerial part of the beet plants, and the dose of 2.8 g of nitrogen per pot showed the highest water content in the aerial part (WCAP), corresponding to 90.9% (Fig. 2B). This fact demonstrates that the water supply associated with the application of fertilization leads to an increase in water absorption by plants and, on the other hand, increases the accumulation of green biomass (Taiz and Zaiger, 2013).

The water content of root (WCR) associated with the types of fertilization is shown in Fig. 3A. The control treatment showed lowest water content, compared to the application of earthworm humus and earthworm humus + NPK, a fact that can be justified due to the greater supply of nutrients to the plants and consequently better absorption of water.

The mathematical model that best fitted the effect of the nitrogen doses by fertirrigation in the (WCR) at 90 days after the transplant was linear. It is observed that, when the doses were increased, there was an increase in WCR. A fact that can be justified as a result of the higher nutritional supply, which provided better conditions for the assimilation of water and nutrients to the plants (Fig. 3B).

According to Silva et al. (2016), the increase of the water content in the plants submitted to different types of soil fertilization can be explained by the high water consumption of these plants, since the increase in the nitrogen dose applied by fertirrigation increases the water consumption of the plant.

The fresh biomass of the aerial part showed better performance in the treatment with earthworm humus and earthworm + NPK humus with approximately 93g per biomass plant (Fig. 4A). This result is similar to that obtained by Silva et al. (2016), which obtained an average of 54.8 g for the fresh shoot mass, studying the different types of fertilization on radish production.

The organic fertilizer to meet the nutritional needs of the crops must present a high content of nutrients and capacity of availability to attend to the capture of the crop (Santos et al., 2012).

According to the regression equation, the best mathematical model that fits the fresh biomass of the aerial part (FBAP) as a function of the doses of nitrogen applied by fertigation was the quadratic one (Fig. 4B). The maximum yield for the FBAP was obtained in the dose of 1.72 g of nitrogen per pot, corresponding to 91.71 g. A decrease after this point can be related to the excess of nitrogen applied, because this imbalance can contribute to the reduction of other elements, leading to nutritional deficiency with reflections in the leaf area of the plants (Faquin, 1994). The fresh biomass of tuberous root of beet is shown in Fig. 5A according to the types of foundation fertilization. It is observed that the treatments differed statistically according to Tukey test and treatment with earthworm humus + NPK showed the best results for the fresh tuberous root biomass.

Andrade et al. (2012) stated that the use of organic and minerals fertilizers together promotes greater efficiency than using them as separate form. This is justified as a fact that the absence of essential nutrients in one of the fertilizers types can be compensated other type of fertilizer when used combined.

The efficient use of water (EUW) obtained a similar result to fresh biomass of the root. We observed that application of earthworm humus + NPK treatment generated the highest EUW, corresponding to approximately 10 g L^{-1} (Fig 5B). Treatments with application of organic and mineral fertilization increased the productive gains of the beet and consequently increased the efficiency of water use by crop.

Oliveira Neto et al. (2011) reported that crops with higher water use efficiency are of great importance, when they come to the economics of water resources. That is the rational of water use, since they allow a higher yield per liter of applied water.

Materials and methods

Plant materials

In this study, the beet cultivar was Early Wonder cv. belong to the species (*Beta vulgaris L.*), one of the most cultivated in greenhouse by small and large producers. The experiment lasted 100 days. The application of the treatments began on the day of the transplanting of the seedlings, 10 days after sowing. The seedlings were produced in expanded polyethylene trays with 128 cells, filled with commercial substrate. Transplanting was done using one seedling per pot, which occurred around ten days after sowing.

Characterization of area and climatic variables

The experiment was conducted in greenhouse of the agricultural engineering academic unit, Federal University of Campina Grande - Paraiba, from April to May 2016. The soil used in the experiment was classified as medium-texture sandy loam. The physical and chemical characteristics of the soil in the layer of 0.0-0.2 m and humus used in the experiment are presented in the Tables 3 (Embrapa, 2013).

The data of temperature and relative humidity of the air during the experiment period from transplanting to harvesting, corresponding to 90 days after transplanting (DAT), were collected from a digital hygrometer installed inside the greenhouse (Fig.6).

The mean air temperature during the experimental period was 27.1 °C, the highest daily average was 29.5 °C and the lowest daily mean value was 24.7 °C. Meanwhile, the maximum air temperature during 90 DAT showed a maximum average of 32.0 °C, the lowest value of the maximum was 27.7 °C and the highest recorded value for maximum was 35.0 °C. For the minimum air temperatures, the minimum average was 22.2 °C, the highest minimum value was 26.0 °C and the lowest minimum was 20.1 °C (Fig. 6A).

The mean relative (RH) air humidity during the 90 days of cultivation was 57.5%, while the highest RH value was 69.5% and the lowest RH of 46.0%. The maximum relative humidity was 68.6%, the highest value 78.0% and the lowest 49.0%. Meanwhile, the minimum RH was 46.3%, the highest minimum 68.0% and the lowest minimum 35.0% (Fig 6B).

Treatments and experimental design

The statistical design was a completely randomized block design with four replications, so that the studied factors were arranged in a 5 x 3 factor design. The treatments consisted of the combination of two factors consisted of five doses of nitrogen fertilizer applied by fertigation (0, 50, 100, 150 and 200 mg of nitrogen per dm3 soil), and three types of basal fertilization earthworm humus (A1), earthworm humus + NPK (A2) end soil without fertilization – control (A0). The 15 treatments were arranged in 60 plots, using 60 cylindrical pots of 12 L spaced by 0.5 m between plants and 1.0 m between rows.

The source of nitrogen was urea, and the levels of nitrogen per pot corresponded to 0, 0.7, 1.4, 2.1 and 2.8 g N per pot, according to the methodology proposed by Silva and Silveira (2012) cited in Silva et al. (2016), divided into three applications as follows: the first application was carried out on day 20 after transplanting (DAT); the second, on day 40 after transplanting, and the third, on day 60 after transplanting.

Each experimental unit consisted of one pot with holes in the bottom, containing a 1-cm layer of gravel number 1, covered with geotextile blanket to facilitate drainage. The pots were filled with approximately 20 dm^3 of soil.

Irrigation system used and management

A drip irrigation system was used with pressure-compensating emitters with a nominal flow rate of 2.3 L h^{-1}, coupled with irrigation lines (16-mm polyethylene tubes). The registers were set at the beginning of each line, which allowed differentiating the treatments. The application of nitrogen doses per fertigation and a hydrometer at the beginning of the control drophead recorded the amount of water per sideline, an indispensable condition for the control of irrigation and fertigation management.

Pumping was performed with a centrifugal pump model IBD 35®. To prevent the entry of suspended particles larger than the diameter of the emitters in the system, a 1 "screen filter", with capacity for 5 m^3h^{-1} flow was used.

Irrigation management was daily performed based on the method of (Hargreaves and Samani, 1985), which requires only temperature data. The equation showed the following form (Jensen et al., 1990) adapted to the symbols used here (Equation 1). This method of determination of reference evapotranspiration has been very useful for the management of irrigation in pots, due to its practicality, since it uses easily available meteorological elements such as temperature and relative humidity in addition to knowing the area of the pot (Silva et al., 2016; Santos et al., 2016).

Analyzed variables

During the 90 DAT, reference evapotranspiration was determined by the method of Hargreaves and Samani (1985), cited by Lima Junior et al. (2016), according to Equation 1.

$$ET_0 = \alpha.(T_{máx} - T_{mín})^{\beta}(T_{méd} + 17{,}8)Ra.0{,}408 \quad (1)$$

Where: ET_0=Reference evapotranspiration, mm d^{-1}; Ra= extraterrestrial radiation, mm d^{-1}; Tmax= maximum temperature, in °C; Tmin= minimum temperature, in °C; Tmd=mean daily temperature = 0.5(Tmax + Tmin), in °C; α = empirical parameter, (0.0023); and β =exponential empirical parameter, (0.5).

The applied irrigation blade was based on the evapotranspiration of the crop, according to Equation 2.

$$T_c = ET_0 * Kc \quad (2)$$

Where: ET_c = Crop evapotranspiration, mm d^{-1}; ET_0= Reference evapotranspiration, mm d^{-1}; Kc = Crop coefficient.

The culture coefficient used was 0.50, 0.75, 1.10 and 0.90 adapted from Doorenbos and Pruitt (1977). Irrigation management was carried out by a two-day fixed irrigation, maintaining soil moisture close to the field capacity during the entire crop cycle.

At 90 days after sowing, the following variables were analyzed: the water content of the area part and the root, fresh biomass of the area and root and the efficiency in the use of water.

The water content in the aerial part (WCAP) and root (WCR) was calculated by the relation between the fresh mass and the dry mass of the plants according to (Silva et al., 2012), according to Equation 3.

$$WCAP = \frac{MFPA - MSPA}{MFPA} * 100 \quad (3)$$

Where: WCAP or WCR= water content in area or root of the plant, %; MFPA= mass of fresh matter in the area or root of the plant, g; and MSPA= mass of dry matter in the area or root of the plant, g.

To determine the fresh biomass of the area part and the root, the plants were removed from the pots and washed, then roots were weighed separately.

The efficiency of the water use was determined by the relationship between the fresh matter mass (measured on the precision scale) and the water consumption of the plant (Silva et al., 2012; Jabro et al., 2012) according to Equation 4.

$$EUW = \frac{MFT}{ETc} \quad (4)$$

Where; EUW = water use efficiency, g L^{-1}; MFT = phytomass Total fresh, g; ETc = Crop evapotranspiration, L.

Statistical analysis

The variables were statistically analyzed by F-test, with follow-up analysis always in case of significant interaction. The quantitative factor relative to the N doses was statistically analyzed through polynomial regression (linear and quadratic). The types of basal fertilization were analyzed by Tukey test at 0.05 probability level, using the computer program Sisvar (Ferreira, 2008).

Conclusion

To meet the water requirement of the crop, irrigation must be managed according to stage of development. The highest daily water consumption in these growing conditions was obtained in the third stage of development, at which the evapotranspiration of the crop exceeded the reference evapotranspiration. Fertilization with earthworm humus in greenhouse beet cultivation increases the efficiency of water use and can be used instead of chemical fertilization to meet the nutritional needs of the crop. The nitrogen dose of 2.8 g per pot, corresponding to 6.22 g of urea per plant, was the best one that provided the highest water content in beet cultivation in greenhouse.

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