



Water requirement of upland Taro (*Colocasia esculenta*) under humid tropical zones of India

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ABSTRACT

Present study was carried out at the research farm of ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala during 3 summer seasons of 2016–17, 2017–18 and 2018–19 to assess the crop water requirement of upland taro (*Colocasia esculenta* L. Schott) and to arrive at a suitable irrigation schedule under humid tropical conditions of Kerala. The experiment was conducted in randomized block design (RBD), with 7 treatments as 5 levels of drip irrigation, [50% (I_1), 75% (I_2), 100% (I_3), 125% (I_4) and 150% (I_5) of the crop evapotranspiration, ET_c], furrow irrigation and a rainfed crop with 3 replications. Crop water requirement was calculated as same as crop evapotranspiration (ET_c) assuming that there is no other water losses. Pooled analysis of the data collected for three seasons indicated that, I_3 , drip irrigation at ET_c 100% is optimum for achieving maximum cormel yield and optimum water productivity. The optimal water requirement for upland taro was observed as 610–628 mm, including effective rainfall, based on the crop, soil and climatic parameters. The information will support the farmers to develop irrigation plans in advance during summer season, and for ensuring effective usage of irrigation water in water scarce areas, in this era of climate change.

Keywords: Cormel yield, Drip irrigation, Irrigation schedule, Water productivity, Water requirement

Taro or *Colocasia* (*Colocasia esculenta* L. Schott) is one of the important root crops of the world. It is one among the oldest crops, dating back to more than 10,000 years, known to man. Presently, it provides the main staple food of many people of humid tropics and sub-tropics. Taro is grown in 49 countries with an area of 1.72 million hectare (mha) and a production of 10.22 million tonnes, of which 74% production is concentrated in Africa. The average productivity of taro is highest in Asia (16.5 t/ha) and lowest in Africa (4.3 t/ha) and the world average productivity is reported as 5.39 t/ha (FAOSTAT 2018).

Taro is adapted to tropical low lands with annual rainfall of 2000 mm, but can be grown even with 1500 mm if evenly distributed. There are two common production systems for taro cultivation, the low land or flooded system where water is available throughout and the upland taro which is supplemented with irrigation. Taro is reported as one of the least water efficient crops (Uyeda *et al.* 2011). The crop requires a high water volume to achieve optimal yields and with climate change, taro is more exposed to long periods of water shortage (Ganança *et al.* 2018). In India, taro is

mainly cultivated in almost all the states and is consumed as a routine vegetable. The crop is mostly cultivated with monsoon rains and supplemental irrigation, using furrow system. Still, it remains as an underexploited crop in terms of water needs and response of stress at various stages of growth. Most of the varieties and land races are season insensitive and can be grown in any part of the year. A water shortage is experienced during summer and post monsoon periods and climate change is expected to cause water scarcity in future, for tuber crops due to the higher demand of water for other major crops (Sunitha *et al.* 2020). Hence, the present study was undertaken to assess the water requirement of upland taro for optimum production.

MATERIALS AND METHODS

Field experiments were conducted during the three consecutive summer seasons of 2016–17, 2017–18 and 2018–19 at the research farm of ICAR-Central Tuber Crops Research Institute (ICAR-CTCRI), Thiruvananthapuram (8.54° N and 76.91° E with an altitude of 50 m amsl), Kerala. In all the seasons, the crop was planted in November and harvested in May to avoid the rainy period. Based on the USDA taxonomic system, the soil was classified as sandy clay loam having 62% sand, 10% silt and 28% clay content. Field capacity and permanent wilting point of the site were determined by a Pressure

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Table 1 Physical and chemical properties of soil of experimental field

Physical						Chemical					
FC (%)	PWP (%)	BD (g/cc)	PD (g/cc)	WHC (%)	Porosity (%)	pH	EC (ds/m)	OC (%)	Available nutrients (kg/ha)		
									N	P	K
25.5	11.1	1.10	1.85	41.5	45.2	4.96	0.08	1.18	252	121	188

FC, field capacity; PWP, permanent wilting point; BD, bulk density; PD, particle density; EC, electrical conductivity; OC, organic carbon; N, nitrogen; P, phosphorous; K, potassium.

plate apparatus. The representative soil samples collected from 0–30 cm were analysed for physical properties and available nutrient status (Table 1). Daily evaporation data were collected from a Class A open pan evaporimeter, placed in the meteorological station.

The experiment was laid out in randomized block design (RBD) with 5 levels of drip irrigation, viz. 50% (I_1), 75% (I_2), 100% (I_3), 125% (I_4) and 150% (I_5) of crop evapotranspiration (ET_c), and two controls, furrow irrigation (F) and rainfed crop (RF). Improved variety of taro, Muktakeshi was used for the experiment which is suitable for both uplands and low lands, having duration of seven months. As per the package of practices recommended by ICAR-CTCRI, 12 tonnes of FYM as basal and 80 kg N, 25 kg P and 100 kg K were applied in 3 split doses.

The pan evaporation (E_p) data collected from the study location were used for the calculation of crop evapotranspiration (Allen *et al.* 1998) as $ET_c = K_c \times K_p \times E_p$, where K_p is the pan coefficient (0.7), K_c is the stage specific crop coefficient. Crop coefficient (K_c) values for taro as described by Fares (2008) were taken at different growth stages of the crop. K_c (initial) = 1.05 (2 months), K_c (med) = 1.15 (3 months) and K_c (late) = 1.1 (1 month). Crop water requirement was calculated as the same as crop evapotranspiration (ET_c) assuming that there are no other water losses. Irrigation given through drip system was controlled using a water meter. For the intermittent rains received during the period, effective rainfall was calculated (Pongpinyopap and Mungcharoen 2012).

$$P_{\text{eff}} = (P \times (125 - 0.2 \times 3 \times P)) / 125 \text{ for } P \leq 250 / 3 \text{ mm}$$

$$P_{\text{eff}} = 125 / 3 + 0.1 \times P \text{ for } P > 250 / 3 \text{ mm,}$$

where P, the rainfall in mm.

The net irrigation water requirement (IR_n) was calculated as:

$$IR_n = ET_c - P_{\text{eff}}$$

Observations on sprouting of cormels, growth parameters, viz. plant height, number of tillers, number of leaves, and leaf area were recorded. Soil moisture content was assessed gravimetrically at monthly interval. At harvest, yield and yield attributes, viz. cormel yield, average number and weight of cormels, cormel to corm ratio were recorded. Water productivity (WP) was worked out based on cormel yield and total water used by the crop (Heydari 2014):

$$WP \text{ (kg/m}^3\text{)} = \text{Cormel yield (kg/ha)} / \text{total water used (m)}$$

Crop water requirement (CWR) is taken as actual crop

evapotranspiration (ET_c) and assumed that there is no other loss. i.e. $CWR = ET_c$

The data from each season and over the years were pooled and analysed statistically following Indian NARS Statistical computing portal (SSCNARS) by applying the technique of Analysis of Variance (ANOVA) for RBD and multiple comparison of treatment means was done by least significant difference.

RESULTS AND DISCUSSION

Emergence of the crop: During all the seasons, the cormels started sprouting almost uniformly, irrespective of the treatments. The crop took 16–27 days for initiating sprouting. However, for 50% and 100% establishment of the crop, there was significant difference among the irrigation levels. Fifty per cent sprouting was achieved within 6–7 weeks in all the treatments. More than 80% sprouting was achieved within 9 weeks under all the drip irrigation levels. The control, furrow irrigation took 16 days for sprouting and 36 days for 50% sprouting, based on the pooled means.

Drip irrigation ensures smaller percentage of wetted surface to save water, which in turn would hasten sprouting with adequate moisture near the planted zone. Furrow irrigation also ensured comparable sprouting as the cormels were planted in pits and sufficient moisture was provided. Rainfed crop took 8 weeks to achieve 50% sprouting and even after 9 weeks, only 60–70% of the plants were established. This clearly indicates the requirement of sufficient soil moisture for sprouting of taro cormels, either through adequate rainfall or supplementary irrigation. Under dry land conditions, taro land races took about 70 days for emergence (Mare 2010) and slow and erratic emergence of taro failing to reach 50% emergence by 49 days after planting under different levels of drip irrigation is also reported (Mabhaudhi *et al.* 2013).

Soil moisture content: Pooled data analysis of three seasons showed significant difference in soil moisture content with levels of irrigation (LSD 2.92; $P < 0.05$). Drip irrigation assured soil moisture equivalent to 66–93% of field capacity at all the growth stages with all the irrigation levels (Fig 1). Furrow irrigation maintained 65–76% of the field capacity at various stages. Under rainfed conditions, soil moisture was almost 50–52% of field capacity. In potato, drip irrigation resulted in uniform soil moisture distribution and availability of water in the upper soil layers with a lower water volume compared to seepage irrigation (Joel *et al.* 2016).

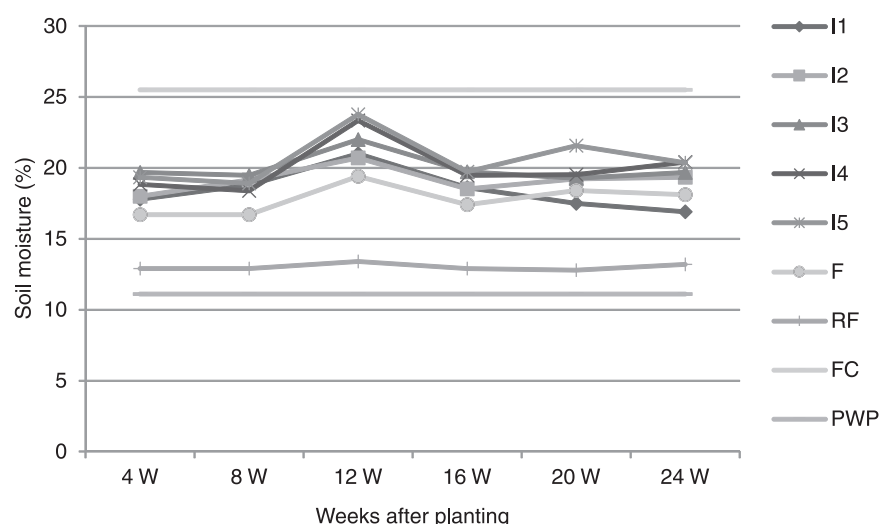


Fig 1 Variation in soil moisture under different irrigation levels.

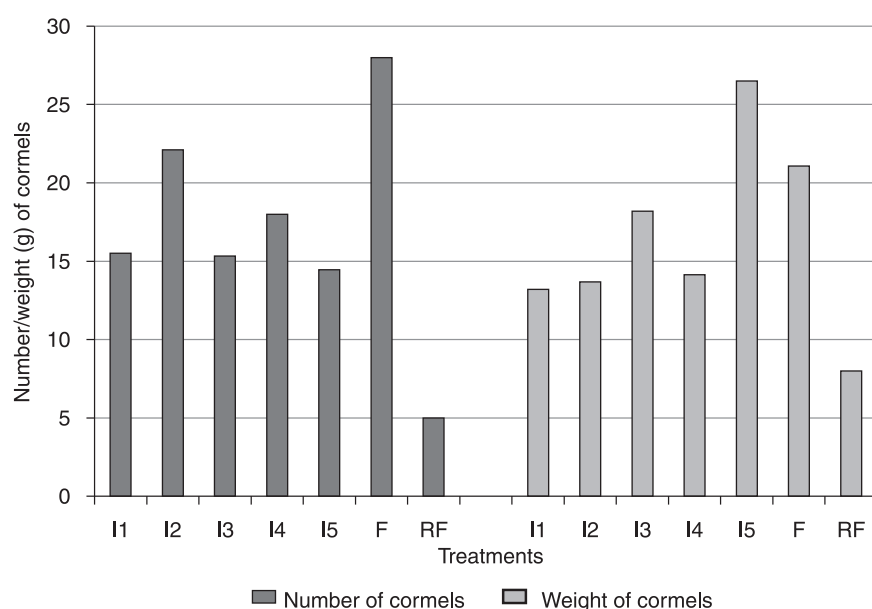


Fig 2 Number of cormels/plant and average weight of cormels under different treatments.

Crop growth attributes: Crop growth in terms of height, number of leaves and leaf area was more under higher levels of irrigation, and was statistically insignificant with lower levels. Under drip irrigation, values were high in 150% ET_c at 4 and 5 months after planting, however, at 6 months, number was high in furrow irrigation as the plants started senescence. However, growth was significantly reduced with rainfed crop, growing in summer. As the initial leaves started drying towards physiological maturity, decrease in plant height was noted in all the treatments. Water stress also resulted in reduced number of leaves subsequently as a result of premature senescence as reported by Mabhaudhi *et al.* (2013) in taro and Shu-han Zhang (2018) in potato. Number increased gradually and reached the peak at 5 months after planting depicting the importance of moisture almost throughout the lifecycle. Similarly, increase in leaf area index (LAI) values with sufficient soil moisture retention

is reported in taro by Manyasi *et al.* (2011). In potato, the most sensitive stages of water stress is reported as vegetative and tuberization stage (Cameron *et al.* 2021), and is having negative impact on the crop.

Yield attributes and yield: Pooled data analysis showed a decrease in number of cormels per plant with increase in irrigation levels (LSD- 4.86; $P < 0.05$). However, a corresponding increase was not noticed from I_1 to I_5 . Furrow irrigation produced maximum number of cormels per plant (28), followed by drip irrigation at 75% ET_c (22.1). Irrigation at 150% ET_c resulted in minimum number of cormels (14.4) (Fig 2).

On the contrary, average cormel weight was more with higher irrigation levels. Average cormel weight per plant ranged from 13.2–26.5 g among the irrigation treatments which showed significant difference among the values (LSD-5.16; $P < 0.05$). Average cormel weight was maximum with 150% ET_c and minimum with 50% ET_c . Similar production of larger tubers with fully irrigated crop and water shortage leading to more number of smaller tubers and less tuber yield is common in potato also (Fabeiro *et al.* 2001, Mattar *et al.* 2021).

Cormel yield of taro varied significantly with different treatments and seasons. During all the seasons, the highest cormel yield was recorded by 100% ET_c , which was not statistically different from other drip irrigation levels except 50% ET_c during first and second seasons. During third season, cormel yield under 100% ET_c (20.02 t/ha) was significantly higher than 50% and 75% ET_c . Furrow irrigation also performed equally good with respect to cormel yield in first season, but during second and third season, recorded significantly lesser values (Table 2).

Pooled analysis of three season data showed statistical difference in cormel yield only with treatments, not among the seasons. The cormel yield varied significantly among different drip irrigation levels. The yield varied from 13.18–21.08 t/ha under drip irrigation and the rainfed crop recorded 3.47 t/ha cormel yield. There was 45% increase in cormel yield under drip irrigation at 100% ET_c , compared to furrow irrigation. Cormel to corm ratio (mother corms used for planting) did not show any definite trend with increase in drip irrigation from 50% ET_c to 150% ET_c , however, the value was the highest at 100% ET_c .

Table 2 Taro cormel yield (t/ha) and cormel/corm ratio under different irrigation treatments

Treatment	2016–17	2017–18	2018–19	Pooled	Cormel/corm ratio (pooled)
50% ET _c	10.53	13.79	15.22	13.18	1.32
75% ET _c	19.49	17.08	16.56	17.71	1.35
100% ET _c	23.3	19.91	20.02	21.08	1.64
125% ET _c	21.67	16.94	17.78	18.80	1.42
150% ET _c	18.09	18.25	18.45	18.26	1.50
Furrow irrigation	19.15	15.25	9	14.47	1.39
Rainfed	3.88	3.63	2.9	3.47	1.06
LSD	3.706	3.178	3.051	3.005	0.252

Reduction in all the growth parameters, especially, number of leaves and leaf area would have resulted in less photosynthetic accumulation and source-sink partitioning, which ultimately suffered yield loss under 50% ET_c. Mother corm yield was more under lower levels of irrigation, but cormel yield was more with higher levels of drip irrigation, though the values were not statistically different under different irrigation levels, above 100% ET_c. More number of tillers produced under lower levels of irrigation resulted in more mother corm yield. It is evident from the values of cormel to corm ratio, which was the highest for 100% ET_c (1.64), but was comparable with 125% ET_c and 150% ET_c. 50% ET_c recorded the lowest value (1.32). Increased cormel yield in taro (Mabhaudhi *et al.* 2013) and tuber yield in potato (Badr *et al.* 2012) is reported with increase in amount of water applied. In the present study, the highest cormel yield was observed for 100% ET_c, beyond which the yield showed a declining trend. In potato, Camargo *et al.* (2015) found 80% of irrigation showed statistically similar yields to 100 and 120% of irrigation.

In all the seasons, the cormel yield was above the world average of 5.39 t/ha and above the Asian average of 16.5 t/ha, except at 50% ET_c. Low land production systems and the upland production supplemented with irrigation is a must for realising good yield in taro. Irrigation would be beneficial for taro production in summer months as well as low rainfall areas as reported in potato where physiological traits of stomatal conductance and chlorophyll content affecting carbon assimilation, partitioning and eventual tuber yield due to water deficit stress is reported (Ernest *et al.* 2020). In field experiment in taro, 50% ET_c recorded the highest reduction in terms of vegetative growth, yield characteristics, yield and bio constituents compared to 75% and 100% of ET_c level (Abd El Aal *et al.* 2019). In yet another study, *in situ* moisture conservation methods influenced soil water availability and subsequent vegetative growth and yield of taro under upland conditions (Manyatsi *et al.* 2011).

Water productivity of taro ranged from 1.9–3.9 kg/m³ at different levels of irrigation, i.e. 150% ET_c to 50% ET_c. Drip irrigation at 100% ET_c recorded 45% increase in cormel yield and 2.1 times the water productivity than the furrow irrigation. WUE increases either through increasing yield

or decreasing water-use. In taro, Mabhaudhi *et al.* (2013) reported less water use efficiency values of 0.22–0.24 kg/m³ with irrigation levels of 30, 60 and 100% ET_c, mainly because the land races tried were adapted to wet land conditions. Muktakeshi variety used in the present study is well adapted to upland conditions, and hence responded well to irrigation and lower level of irrigation led to higher water productivity. In earlier studies with drip irrigation in taro at 10, 20, 30, 40 and 50% soil moisture depletion resulted in greater water use efficiency values of 3.87 and 3.77 kg/m³ under 10 and 20% depletion than higher levels of depletion (Vieira *et al.* 2018).

Crop water requirement, net irrigation requirement and irrigation scheduling: Crop water requirements (CWR) encompass the total amount of water used in evapotranspiration. During the experimental period, the daily evaporation values were less during the initial months due to withdrawal of winter and from January onwards, it started increasing, reaching peak during February, March with onset of summer season and then it started declining from April. Of the five levels of crop evapotranspiration (ET_c) studied, 100% ET_c was found optimum, as there was no corresponding increase in taro cormel yield with irrigation more than 100% ET_c. Hence, the water requirement or the gross irrigation requirement (IR_g) was estimated at 619, 628 and 608 mm during the season I, II, III respectively, with an average value of 618 mm. Positive response of drip fertigated potato from 60–100% ET_c is observed by Shaohui Zhang *et al.* (2022). An effective rainfall (P_{eff}) of 96, 126, and 120 mm respectively was received during the three cropping seasons. Accordingly the net irrigation requirement (IR_n) was worked out to be 523, 502 and 488 mm, respectively during 2016–17, 2017–18 and 2018–19.

The water requirement was calculated following the pan evaporimeter method, which is the one of the best methods to calculate E₀ comparable with FAO-Penman-Monteith modified equation (Stan and Neculau 2015). It is assumed that the crop water requirement is fully met and ET_c is equal to the CWR. This is the optimal water requirement of taro which corresponds to an optimal cormel yield and water productivity under the humid tropical conditions of Kerala, India, with no significant yield reduction. This information can be used to plan taro cultivation and allocation of irrigation water to farm levels during summer months. The requirement varies with crop stages as 68–72 mm/month during first two months, 118–126 mm during 3–5 months, 110–112 mm during 6th month. Accordingly, water managers can plan water allocation for other crops or can increase the area to enhance the water productivity through drip irrigation as reported in cassava (Raji *et al.* 2020).

The present study focused on estimating the water requirement and developing optimal irrigation schedule for taro when grown in uplands of tropical humid conditions of India. From the field studies conducted over three seasons, drip irrigation @ET_c 100% is found optimum for maximising the cormel yield and water use efficiency. The optimum water requirement of upland taro was observed as 618 mm for

a period of six months. In the era of agriculture becoming both the cause and victim of water scarcity, the information from the study will help the farmers and water managers to judiciously use irrigation water for taro and other crops grown during summer season and to increase the area under taro for achieving maximum yield and water productivity.

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