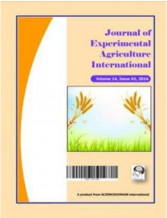

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Strategies for Taro (*Colocasia esculenta*) Irrigation

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Authors' contributions

This work was carried out in collaboration between all authors. Authors GHSV and GP designed the study and managed the writing of the manuscript. Author GHSV performed the statistical analysis and the translation of the manuscript. Authors JBL, GP and CMMP helped to carry out the field experiment, evaluating the parameters analyzed in the study. Authors JNC and PAVLM assisted with interpretations surrounding the discussions and results. All authors read and approved the final manuscript. All authors read and approved the final manuscript.

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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 the Instituto Federal do Espírito Santo, Santa Teresa Campus, Brazil, at an altitude of 130 m above sea level. A drip irrigation system was installed, which was divided into subunits, to irrigate the plots individually, according to the treatments. The irrigation intervals established for each treatment were based on the water availability for the crop (F factor), which, in turn, was related to the soil water depletion. Thus, irrigation was performed when the water in the soil was depleted equivalent to 10, 20, 30, 40 and

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50% of the total available water, 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, and the daily water balance was calculated 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 the consequent application of light and frequent irrigation promoted the reduction of the irrigation depths and favored the taro development and yield, besides supporting 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 country's largest producing state, and it is explored in family farming. Taro presents fleshy cormels, with similar nutritional value to potato tubers [2].

World production of taro in 2016 reached 10.128 million tons grown on 1.670 million hectares, and Nigeria was responsible for about 3.474 million tons, followed by China with 1.573 million tons and Ghana with 1.518 million tons [3]. However, the FAO estimates that only 145,000 t are sold, and the remainder is used as the staple food for these people. No recent data exists regarding the taro corm production on the national scene of Brazil, but it is estimated that this is around 200,000 t.

Despite the potential to cultivate taro under excess moisture environments, excessive shading and other climatic stress [4], there is still a lack of information related to these aspects. Even the water needs for the crop are not consolidated, and most often it is not linked to technical criteria, resulting in unnecessary expenditure of energy for irrigation and water waste or under-utilization of the irrigation system.

The current expansion of irrigated areas is tied to concerns about the availability of water for agriculture and energy costs associated with the irrigation 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 crop is a function of complex biological, physiological, physical and chemical processes, which are determined by the environmental conditions and genetic factors of the crop. Thus, the realization of irrigation tends to raise the productivity of crops. However, irrigation alone, without efficient management of the crop, considering the physiological aspects of the species, physical, chemical and physicochemical attributes of the soil and particularities of the adopted irrigation system [7], not only 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 an increase in 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 about Brazilian soils and climate conditions, and the reported data mostly comes from other countries [11-12]. Consequently, the water demand for this crop is unclear and the water requirements throughout its phenological phases in regards to the conditions of Brazilian agricultural ecosystems are also not yet established. Therefore, the present study aimed to evaluate the response of taro to different irrigation strategies (F factors).

2. METHODOLOGY

Taro variety São Bento was cultivated at the Vegetable Crops Sector of the Instituto Federal do Espírito Santo, Santa Teresa Campus, Espírito Santo State, Brazil. The area is located at 19º48'36"S latitude and 40º40'48"W longitude and has an altitude of 130 m above sea level, with soil classified predominantly as Latosol Yellow Eutrophic clayey, containing 63% 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 (TAW) of the soil is 72.96 mm.

Before planting the crop, the experimental area was prepared and fertilized. The spacing between planting rows was 0.7 m, and the spacing between plants was 0.3 m. The plots had an area of 2.8 × 2.4 m, with 4 rows of planting and 8 plants per row. Six plants were evaluated in each of the two central rows, called useful plants of the plots. Sowing occurred on 20 April 2015, and the crop was harvested on 5 October 2015. Taro corms were distributed, with the yolks face-up, in the planting furrows. Then, the corms were covered with soil until about 2 cm above the yolks apex.

A drip irrigation system was installed, which was divided into 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 × 0.7 m, and a flow rate of 15.4 L h^{-1}, providing an application intensity of 73.33 mm h^{-1}. The irrigation intervals established for each treatment were based on the water availability for the crop (F factor), which, in turn, was related to the soil water depletion, as shown in Table 1. Thus, irrigation was performed when 10, 20, 30, 40 and 50% of the TAW in the soil was depleted, for the treatments T1, T2, T3, T4 and T5, respectively, which were arranged in a randomized block design, with four replications. Fig. 1 shows a part of the experimental area.

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

Table 1. Treatments and their respective F factors and water deficits (mm) at the 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

Fig. 1. Taro cultivated in the experimental area, located at the Instituto Federal do Espírito Santo, Santa Teresa Campus, Brazil

We determined the irrigation levels (mm), individually for each treatment, using spreadsheets that calculated the water balance, with climate measurements (maximum and minimum temperatures and the rainfall) and sporadic determination of soil moisture, by the stove method, for verification purposes. To determine the irrigation depths (mm), which were applied to the plots, we calculated the crop evapotranspiration (ET_c), using Equation 1 [13-14]. The reference evapotranspiration (ET_0) was determined by the Hargreaves and Samani method [15]. The single crop coefficient (K_c) used for taro was proposed by [16], which suggests the following values: K_c initial: 1.05 in the first 60 days after planting; K_c mid: 1.15, the second to the sixth month after planting, and K_c final: 1.1, the sixth month until harvest.

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

Where:

ET_C – crop evapotranspiration, mm d^{-1};
ET_0 – reference evapotranspiration, mm d^{-1};
K_C – single crop coefficient, dimensionless;
K_S – water stress coefficient, dimensionless;
K_L – correction factor due to the drip irrigation, based on the wetted and shaded area, dimensionless.

At the beginning of the experiment, we applied two irrigations, with the same depth in all treatments, one on the 1st day and another on the 14th day, of 18.3 and 12.2 mm, respectively, to facilitate the initial growing of all plots. From the 30th day, the irrigations were conducted according to the treatments until the end of the experiment.

Due to the occurrence of hail rain, which damaged the aboveground part of the crop, it was necessary to harvest earlier than scheduled. Consequently, the crop cycle had only 169 days, namely, 41 days less than planned. Thus, the K_c values used were: 1.05 in the first 60 days and 1.15 from day 61 until harvest.

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

The yield performance was evaluated from the average productivity of cormels obtained in treatments, and the commercial cormels production was quantified. The cormels were classified, according to the transverse diameter, as large (>47 mm), medium (33–46 mm), and little cormels (<33 mm), as recommended by [18]. For the aggregation of commercial cormels, the sum of large and medium cormels was considered.

The WUE was determined by the ratio of the productivity (t ha^{-1}) values and the seasonal ET_c (mm) in each treatment, and the results expressed in kg m^{-3}, as cited by [14], [19] and [20]. Similarly, we calculated the irrigation water use efficiency, by dividing the seasonal irrigation depths applied by the productivities observed in each treatment.

The data were evaluated by analysis of variance and regressions, and the coefficients were analyzed at 1% level of probability by the F test.

3. RESULTS AND DISCUSSION

During the experimental period, the total rainfall was 150 mm, with the greatest amount occurring in the initial phase, with precipitation decreasing until day 137. On day 138, the rainfall was 19 mm, and on day 140 it was 2.5 mm, respectively, with no further rain in that period. Temperatures ranged from 10.8 to 38.2°C, as seen in Fig. 2.

Fig. 3 displays the rainfall and soil moisture variation relative to the FC and PWP in different treatments throughout the crop cycle. Initially, because we applied the same amount of water in all treatments and there were relatively greater amounts of rainfall at this time, the moisture contents were very similar. From day 39 after sowing, the rains decreased, and the irrigations were differentiated, regarding depths and frequencies, according to the 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 rainfall, we did not irrigate. The last irrigation depths were applied on days 1, 2, 3, 4 and 6 before harvest, for the T1, T2, T3, T4 and T5 treatments, respectively.

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

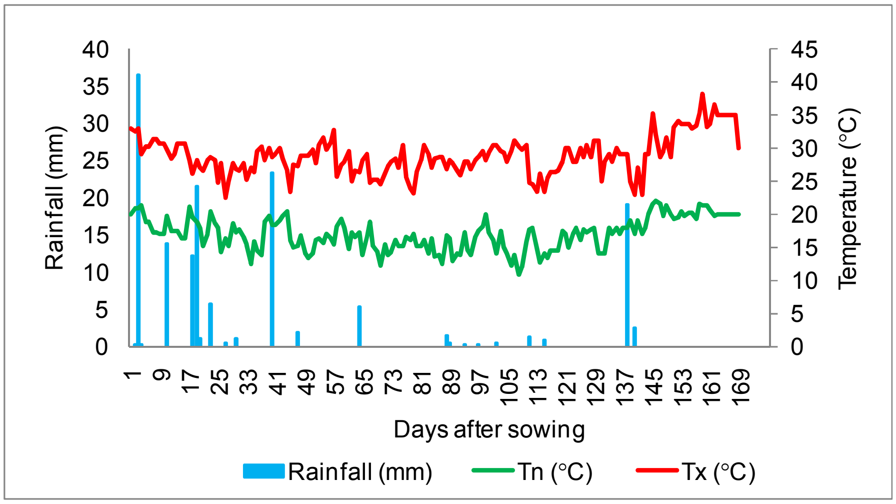

Fig. 2. Meteorological variables during the taro growing seasons

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

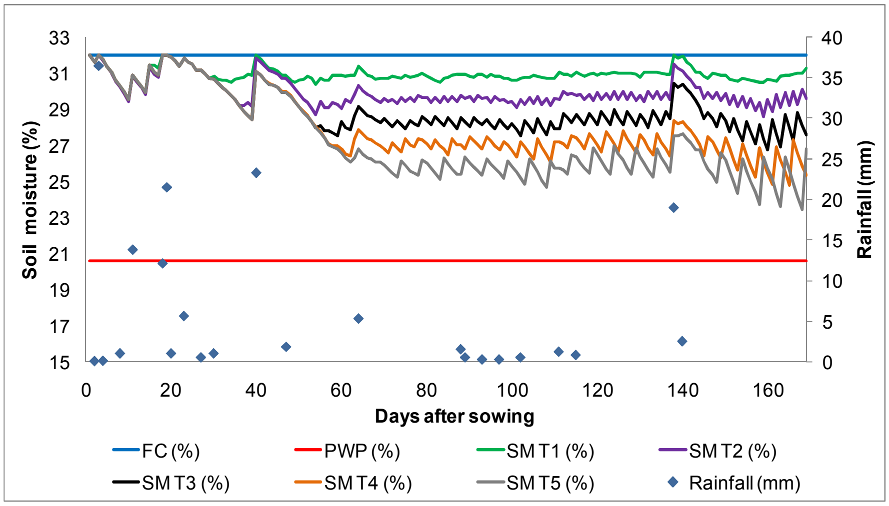

Fig. 3. Water balance during the crop cycle

FC = field capacity (%); PWP = permanent wilting point (%); SM = soil moisture for all treatments (T1–T5).

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
ET_c (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
Number of irrigations	119.0	56.0	37.0	27.0	24.0
Irrigation depths (mm)	304.0	277.4	261.5	256.6	246.8

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

Fig. 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 provided a reduction in the total water depth applied to the crop.

The total water depth in the T1 treatment (F factor equals 0.1) was 454 mm, and in the T5 treatment (the largest F factor), 397 mm was available to the crop, corresponding to a difference of approximately 12.6%. This behavior 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, causing a reduction in evapotranspiration and therefore lower replacement water through irrigation.

Fig. 5 reveals the taro yield, in relation to the F factors. We observed that increasing the irrigation intervals, reduced the yield of trade cormels.

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

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

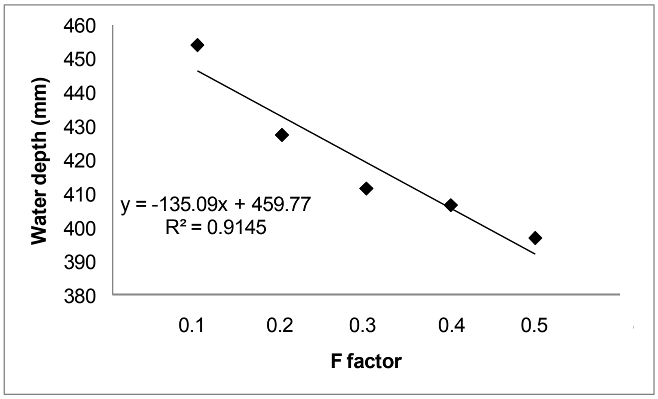

Fig. 4. Total water applied at different irrigation frequencies (F factor).

*Significant from F test *P = 0.01*

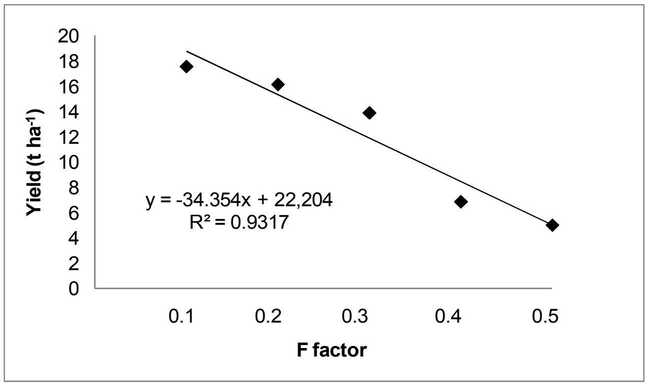

Fig. 5. Average yield of taro cultivar "São Bento" under different irrigation frequencies (F factor)

*Significant from F test *P =0.01*

We observed a tendency to increase yield as the irrigation interval was reduced. 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 attained was only 5.01 t ha^{-1}, which is 71.4% lower than yielded by T1. As cited by [22], stress conditions, such as lack of water, lead to slow growth and retarded development of cormels, as in this experiment.

Previously, [23] found a maximum 22.23 t ha ^{1} of marketable productivity of taro (Japanese clone). According to [24], the taro productivity of Macaquinho and Chinese clones were 37.05 and 26.49 t ha^{-1}, respectively. Also, [25] recorded a maximum yield of marketable corms of 31.17 t ha^{-1}. Values up to 23.9 t ha^{-1} were documented by [12], for 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 but also to the soil type, plant population and the clone used, as reported by [23].

Figs 6A and 6B illustrate, respectively, the water use efficiencies (WUEs) and the irrigation water use efficiencies (IWUEs) in relation to the F factors. T1 and T2 present the greater efficiencies among all the treatments, with values of 4.3 and 4.0 kg m^{-3}, respectively. In T1 and T2, the soil remained wetted between irrigation intervals, which provided better conditions for the crop development, enabling high yields. In comparison, [12] noted a WUE of up to 0.53 kg m^{-3} in studies with South African landraces of taro under a rain shelter. In a study of 33 cultivars of taro in Madeira, Portugal, [26] observed up to 15.8 kg m^{-3}, with an average of 35.4% decrease in taro WUE under water stress conditions, compared to plants growing under good soil moisture conditions.

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 soil of the experimental area possesses a high clay content (69%), with a hard consistency

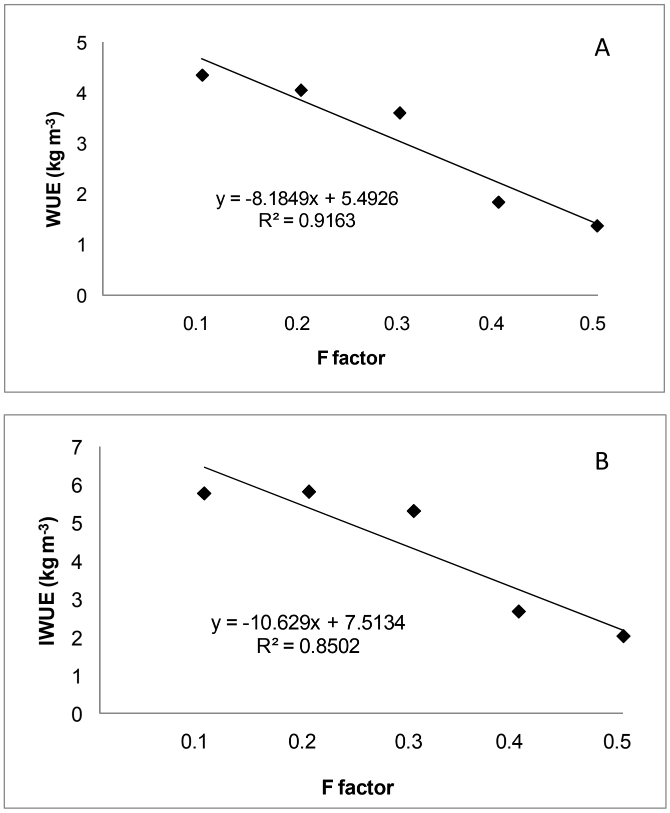

Fig. 6. Water use efficiency (WUE) (kg m^{-3}) and irrigation water use efficiency (IWUE) (kg m^{-3}) of taro cultivar "São Bento" under different irrigation frequencies (F factor)

*WUE = water use efficiency; IWUE = irrigation water use efficiency. Significant from F test. *P = 0.01* when the moisture content is low. In this case, it is important to increase the irrigation frequency, establishing relatively lower F factors, to ensure the soil surface layer remains moist for an extended 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 WUE (up to 4.3 kg m^{-3}) and IWUE (up to 5.8 kg m^{-3}) values. Thus, these management conditions may be recommended for its cultivation.

DISCLAIMER

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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