

STRATEGIES FOR TARO (*Colocasia esculenta*) IRRIGATION^a

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ABSTRACT

This study aimed to evaluate the taro (*Colocasia esculenta*), var. São Bento, in response to different irrigation strategies. The experiment was carried out in 2015, at Instituto Federal do Espírito Santo, Santa Teresa campus, Brazil, at an altitude of 130 meters above sea level. It was installed a drip irrigation system, divided in subunits, to irrigate the plots individually, according to the treatments. The irrigation intervals were determined according to the water availability for the crop (F factor), related to the soil water depletion, established for each treatment. Thus, irrigation was performed when the water in the soil was depleted equivalent to 10; 20; 30; 40 and 50% of the total water available, respectively, for the treatments T1, T2, T3, T4 and T5, in a randomized block design, with four replications. Meteorological data were used to estimate the crop water demand, performing daily water balance using spreadsheets. We evaluated the applied water depth, the yield of commercial cormels and the water use efficiency by taro, due to the F factor. The results were submitted to analysis of variance and regressions. The increase of the F factor and a consequent application of light and frequent irrigation promoted reduction of the irrigation depths and favors the taro development and yield, besides promoting the highest values of water use efficiency. Thus, these management conditions may be recommended for its cultivation.

Keywords: F factor, water depletion, cocoyam, productivity, water use efficiency.

1. INTRODUCTION

The taro (*Colocasia esculenta*), also known as cocoyam, is of great economic and social importance in many tropical and subtropical regions of the world, occupying a prominent place in the diet of many people in these regions [1]. In Brazil, it is grown mainly in the states of the Mid-South region. It is present in almost all the municipalities of Minas Gerais State, which is the state's largest producer of the country and it is explored in family farming. Taro presents fleshy cormels, with similar nutritional value of potato tubers [2].

World production of taro in 2013 reached 9.976 million tons grown on 1.299 million hectares, and Nigeria was responsible for about 3.450 million tons, followed by China with 1.845 million tons and Cameroon with 1.551 million tons [3]. However, the FAO estimates that only 145,000 tons are sold and the remainder is used in the food base of these people. Recent data are not found on the production of taro corms on the national scene of Brazil, but it is estimated that this is around 200,000 tons.

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Despite the potential that culture has to develop in excess moisture environments, excessive shading and other climatic stress [4], there is still a lack of information about it. Even the need for water for the crop is not consolidated, and most often is not linked to technical criteria, resulting in unnecessary expenditure of energy for irrigation and waste of water or under-utilization of irrigation system.

The expansion of irrigated areas, currently held, this tied to concerns about the availability of water for agriculture and energy costs associated with practice. Consequently, the adoption of strategies aimed to reduce the water wastes, without incurring losses in productivity [5], become essential to the efficient use of these water and energy resources.

According to [6], the productivity of a culture is a function of complex biological, physiological, physical and chemical processes, which are determined by environmental conditions and genetic factors of crop itself. Thus, the realization of irrigation tends to raise the productivity of crops. However, only irrigation without an efficient management to consider the crop and physiological aspects of the species, physical, chemical and physicochemical soil and particularities of the adopted irrigation system [7], just not provide a significant increase in productivity, but an expressive expenditure reduction associated with the cultivation.

Proper and strategic water management can be done using the water use efficiency (WUE) index for irrigation planning and decision-making, which would promote increasing the crop yield [8]. Thus, a good management strategy of irrigation is essential to save water without, however, endangering the crop yield [9-10].

In the case of taro, there is a shortage of technical information of Brazilian soils and climate conditions, and most of the studies reported, in researches, comes from other countries [11-12]. As regards, the water demand for this crop is lack of clear information and we do not know about it in their phenological phases to conditions of Brazilian agricultural ecosystems. Therefore, the present study was due to evaluate the response of taro to different strategies of irrigation (F factors).

2. METHODOLOGY

The experiment was conducted in the Vegetable Crops sector of the Instituto Federal do Espírito Santo, Santa Teresa campus, Espírito Santo state, Brazil. The area is located in the coordinates latitude 19°48'36" south and longitude 40°40'48" west, has an altitude of 130 m above sea level, with soil classified predominantly as Latosol Yellow Eutrophic clayey, containing 63% of clay in its composition. In the area where the experiment was carried out, the field capacity (FC) is 32%; the permanent wilting point (PMP) is 20.6%; the bulk density is 1.60 g cm⁻³, the crop root depth is 40 cm and the total available water of the soil is 72.96 mm.

It was cultivated the taro São Bento variety and, before the crop planting, the experimental area was prepared and fertilized. The spacing between planting rows was 0.7 m and between plants 0.3 m. The plots had 2.8 x 2.4 m, with 4 rows of planting and 8 plants in each row. Six plants were evaluated in each of the two central rows, called useful plants of the plots. Sowing occurred on April 20, 2015 and harvest on October 05, 2015. Taro corms were distributed in the planting furrows so that the yolks placed face up. Then the corms were covered with soil until about two centimeters above the yolks apex.

It was installed a drip irrigation system, divided in subunits, to irrigate the plots individually, according to the treatments. There was one lateral line per row of plants with one emitter per plant, at a spacing of 0.3 x 0.7 m, with a flow rate of 15.4 L h⁻¹, providing an application intensity of 73.33 mm h⁻¹. The irrigation intervals were determined according to the water availability for the crop (F factor), related to the soil water depletion, established for each treatment, as shown in Table 1. Thus, irrigation was performed when the water in the soil was depleted equivalent to 10; 20; 30; 40 and 50% of the total water available, respectively,

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85 for the treatments T1, T2, T3, T4 and T5, in a randomized block design, with four
 86 replications. Figure 1 shows a part of the experimental area.
 87



88
 89 **Figure 1: Taro cultivated in the experimental area, localized in the Instituto Federal do**
 90 **Espírito Santo, Santa Teresa campus.**
 91

92 The treatments were irrigated at different times, so when the irrigations occurred, the amount
 93 of water in the soil was different, which gave different soil water deficits (water depletions) for
 94 each treatment, as shown in Table 1.
 95

96 **Table 1: Treatments and their respective F factors and water deficits, in mm, at the**
 97 **time of irrigation**

Treatment	T1	T2	T3	T4	T5
F factor	0.1	0.2	0.3	0.4	0.5
Water depletion (mm)	7.3	14.6	21.9	29.2	36.5

98
 99 We determined the irrigation levels (mm), individually for each treatment, using
 100 spreadsheets that calculated the water balance with climate measurements (maximum and
 101 minimum temperatures and the rainfall) and sporadic determination of soil moisture, with the
 102 stove method, for checking purposes. To determine the irrigation depths (mm), which were
 103 applied in the plots, we calculated the crop evapotranspiration, using Equation 1 [13-14]. The
 104 reference evapotranspiration was determined by Hargreaves and Samani method [15]. The
 105 single crop coefficient (Kc) used for taro was proposed by [16], which suggests the following
 106 values: Kc initial: 1.05 in the first 60 days after planting; Kc mid: 1.15, the second to the sixth
 107 month after planting and Kc final: 1.1, the sixth month until harvest.
 108

109
$$ET_c = ET_0 K_C K_S K_L \quad (1)$$

110 Where:

111 ET_C - crop evapotranspiration, mm d^{-1} ;

112 ET_0 - reference evapotranspiration, mm d^{-1} ;

113 K_C – single crop coefficient, dimensionless;

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114 K_S – water stress coefficient, dimensionless;
115 K_L - correction factor due to the drip irrigation, based on the wetted and shaded area,
116 dimensionless.

117
118 In the experiment beginning we applied two irrigations, with the same depth in all treatments,
119 one at the 1st day and another at the 14th day, with 18.3 and 12.2 mm, respectively, to
120 facilitate the initial growing of all plots. From the 30th day, the irrigations were carried out
121 according to the treatments until the end of the experiment.

122 Due to the occurrence of hail rain, which damaged the aboveground part of the crop, it was
123 necessary to perform the harvest before the planned. Thus, the crop cycle had only 169
124 days, that is, 41 days less than planned. Thus, the K_c values used were: 1.05 in the first 60
125 days and 1.15 from day 61 until harvest.

126 The irrigation system was assessed following the method proposed by [17] and determined
127 the Distribution Uniformity (DU) coefficient of the irrigation system. These authors suggest
128 collecting flow rates at 4 points (emitters) along the lateral line, i.e., the first dripper, the
129 drippers located at 1/3 and 2/3 of the length of the line and the last dripper. The lines
130 selected within the sector should be: first, those located at 1/3 and 2/3 of the length and the
131 last lateral line, assessing 16 values as a whole.

132 The yield performance was evaluated from the average productivity of cormels obtained in
133 treatments, and quantified the commercial cormels production. The cormels classification
134 was performed according to the [18] recommendation, from the transverse diameter, being
135 large (>47mm), medium (33-46mm), and little cormels (<33mm). For the aggregation of
136 commercial cormels it was considered the sum of large and medium cormels.

137 The water use efficiency was determined by the ratio of the productivity ($t\ ha^{-1}$) values and
138 the seasonal crop evapotranspiration (mm), in each treatment, and the results expressed in
139 $kg\ m^{-3}$ as cited by [19], [20] and [14]. In a similar way, we calculated the irrigation water use
140 efficiency, by dividing the seasonal irrigation depths applied by the productivities observed in
141 each treatment.

142 The data were submitted to analysis of variance and regressions, and the coefficients were
143 analyzed with 1% level of probability by the F test.

144
145

146 3. RESULTS AND DISCUSSION

147
148 During the experimental period, a total rainfall of 150 mm was rained, with the greatest
149 amount occurring in the initial phase, with precipitation decreasing until day 137. On the 138th
150 day, rainfall was 19 mm and on 140th day, 2.5 mm, from which no more rainfall occurred in
151 that period. Temperatures ranged from 10.8 to 38.2 °C, as seen in Figure 2.

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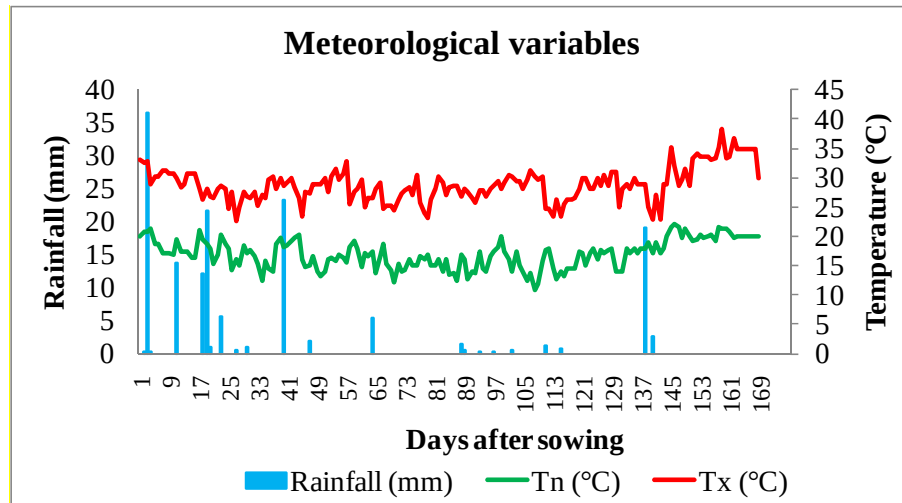


Figure 2: Meteorological variables during the taro growing seasons.

Rainfall = total rainfall during crop cycle. Tn = minimum temperature. Tx = maximum temperature.

In Figure 3 we can see the rainfall and soil moisture variation relative to the field capacity and permanent wilting point in different treatments throughout the crop cycle. In the beginning, as we applied the same amount of water in all treatments and there were greater amounts of rainfall, their moisture was very similar. From the 39th day after sowing, the rains decreased and the irrigations were differentiated, in terms of depths and frequencies, according to the treatments.

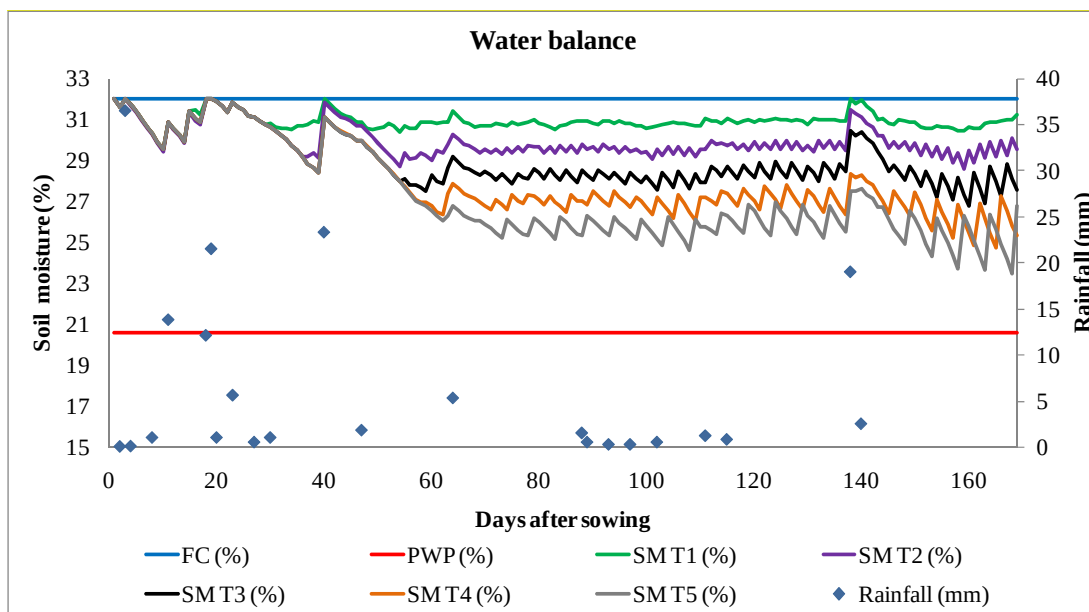


Figure 3: Water balance during the crop cycle.

FC= field capacity (%); PWP = permanent wilting point (%); SM = soil moisture for all treatments.

For the T1 treatment, the irrigations were performed daily, to restore the depth that was evapotranspired until the depleted water limit (10% of TAW). If there was a rainfall, we did

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not irrigate. The last irrigation depths were applied 1, 2, 3, 4 and 6 days before harvest, for the T1, T2, T3, T4 and T5 treatments, respectively.

The seasonal crop evapotranspiration (Etc), the water use efficiency (WUE), the irrigation water use efficiency (IWUE), the number of irrigations and the depths applied during the growing season in all treatments are presented in Table 2. In T1 and T2 treatments (more frequent irrigations) we observed the higher values of WUE and IWUE with more irrigation events and higher depths.

Table 2: Seasonal crop evapotranspiration, water use efficiency, irrigation water use efficiency, number of irrigations and irrigation depths during the crop cycle

Treatment	T1	T2	T3	T4	T5
ETc (mm)	404.0	398.7	386.3	375.5	368.1
WUE (kg m ⁻³)	4.3	4.0	3.6	1.8	1.4
IWUE (kg m ⁻³)	5.8	5.8	5.3	2.7	2.0
N° irrigations	119.0	56.0	37.0	27.0	24.0
Irrigation depths (mm)	304.0	277.4	261.5	256.6	246.8

Etc = seasonal crop evapotranspiration; WUE = water use efficiency; IWUE = irrigation water use efficiency.

Figure 4 shows the relationship between the total water depths (irrigation and rainfall) depending on the soil water depletion. It is observed that the F factor increase has provided a reduction in the total water depth applied to the crop.

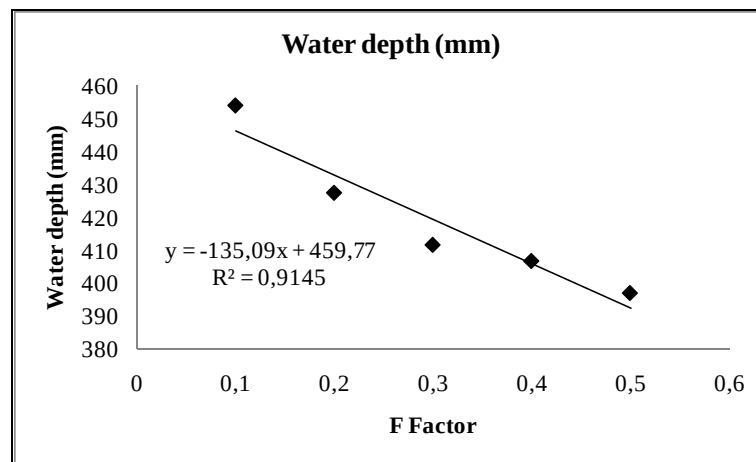


Figure 4: Total water applied in different irrigation frequencies (F factor). Significant from F test. *P = 0.01

In the T1 treatment (F factor equals 0.1) the total water depth was 454 mm and in the T5 treatment (the largest F factor), 397 mm were available to the crop, with approximately 12.6% of difference. This occurs because for higher f factor values, the intervals between irrigations (irrigation frequency) become larger, which promotes greater soil water depletion by reducing its moisture and consequent reduction in evapotranspiration and therefore lower replacement water through irrigation.

In Figure 5 we can see the taro yield, in relation to F factors. We observed that the irrigation intervals increasing provided yield reduction in trade cormels.

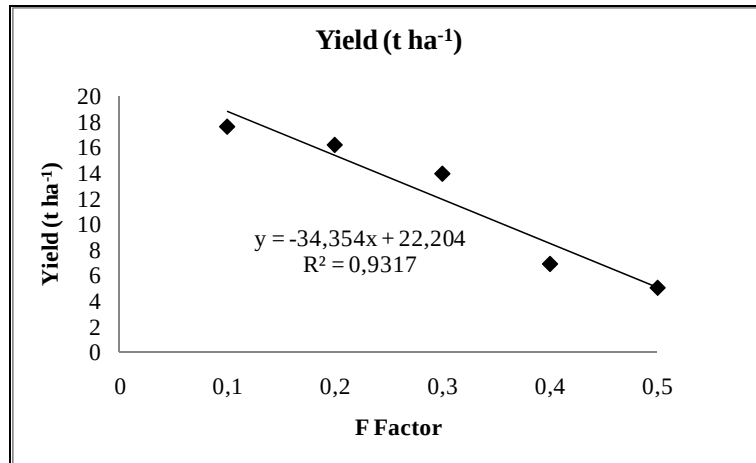


Figure 5: Average yield of taro cultivar "São Bento" under different irrigation frequencies (F factor).

Significant from F test. *P =0.01

The T1 and T2 treatments had the highest yields among all tested. This occurred because with the high irrigation frequency, the plants were subjected to less or no water stress, unlike the T4 and T5 treatments that were submitted to the largest individual irrigation levels, but in larger intervals, which may be caused drought stress and thus reduced plant yield. The results are in line with statement of [21] that taro corms grow better in wet than in dry conditions.

The T5 treatment plants had few or no large cormels, predominantly medium and small cormels, in addition to the mother cormel, occurring cormels damaged by rot, which are not viable to trade. The T1 and T2 treatments presented a number of large and medium-sized cormels in a satisfactory amount for each class, with low number of small and damaged cormels.

We observed a tendency to increase yield with the irrigation interval reducing. The highest yield of commercial cormels was achieved with the T1 treatment, with the observed mean of 17.55 t ha⁻¹. For the T5 treatment the average yield achieved was only 5.01 t ha⁻¹, that is 71.4% lower than the first one. As cited by [22], stress conditions such as lack of water led to slow growth and retarded development of cormels, as in this experiment.

[23] found maximum values of marketable productivity of taro (Japanese clone) of 22.23 t ha⁻¹. [24] evaluated the taro productivity on the clones Macaquinho and Chinese and found 37.05 t ha⁻¹ and 26.49 t ha⁻¹, respectively. [25] found maximum yield of marketable corms of 31.17 t ha⁻¹. Values up to 23.9 t ha⁻¹ were found by [12] with South African landraces of taro. These values are higher than that obtained in this study (maximum of 17.55 t ha⁻¹) and the difference in yield obtained in these works can be attributed, mainly, to the early harvest and also to the soil type, the plant population and the clone used, as reported by [23].

In Figures 6A and 6B we can see, respectively, the water use efficiencies (WUE) and the irrigation water use efficiencies (IWUE) in relation to the F factors. The greater efficiencies can be seen at T1 and T2, with values of 4.3 and 4.0 kg m⁻³, respectively. In these treatments the soil remained wetted between irrigation intervals, which provided better conditions for the crop development and to achieve high yield. [12] found up to 0,53 kg m⁻³ of WUE in studies with South African landraces of taro under rainshelter. [26] observed up to 15.8 kg m⁻³, studying 33 cultivars of taro in Madeira, Portugal, with an average of 35.4% decrease in taro WUE under water stress conditions, compared to that plants growing under good soil moisture conditions.

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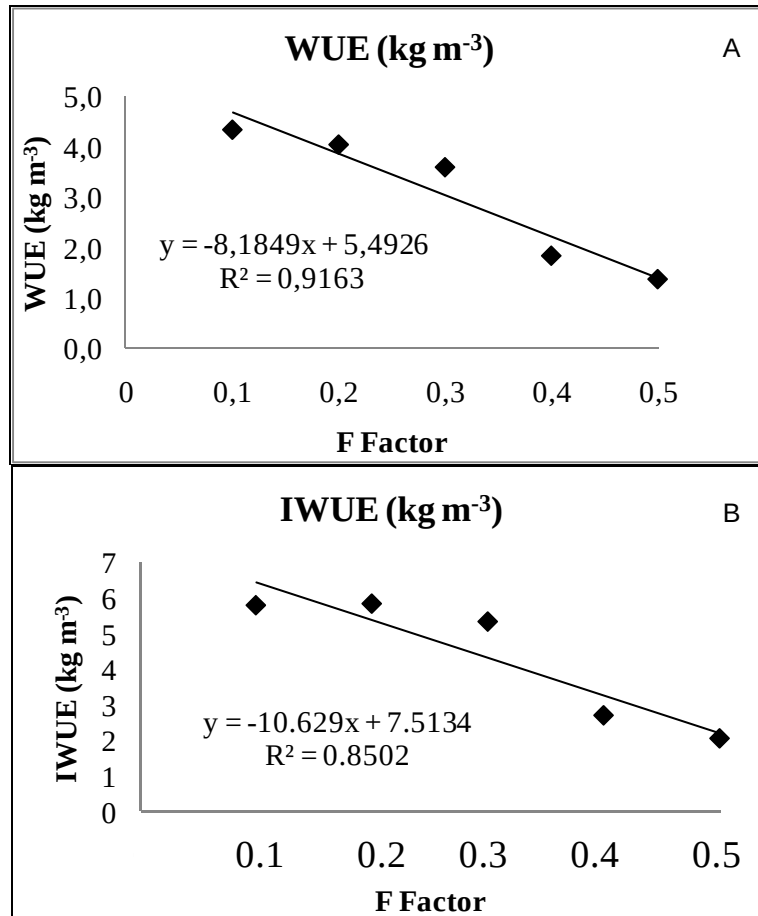


Figure 6: Water use efficiency (kg m⁻³) and irrigation water use efficiency (kg m⁻³) of taro cultivar "São Bento" under different irrigation frequencies (F factor). Significant from F test. *P = 0.01

According to [27], when the irrigation interval is too long, the friability of the soil immediately obtained after irrigation undergoes a progressive alteration and, depending on the texture, can at the end of the period, present hard consistency, hindering the penetration of roots of cultivated plants. The soil of the experimental area presents high clay content and when it is with low moisture, it presents hard consistency. In this case it is important to increase the irrigation frequency, establishing lower F factors, a condition that keeps the soil surface layer moist for a longer time. Therefore, we recommend the application of lighter and more frequent irrigation depths.

4. CONCLUSION

The analysis of the results obtained in the present study suggests that the decrease of the F factor (less water depletion in the soil) and a consequent application of light and more frequent irrigation promoted increases of the irrigation depths applied during the crop cycle and favor the taro development and yield (up to 17.6 t ha⁻¹), besides promoting the highest values of water use efficiency (up to 4.3 kg m⁻³) and irrigation water use efficiency (up to 5.8 kg m⁻³). Thus, these management conditions may be recommended for its cultivation.

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COMPETITIVE INTERESTS

The authors have stated that there are no competing interests.

AUTHORS CONTRIBUTIONS

Authors 1 and 2 designed the study and managed the writing of the manuscript. The author 1 performed the statistical analysis and the translation of the manuscript. Authors 3, 4 and 5 helped to carry out the experiment in the field, performing the evaluations of the parameters analyzed in the study. Authors 6 and 7 helped on the discussions and results interpretations. All authors read and approved the final manuscript.

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