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Water use efficiency and growth variables of *Operculina macrocarpa* L. Urban grown in tropical environment

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Most of the population in developing countries still uses medicinal plants as the main source to meet their medical needs. Field experiments were carried out at tropical environment in Brazil in order to determine the main characteristics of 'batata-de-purga' (*Operculina macrocarpa* L. Urban), cultivated under 5 different levels of irrigation. The crop was cultivated with and without shading, using a plastic cover. The irrigation treatments were based on reference evapotranspiration (ET_o): T1 = 25% ET_o; T2 = 50% ET_o; T3 = 75% ET_o; T4 = 100% ET_o; and T5= 125% ET_o. Irrigation was performed in interval of three days and the applied water volume was based on treatment T4. The daily values of ET_o were determined according to the method of Penman-Monteith. The results indicated that the growth variables of 'batata-de-purga' production components were strongly influenced by both the applied water levels and the cultivation conditions.

Key words: Evapotranspiration, irrigation water use efficiency, yield.

INTRODUCTION

The products of the Brazilian flora have aroused the curiosity and economic and scientific interest since the period of the New World colonization. Such national richness is revealed especially in the Amazon flora and in the Caatinga biome of the Brazilian semiarid region, which is the most biodiverse of the world, where there are plants with dyeing, odoriferous, stimulant, condimental, hallucinogenic and resinous, and balsamic properties.

There is an increasing interest in the practice of biomedicine and ethnoveterinary worldwide, particularly,

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when it relates the use of medicinal plants to treat various diseases (Bizimenyera et al., 2006). The phytotherapy can be used to contribute to the cure of infectious diseases, especially in small ruminants, because the isolated or associated use of natural substances generate products with less residues and more valued in the market, besides not causing environmental pollution and reducing the problem of waste (Krecek and Waller, 2006; Cenci et al., 2007).

In the context outlined earlier, goat/sheep farming is one of the most performed activities in the Brazilian semiarid region, notably due to the capacity of resistance of these animals to adverse climatic conditions, besides a social and economic function as source of nutrition and income. In the tropics and subtropics, nematode-caused diseases are among the most common and economically important infectious diseases of these small ruminants (Hoste et al., 2005). The epizootic outbreaks of haemonchosis and strongyloides that occur in the northeastern semiarid region increases goat morbidity and mortality (Rodrigues et al., 2007). 'Batata-de-purga' (*Operculina macrocarpa* L. Urban) is widely used by the population of the Brazilian semiarid region, due to its laxative, purgative and purifying action against skin diseases and in the treatment of leukorrhea in goat/sheep farming.

Operculina macrocarpa L. Urban has its therapeutic value recognized by the science and its use in the treatment against skin diseases and leucorrhea has gradually increased. This wild species, popularly known as 'batata-de-purga' or 'jalapa' (Convolvulaceae), has been the target of many studies on its chemical-taxonomical characteristics in the control of gastrointestinal helminth diseases of naturally infected goats (Michelin et al., 2010). In the last ten years, the interest in higher plants, especially in phytotherapeutic agents, has expressively increased, not only in developing countries, but also in industrialized countries. Despite the richness of the Brazilian flora and the wide use of medicinal plants by the population, scientific studies on the subject are insufficient. In addition, despite many studies on crop coefficient and water use efficiency of various species cultivated in the Brazilian semiarid region (Campos et al., 2008), none of them focuses on 'batata-de-purga'. Therefore, considering the importance of goat/sheep farming for the semiarid regions, as well as the absence of any study on the addressed subject, this study aimed to determine water use efficiency and analyze the growth variables of 'batata-de-purga' cultivated in shaded environments and exposed to natural environmental conditions under various irrigation levels.

MATERIALS AND METHODS

Study area and field experiment

This study was carried out in a community that produces exclusively organic food, called 'Grupo Ribeiro', which is located in the municipality of Alagoa Nova-PB, Brazil. This community belongs to the 'Brejo Paraibano' Microregion and its climate is humid with rains distributed from January to September (Silva et al., 2010). The experimental design of the field study with 'batata-de-purga' was a randomized block, in a factorial scheme with 30 plots, containing 3 plants each and the factors were irrigation depths and shading conditions. The treatments with shading and without shading were used for assessing the luminescent effect on crop yield. Five irrigation levels, with and without shading and three replicates were used in the experiment. Plants were cultivated at spacing of 1.5 × 1.5 m, to facilitate experimental management and follow the contour line of the terrain. Irrigation treatments were applied from 30 to 210 days after sowing (DAS), during the period of November 2012 to July 2013 and replicated from December 2013 to August 2014.

Irrigation management and growth variables

The treatment corresponded to irrigated cultivation according to the atmospheric demand to evaluate the behavior of the plants. Irrigation depths were determined based on reference evapotranspiration (ET_o): T1 = 25% ET_o; T2 = 50% ET_o; T3 = 75% ET_o; T4 = 100% ET_o; and T5 = 125% ET_o. Reference evapotranspiration was determined by Penman-Monteith method (Allen et al., 1998). The data for ET_o determination were obtained from the automatic weather station close to the experimental area. Irrigation water was collected directly from a local supply damn and stored in a 1000-L tank, to be later used by the system. Irrigations were performed using a localized system (perforated hose-type), with flow rate of 1 L ha^{-1}. Irrigation interval was equal to three days and based on treatment T4.

Stem diameter was determined every 10 days, 5 cm high from the base of the plant, using a digital caliper. 'Batata de purga' seeds and tubers were collected and dried in the shade for 3 days, in order to obtain the number of seeds and tuber weight. The other crop production components, such as tuber size, tuber diameter, number of seeds and number of climbing stems in both cultivation conditions were also analyzed. Water use efficiency (WUE) was expressed by the relationship of 'batata-de-purga' yield expressed in grams of seed, number of seeds and number of climbing stems per liter of water consumed, according to each irrigation treatment, for cultivation conditions with and without plastic cover (Figure 1). Polycarbonate sheets were used for reducing the luminescent effect on plants.

Before and after the experimental period, soil samples were collected in the layer of 0 to 20 cm for analyses at the Laboratory of Irrigation and Salinity of the Federal University of Campina Grande, to evaluate the effects of 'batata-de-purga' on the soil. The samples were air-dried and sieved through a 2-mm mesh.

The contents of calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), aluminum (Al), carbon (C), organic carbon (OC), nitrogen (N), organic matter (OM), phosphorus (P) and the values of pH and electrical conductivity of the saturation extract (ECse) were determined, as shown in Table 1. The growth variables data were subjected to an analysis of variance at the 5% level of significance using the F test. All analyses were performed based on three samples and after repetition with the same physical-sample drawing number. Ion activity was determined using the potentiometric method.

RESULTS

Soil and crop growth

Soil chemical properties in the experimental area were

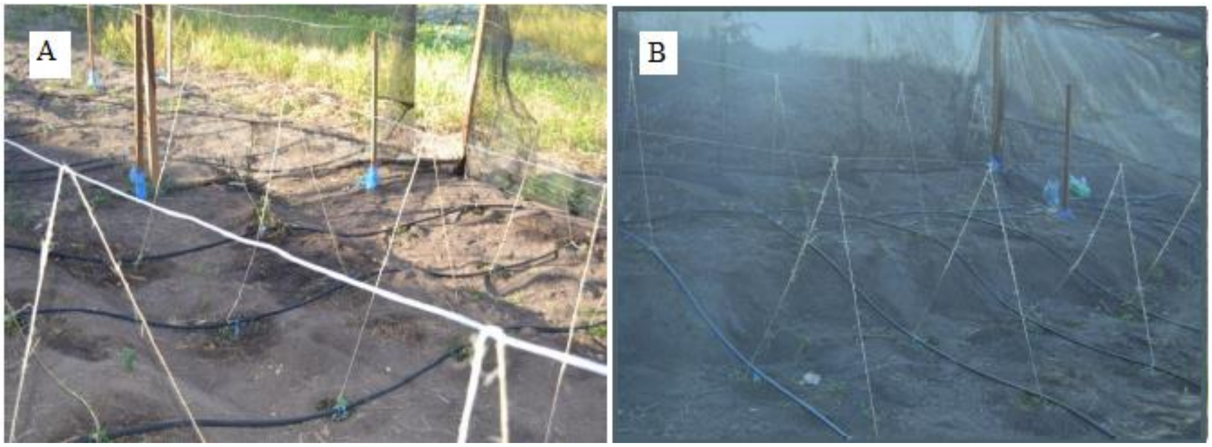

Figure 1. Experimental plots without plastic cover (A) and with plastic cover (B).

Table 1. Analysis of soil chemical properties of the experimental area in Lagoa Nova-PB, Brazil, before and after sowing of 'batata-de-purga'.

Chemical characteristics	Before	After
Calcium (Meg/100 g of soil)	0.67	1.46
Magnesium (Meg/100 g of soil)	1.19	1.21
Sodium (Meg/100 g of soil)	0.03	0.20
Potassium (Meg/100 g of soil)	1.07	1.14
Aluminum (Meg/100 g of soil)	0.80	0.00
Carbon (%)	1.10	1.48
Organic matter (%)	2.19	1.83
Nitrogen (%)	0.09	0.10
Phosphorus (mg/100 g)	0.10	3.52
pH H_2O	5.20	6.80
Electrical conductivity (mmhos/cm)	0.10	0.16

modified after the experiment; some contents increased and others decreased (Table 1). Some aspects of these properties are relevant; for example, according to the soil conditions before and after planting 'batata-de-purga', the increases in the contents of Ca, Na and P were above 100%, while the Al content decreased after the experiment.

Planting density may promote changes in soil physical and chemical properties. While physical characteristics are modified by the root system of the species, besides the type and amount of plastic cover deposited, chemical characteristics are affected by the dynamics of 'nutrients in the soil, due to the absorption by plants, and by the organic matter. Seed weight values under both cultivation conditions are equal in the treatment T1 and then vary linearly as a function of the increase in irrigation depth, always with higher values in the cultivation without cover, in comparison to that with cover (Figure 2A). The mean seed weight of all irrigation treatments for the planting condition without cover was only 3.2 g higher than that in the planting condition with plastic cover.

The tuber weight for plants cultivated under cover increased linearly by 0.7 kg between the treatments T1 and T2; however, in the plot without cover, the increase in irrigation depth caused a slight reduction of only 0.2 kg in tuber weight (Figure 2B). As observed for previous production components, in both cultivation conditions, the number of seeds increased linearly with the increment in irrigation, generating high coefficients of correlation that are statistically significant at 0.01 probability level by the Student's t-test (Figure 2E). In the treatment T1, plants produced 114 and 180 seeds for cultivation with and without cover, respectively, with a difference of 66 seeds.

The smallest difference in the number of seeds between the cultivation conditions occurred in the treatment T4, with only 16 seeds. The mean values of number of seeds for all irrigation treatments under planting conditions without and with cover were 209 and 166 seeds, respectively. The evolution in the number of climbing stems of 'batata-de-purga' cultivated without

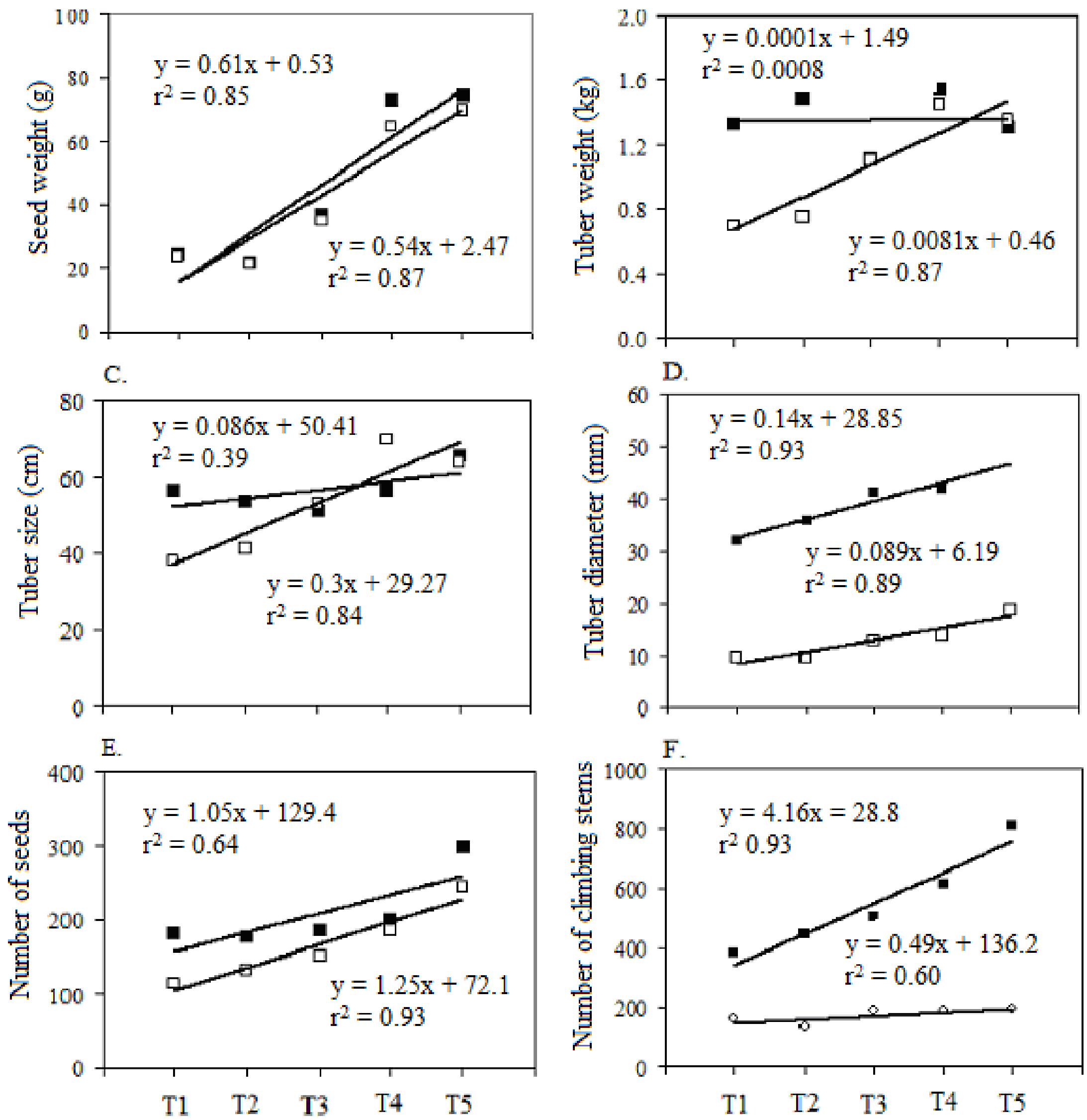

Figure 2. Evolution of seed weight (A), tuber weight (B), tuber size (C), tuber diameter (D), number of seeds (E) and number of climbing stems (F) of 'batata-de-purga' as a function of irrigation depths T1 (25% ET_o), T2 (50% ET_o), T3 (75% ET_o), T4 (100% ET_o) and T5 (125% ET_o). Black data points = without plastic cover and white data points = with plastic cover.

cover increased linearly as a function of irrigation depth, with high coefficient of correlation, which was statistically significant at 0.01 probability level by the Student's t-test. However, the number of climbing stems in the condition with cover was virtually constant, that is, it was little influenced by irrigation and highly affected by the plastic cover, although it did not show a coefficient of determination that is statistically significant at 0.05 probability level by the Student's t-test. This is confirmed by the fact that, for this cultivation condition, the difference between the highest and the lowest irrigation depths led to a difference of only 34 climbing stems, while in the condition without cover such difference was equal to 434.2 climbing stems.

Water consumption

Water consumption increased with plant growth until 140 DAS and then decreased until 210 DAS in both treatments and in areas with and without plastic cover (Table 2). This is associated with the variability of atmospheric conditions along the experiment, because in periods of high atmospheric demand, water consumption is higher than in periods with high nebulosity and rain events. Under cultivation conditions without plastic cover,

Table 2. Irrigation depth (liters) in the 'batata-de-purga' crop for the treatments T1 (25% ET_o), T2 (50% ET_o), T3 (75% ET_o), T4 (100% ET_o) and T5 (125% ET_o), under cultivation with and without plastic cover as a function of number of days after sowing (DAS).

DAS	T1	T2	T3	T4	T5
Without plastic cover					
30 DAS	19.5	39	58.6	78.0	97.5
60 DAS	51	102.4	153	204.3	255.0
90 DAS	71.25	142.5	213.5	285.3	356.6
120 DAS	58.5	127.1	175.7	234.3	292.8
150 DAS	29.2	58.5	87.5	117.0	146.3
Total	229.45	469.5	688.3	918.9	1148.2
With plastic cover					
30 DAS	19.5	39	58.5	78.0	97.5
60 DAS	44.3	88.6	132.9	177.3	221.6
90 DAS	52.2	104.5	156.7	209.0	261.2
120 DAS	47.1	94.2	141.3	188.5	235.6
150 DAS	50.1	100.2	150.3	200.4	250.5
Total	213.2	426.5	639.7	853.2	1066.4

crop water consumption was higher at 90 DAS, while the lowest consumption occurred at the end of the cycle (120 DAS). This result is directly related to the competition between plants and atmospheric demand.

The difference in crop water consumption between the treatments T1 and T5 was equal to 918.7 L for cultivation without cover and to 853.1 L for cultivation with cover. Additionally, the water consumption of 'batata-de-purga' cultivated without cover was on average 6.6% higher than in the condition with plastic cover. This difference in water consumption may be associated with the increase in crop yield, such as tuber weight, number of seeds, tuber diameter and tuber size, caused by the increase in luminosity. All the growth variables increased with the increase in the irrigation level. WUE values of 'batata-de-purga' in all irrigation treatments and under the cultivation conditions with and without plastic cover are expressed in the present study in terms of weight of seeds, number of seeds and number of climbing stems per volume of water applied to the crop (Table 3).

The irrigation depth of 25% ET_o (T1) in the area with cover showed an increase of 17% in WUE in terms of gram of seeds/liter of water in relation to the area without cover. For the treatment T2, WUE was higher in the area without cover, with a difference of 22%, WUE values, expressed in terms of grams of seed/liter of water, were higher in the cultivation without cover in the treatments T2 and T4. In terms of number of seeds/liter of water, the highest values of WUE were observed in T1 and T2. However, in terms of number of climbing stems/liter of water, WUE values were consistently higher in the cultivation without cover in all treatments in comparison to the cultivation with cover. The growth variables related to tuber increases with increases in irrigation depth. Tube is the unique part of the plant with medicinal effect and commercial value.

Statistical analysis

The analysis of variation of 'batata-de-purga' stem diameter as a function of irrigation treatments, in statistical terms, indicates that all irrigation levels led to difference between tuber diameters for the conditions with and without plastic cover, which was statistically significant at 0.05 probability level by F test (Table 4). Different uppercase letters in the same row indicate significant difference between tuber diameters and equal letters indicate no significant difference between tuber diameters for cultivation with and without cover.

In addition, for the conditions with and without cover, the diameter of 'batata-de-purga' was altered, also significantly at 0.05 probability level by F test, in all irrigation treatments from 30 to 120 DAS. Under both cultivation conditions, crop diameter was significantly altered by the irrigation level from 120 to 150 DAS.

This result suggests that the increase in 'batata-de-purga' diameter is little influenced at the end of the cycle by the increase in soil moisture, for both planting conditions, with and without plastic cover.

DISCUSSION

Agricultural systems with 'batata-de-purga' improved soil chemical conditions, increasing the contents of primary micronutrients and decreasing the contents of Al. Similar results were obtained by Portugal et al. (2010), who

Table 3. Water use efficiency (WUE) in the 'batata-de-purga' crop for the treatments T1 (25% ET_o), T2 (50% ET_o), T3 (75% ET_o), T4 (100% ET_o) and T5 (125% ET_o) under cultivation with and without plastic cover in terms of weight of seeds, number of seeds and number of climbing stems per volume of water

Treatments	Without plastic cover	With plastic cover
WUE (grams seed/liter of water)		
T1	0.41	0.58
T2	0.51	0.29
T3	0.43	0.58
T4	0.70	0.65
T5	0.53	0.62
WUE (Number of seeds/liter of water)		
T1	0.31	0.28
T2	0.41	0.18
T3	0.22	0.26
T4	0.19	0.19
T5	0.22	0.22
WUE (Number of climbing stem/liter of water)		
T1	0.65	0.39
T2	1.03	0.18
T3	0.59	0.31
T4	0.58	0.19
T5	0.58	0.17

Table 4. Variation of 'batata-de-purga' stem diameter as a function of irrigation treatments (T1 = 25%; T2 = 50%; T3 = 75%; T4 = 100%; and T5 = 125% of reference evapotranspiration – ET_o) and days after sowing (DAS) under planting conditions with and without plastic cover.

DAS	With plastic cover	Without plastic cover
Treatment T1 = 25% ET_o		
30	0.5617^{Aa}	1.8733^{Ba}
60	1.4333^{Ab}	3.1767^{Bb}
90	2.2100^{Ac}	5.0167^{Bc}
120	2.4650^{Ad}	6.2133^{Bd}
150	2.7183^{Ad}	6.3000^{Bd}
Treatment T2 = 50% ET_o		
30	1.1733^{Aa}	2.2717^{Ba}
60	2.2600^{Ab}	3.5167^{Bb}
90	3.6283^{Ac}	5.4983^{Bc}
120	3.9017^{Ad}	6.2050^{Bd}
150	4.0900^{Ad}	6.8383^{Bd}
Treatment T3 = 75% ET_o		
30	1.0117^{Aa}	2.2550^{Ba}
60	2.5000^{Ab}	3.2450^{Bb}
90	3.9183^{Ac}	5.4883^{Bc}
120	4.7500^{Ad}	6.8283^{Bd}
150	5.0733^{Ad}	7.0283^{Bd}

Table 4. Contd.

Treatment T4 = 100% ET_o		
30	1.1767^{Aa}	2.2717^{Ba}
60	2.2117^{Ab}	3.3500^{Bb}
90	3.8400^{Ac}	5.2883^{Bc}
120	4.5183^{Ad}	5.8733^{Bd}
150	4.9783^{Ad}	6.3350^{Bd}
Treatment T5 = 125% ET_o		
30	1.5333^{Aa}	2.6783^{Ba}
60	2.6000^{Ab}	3.6300^{Bb}
90	4.1000^{Ac}	5.8383^{Bc}
120	4.7833^{Ad}	6.7683^{Bd}
150	5.2000^{Ad}	7.0833^{Bd}

Means followed by the same lower case letters in a column and capital letters on the lines do not differ significantly by the F test ($p < 0.05$).

analyzed physical and chemical properties of a Latosol under different agricultural systems in the Zona da Mata region, in Minas Gerais. These authors observed that the agricultural systems with orange orchard and sugarcane plantation improved soil chemical conditions, increasing the contents of nutrients and decreasing the Al^{3+} of the exchange complex, but showed reduction in the contents of soil organic matter and intermediate levels of physical degradation. The lowest difference in seed weight between the cultivation conditions occurred in the treatment T1 (only 0.19 g), while the greatest difference occurred in the treatment T4 (8.9 g); then, it decreased to 4.4 g in T5. In this context, Bisognin et al. (2008) emphasize that the development of tubers is a critical period that determines crop yield and is one of the main stages directly influenced by solar radiation and amount of water.

The evolution of tuber weight with the increase in irrigation depth, for the cultivation with plastic cover, showed coefficient of determination (r^2) statistically significant at 0.05 probability level by the Student's t-test, while the reduction in the treatment without cover did not show r^2 statistically significant at 0.01 and 0.05 probability levels. The difference between minimal and maximal irrigation depths applied in the experiment was more than double in covered conditions (20.2 mm). However, the difference between the treatments T1 and T2 was only 3.6 mm and between T4 and T5, under these conditions, 9.3 mm. The smallest difference was observed between the treatments T3 and T4, which was equal to only 0.7 mm and below those under covered conditions. This occurs because solar radiation has direct relationship with crop yield, since air temperature and solar radiation affect the processes of plant growth and development (Tazzo et al., 2008).

The effects of luminosity on the production components of a crop are evident, since the presence of light causes a reduction in CO_2 concentration in the mesophyll, due to the photosynthesis, increasing the pH of the environment, which becomes alkaline and favorable to the production of enzymes involved in starch degradation and, therefore, increasing the concentration of glucose in the mesophyll (Michelin et al., 2010). Thus, plants cultivated without plastic cover consumed a greater amount of water due to the high temperatures occurring along the experimental period, in order not to be under stress and cause lower development of tubers. On the other hand, in the area with artificial shading, there was a lower water demand, which directly reflected in all production components of the tuber. Since 'batata-de-purga' is a plant adapted to low technological level systems, it is commonly found in small family-farming farms. Another great advantage from the perspective of family-farming cultivation is that harvest can be scheduled, anticipated or delayed, because the commercial parts are tuberous roots, which form along the crop cycle without a specific moment for harvest.

Conclusions

The results of the present study demonstrate that all growth variables of 'batata-de-purga' were strongly influenced by both soil moisture and cultivation conditions and irrigation depth. The optimum water and cultivation conditions for best plant growth are under 100% ETo and without plastic cover, respectively. The growth variables related to tuber (weight, size and diameter) increases linearly with increases in irrigation depth. Effectively, tube is the unique part of the plant with medicinal effect and commercial value. Irrigation has little influence on the cultivation of the crop exposed to the environmental conditions, while production is substantially increased under controlled conditions of luminosity. Results suggest that the weight of seeds showed higher values of water use efficiency for the cultivation with plastic cover, while the number of seeds and number of climbing stems showed higher water use efficiency for the cultivation without plastic cover. Except for the weight of seeds, which showed higher water use efficiency in the treatment of 100% $ET_{o,}$ the number of seeds and the number of climbing stems proved to be more efficient in the use of water in the treatments with smaller irrigation depths.

Conflict of Interests

The authors have not declared any conflict of interests.

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