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Water smart technologies for enhancing productivity, profitability and energy use efficiency of taro (*Colocasia esculenta*)

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ABSTRACT

The present experiment was conducted during 2019–2020 and 2020–2021 at ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala to compare the effects of different irrigation water saving techniques on productivity, water use efficiency, energy use efficiency and profitability of taro [*Colocasia esculenta* (L.) Schott]. The improved variety of taro, 'Muktakeshi' was used in the experiment under randomized block design (RBD). The crop was raised under upland conditions with drip irrigation and irrigated at the rate of 50% crop evapotranspiration (ET_c) along with water saving treatments, viz. mulching using porous ground cover mat (T_1), bio-mulching (T_2), coir pith mulching (T_3), anti-transpirant spray on foliage (T_4), soil application of pusa hydrogel (T_5) and synthetic super absorbent polymer (T_6). Drip irrigation at 100% ETc and furrow irrigation were kept for comparison. Drip irrigation at 50% ET_c along with mulching using porous ground cover mat resulted in highest taro cormel yield, which was 32.2% higher than irrigation at 100% ET_c. Use of porous ground cover mat also recorded 60% increase in water productivity, 20% higher energy use efficiency, 37% higher energy productivity and 37% increase in net income, in addition to saving in 50% irrigation water. Drip irrigation at 50% ET_c with ground cover mat also recorded 63.8% increase in cormel yield, 3.8 times the water productivity and 100% saving in irrigation water, compared to furrow irrigation. Taro, being a highly water sensitive crop, suitable water saving measures are necessary to ensure its sustainable yield per drop of water, especially in the era of climate change. The results suggested the suitability of porous ground cover mat as a water smart technology for upland taro production in the tropical regions.

Keywords: Energy use efficiency, Porous ground cover mat, Taro, Water productivity, Water saving

Taro [*Colocasia esculenta* (L.) Schott] is widely cultivated, mostly as a staple or subsistence crop, throughout the humid tropics and subtropics and in many warmer regions of the temperate zone. The average productivity of taro is the highest in Asia (16.12 t/ha) and the lowest in Africa (5.98 t/ha) and the world average productivity is reported as 6.91 t/ha (FAOSTAT 2021). In India, taro is grown as sole crop or as intercrop or on a limited scale as homestead crop, but consumed as a food crop or routine vegetable. The crop comes up well in tropical low lands with 2000 mm average annual rainfall or even less, if it is evenly distributed during the growth period. When the crop is raised under rainfed conditions of uplands, supplementary irrigation is required during dry spell for attaining reasonable yields. Taro is highly moisture sensitive and is reported that taro production may decrease upto 40% in the coming 30 years with drought constraints due to climate change (Gananca *et al.* 2018).Water scarcity can cause upto 90% yield loss or total crop failure (Ravi *et al.* 2022).

Most of the varieties and land races of taro are season insensitive and can be grown in any part of the year, provided sufficient soil moisture is assured. The optimum water requirement of upland taro under humid tropical conditions of India was observed as 618 mm for a period of six months by drip irrigation method (Sunitha *et al.* 2022). Under furrow irrigation, it requires 1.5 to 2 times the quantity of water. Water shortage is experienced during summer and post monsoon periods and also climate change is expected to cause scarcity of irrigation water in future, which can influence the production of tuber crops due to the higher demand of water for other major crops (Sunitha *et al.* 2020). Hence, every effort should be taken to minimise the use of irrigation water to achieve maximum water productivity and water use efficiency in farming. In the present study, an attempt was made to compare different water saving technologies for reducing consumptive use of taro and attaining optimum yield and enhancing water and energy use efficiencies.

MATERIALS AND METHODS

The present experiment was conducted during 2019–2020 and 2020–2021 at ICAR-Central Tuber Crops

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Research Institute, Thiruvananthapuram, Kerala. Soil of the experimental site was sandy clay loam having 63% sand, 6% silt and 31% clay content. Soil was acidic (*p*H 5.06), high in organic carbon (1.3%), low in available nitrogen (230 kg/ha), high in available phosphorus (112 kg/ha) and medium in available potassium (210 kg/ha). Daily evaporation data were collected from a Class A open pan evaporimeter. The experiment was laid out in randomized block design (RBD), providing drip irrigation at 50% crop evapotranspiration (ET_c) along with six water saving treatments at planting, viz. soil mulching with porous ground cover mat (plastic sheets of 120 GSM thickness, having perforations) (T_1), bio-mulching (locally available crop residues) (T_2), mulching with coir pith @100 g/plant (T_3), anti-transpirant (kaolinite 0.5%) spray on foliage at monthly intervals (T_4), soil application of pusa hydrogel @0.5 g/plant (T_5), synthetic super absorbent polymer @ 0.5g/plant (T_6). Drip irrigation at 50% (T_7) and 100% ET_c (T_8), and furrow irrigation (T_9) were included in the study, for comparison of different water saving treatments and working out water use efficiencies. All the treatments were imposed at the time of planting taro cormels, except, anti-transpirant which was sprayed on foliage after sprouting cormels and again after two months. Improved variety of taro, 'Muktakeshi' was used for planting at a spacing of 60 cm × 45 cm. As per the package of practices recommended by ICAR-Central Tuber Crops Research Institute, farm yard manure @12 t/ha and 25 kg P as basal and 80 kg N and 100 kg K were applied in three spilt doses. The crop was planted during November and harvested during May in both the seasons. Crop evapotranspiration (ETc) was calculated based on reference evapotranspiration (ET_0) and the crop coefficient. Crop coefficient values of 1.05 for 2 months ($Kc_{\ initial}$), 1.15 for 3 months ($Kc_{\ mid}$) and 1.1 for 1 month ($Kc_{\ late}$) were taken at different growth stages of the crop (Fares 2008). Fifty per cent of ET_c was given through drip irrigation for treatments T_1 to T_7 during non-rainy days. Furrow irrigation was given twice a week @5 mm/day.

At harvest, yield and yield attributes, viz. mother corm yield, cormel yield, total yield (mother corm + cormels), average number of cormels/plant and cormel to corm ratio were recorded. Water productivity was worked out based on cormel yield and total water used (Heydari 2014) under each treatment. Energy equivalents of various inputs and outputs as per treatments were computed (Devasenapathy *et al.* 2009) and energy efficiency indices were worked out (Dazhong and Pimental 1984). Economic indices, viz. cost of cultivation, gross income, net income and benefit: cost ratio, profitability and productivity/ha/day were also worked out based on the cost of various inputs, outputs and labour costs, at the end of the seasons. Data collected over the two seasons were subjected to statistical analysis for the individual years as well as the combined analysis. Analysis of Variance (ANOVA) was performed using the GRAPES (Gopinath *et al.* 2020).

RESULTS AND DISCUSSION

Yield attributes and yield: There was significant variation in number of cormels/plant between the treatments only during the first season and also in the combined analysis, due to season × treatment interaction. Number of cormels ranged from 12.11 in T_6 to 16.0 in T_2 and T_8 (based on combined analysis. Weight of cormels/plant varied with irrigation treatments during both the seasons as well as in combined data analysis. Among water saving treatments, cormel weight was the highest in treatment where ground cover mat was used (860 g) and the minimum was in T_4, where antitranspirant was used (550 g). Cormel size decreased with increase in number of cormels/plant indicating an inverse relationship between number of cormels/plant and mean cormel weight. Mean cormel weight was the highest in T_6, where synthetic polymer was used (57.09 g), closely followed by ground cover mat (56.87 g).

During both the seasons, cormel to corm ratio showed statistical difference due to treatments. Combined analysis of data over seasons showed that number and weight of mother corms were the lowest in T_1, where ground cover mat was used and highest in T_7, where no water saving measures were followed. The highest cormel to corm ratio was recorded in T_1, with porous ground cover mat (4.85) and the lowest in T_7 (2.52). Drip irrigation @100% ET_c recorded statistically comparable values with T_1, for cormel yield/plant (750 g) but varied significantly with respect to mean cormel weight (49.77 g). Furrow irrigation recorded 660 g cormel yield/plant with a cormel to corm ratio of 3.49. Mother corms are used as planting materials and cormels which are more in number, are used for food purpose as well as for planting. More mother corm yield usually results in less cormel yield and a high cormel to corm ratio indicates higher cormel yield and the efficiency of treatments. Higher mother corm yield and a low cormel to corm ratio were reported under sub optimal level of irrigation in taro, compared to optimum irrigation (Sunitha *et al.* 2022). Busari *et al.* (2019) also reported that soil water regimes controlled by irrigation techniques significantly influenced corm yield components, such as biomass, corm mass, corm number, corm size, and harvest index.

The treatment with irrigation at 50% ET_c along with ground cover mat (T_1) recorded the highest cormel yield during both the seasons (29.4 and 27.94 t/ha, respectively) Biomulching recorded statistically on par yield with the highest yield during first season. During second season, T_1 was superior over all other treatments, in terms of cormel yield. Better growth of taro under T_1 resulted in enhanced photosynthesis, proper translocation of starch and thus the yield as reported in taro (Gananca *et al.* 2018, Boampong *et al.* 2020).

There was also significant season × treatment interaction, with combined analysis T_1 was the best treatment followed by T_2. T_7 where drip irrigation was given @50% ETc without any water saving measures, recorded the lowest cormel yield, on par with T_3 (Table 1). Water deficit stress leads to lesser water use efficiency, nutrient use efficiency and photosynthetic efficiency, which in turn reduces total biomass yield. Inhibition of starch accumulation with drought

Table 1 Mother corm and cormel yield of taro under different irrigation treatments (Combined means)

Treatment	Corm yield (t/ha)	Cormel yield (t/ha)
T_1	9.54 ± 2.19	28.67^{a} ± 2.26
T_2	7.74 ± 2.64	23.67^{ab} ± 6.14
T_3	10.35 ± 2.97	16.63^{c} ± 3.63
T_4	9.57 ± 3.1	17.18^{bc} ± 2.96
T_5	8.76 ± 2.06	19.98^{bc} ± 2.03
T_6	7.52 ± 2.41	19.22^{bc} ± 2.64
T_7	6.58 ± 4.21	16.20^{c} ± 3.03
T_8	9.61 ± 3.88	21.69^{bc} ± 2.75
T_9	9.23 ± 3.5	17.50^{bc}± 2.32
CD ($p \leq 0.05$)	NS	6.818

Treatment details are given under Materials and Methods.

stress is reported in taro (Erjin *et al.* 2024). The foremost objective of any kind of mulching is soil moisture retention. Positive effects of mulching by way of reducing soil erosion, evaporation, weed growth, maintaining soil fertility and improving crop yield and quality are reported in many crops (Azad *et al.* 2015, Nachimuthu *et al.* 2017). Conversely, mother corm yield was the highest with application of coir pith during first season and with foliar application of anti-transpirant during second season. Combined data analysis of two seasons clearly indicated positive effect of ground cover mat, which was 21.6 to 44.3% higher than other water saving practices tried. Irrigation at 50% ET_c and 100% ET_c without any water saving practices resulted in 76.9% and 32.2% yield reduction respectively, compared to 50% irrigation with ground cover mat. Ground cover mulching and bio-mulching proved superior over irrigation at 100% ET_c. T_1 (ground cover mat) and T_2 (bio-mulching) were 63.8 and 35.3% superior in terms of cormel yield than furrow irrigation, thereby indicating a good amount of water saving for taro cultivation with proper soil cover. During second season, difference in yield under biomulching may be attributed to minor variations in nutrient addition through crop residues. Organic mulching materials including cover crop mulches, in addition to moisture conservation and weed control aid in soil fertility improvement and better penetration of water (Kosterna 2014, Lordan *et al.* 2015, Sidath *et al.* 2022). Also, all water saving techniques were found on par with irrigation at 100% ET_c, emphasizing the importance of suitable water saving measures to reduce the crop water use in taro. Enhanced growth and corm nutrition in taro with rice husk mulching compared to peanut hull and sugarcane bagasse both in uplands and low lands is reported (Kai-Wei *et al.* 2021).

Water productivity: Water requirement during first season and second season under 100% ETc were 665 and 672 mm and under 50% ETc, 332 and 336 mm, respectively. Furrow irrigation was given irrigation at the rate of 835 and 830 mm. Water productivity based on cormel yield as well as total yield (mother corm + cormel) were the highest for T_1 during both seasons. Combined analysis of data of two seasons indicated that there was no variation in water productivity between seasons, but only with treatments as well as interaction of season × treatments (Fig. 1). The ratio ranged from 5.0–8.6 kg/m^3 in terms of cormel yield and 8.0– 11.4 kg/m^3 in terms of total yield, under different water saving treatments. The water productivity was highest when porous ground cover mat was used for moisture retention. Irrigation at 100% ETc, recorded a water productivity of 3.1 kg/m^3 and 4.7 kg/m^{3}in terms of cormel and total yield respectively, which was almost 60% less productive compared to those with water smart techniques of ground cover mat, which also resulted in a water saving of 50%. In general, water productivity was more when suitable water conserving measures were undertaken, either by porous ground cover mat, bio-mulching or application of absorbent gel in soil. Irrigation at 100% ETc, could not result in a corresponding increase in water productivity, compared to 50% irrigation, as there was no corresponding increase in yield with extra irrigation water. This indicates the wastage of water for non-productive uses when the root zone is exposed, compared to the effective use of water under other techniques. The reduced unproductive loss of water along with ideal agronomic conditions resulted in more water productivity under 50% irrigation, which was 44–50% higher than that under 100% irrigation. Similar reports of well managed drip system is established in many other crops (Chouhan *et al.* 2014, Jha *et al.* 2017). Furrow irrigation recorded the lowest value (2.3 and 3.2 kg/m^3 respectively), clearly indicating the wastage of irrigation

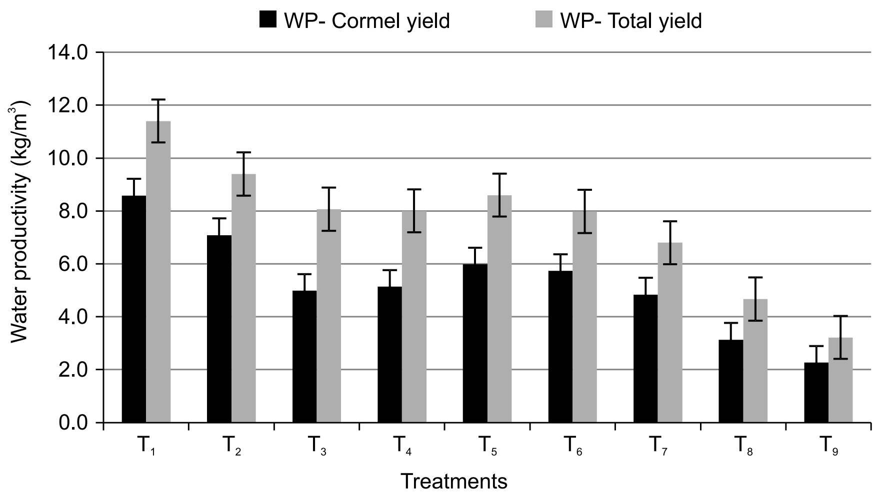

Fig. 1 Effects of treatments on water productivity of taro based on cormel yield and total yield (cormel + mother corm).
Treatment details are given under Materials and Methods.

water. Higher water productivity is an important indicator in improved water management system which shows the efficiency of irrigation, that too with effective utilization of soil moisture for a prolonged time interval of crop growth in the present study. Covering soil with mulching materials improves water use efficiency and water productivity as reported in other crops (Shen *et al.* 2022, Yisfa *et al.* 2023).

Energy efficiency indices: Energy value of various inputs including human labour (men and women) for field preparation, planting, intercultural operations and harvesting and inputs applied, were uniform under all the treatments, except irrigation. The value is computed as 14,513 MJ/ha. Additional energy required for drip irrigation and imposing water saving technologies differed between the treatments and hence the total input energy was calculated separately. Total input energy ranged from 14,795–19,488 MJ/ha in different treatments (Table 2). Agricultural sector consumes a significant amount of energy either directly or indirectly and will continue to increase because the only chance of producers to increase total output will be using more inputs as there is no chance to expand the size of arable lands.

The output energy computed from the total yield ranged from 96,246–1,37,538 MJ. The data showed that porous ground cover mat was superior in terms of all energy efficiency indices (Table 2) and recorded maximum net energy (12,056 MJ), energy use efficiency (7.09), energy productivity (2.25 kg/MJ), and energy output efficiency (654.9 MJ/day) except energy intensity which was the highest for furrow irrigation (0.43 MJ/₹). Drip irrigation at ETc 50% along with ground cover mat resulted in 20% higher energy use efficiency and 37% higher energy productivity than ETc 100% irrigation, clearly depicting the possible energy saving through water smart management practices in taro.

Soil moisture conservation using porous ground cover mat produced significantly higher yield and hence total output energy was higher. Consequently high energy use efficiency and energy productivity were recorded. Ratio of the energy output of production to input energy is termed as energy ratio or energy efficiency and is used to measure energy efficiency in agricultural and food systems (Hadi 2006). In this study, input energy consumption was comparatively high under drip irrigation, however, more corm and cormel yield and high energy value of tubers resulted in high energy output. Energy use and higher energy efficiency values indicate sustainability of agricultural practices to enhance productivity (Suha *et al.* 2019). Yadav *et al.* (2020) observed that mulching boosted energy use efficiency and economic productivity in upland rice production over non mulching.

Economic indices: Economic indices were worked out based on values of the cost of inputs and outputs, prevailed during the season. Of the total cost of cultivation, almost 60% was for labour charges and 40%, input cost. Cost including fixed and variable charges for layout of drip irrigation facilities and treatment costs for water saving, varied from ₹2,67,450 under irrigation at 50% ETc without any water saving measures to ₹ 3,29,850 under irrigation at 50% ETc with porous ground cover mat. However, porous ground cover used is of 120 GSM and can be reused for 4–5 seasons, with proper handling. Only cormel yield was considered for working out gross income, as the corms are used only for planting at field level. Economic analysis revealed that treatment where porous ground cover mat was used, recorded the highest net return (₹11,03,650) and B:C ratio (4.34) based on combined analysis (Table 3). T_1 with ground cover mat recorded 36.4% increase in net income compared to irrigation @ 100% ETc, followed by biomulching which resulted in 12.2% increase in net income. Net income from T_1, T_2 and T_8 were on par as per combined analysis of data. B:C ratios were almost close under T_1 (4.34) and T_2 (4.29), as cost of cultivation was more under T_1, though cormel yield (21%) and net income (11%) were higher under T_1, compared to T_2. These were also on par with other treatments except, T_3, T_4 and T_7.

The productivity/ha/day and the profitability/ha/day were also found to be highest with ground cover

Table 2 Energy efficiency indices of upland taro under different water saving techniques

Treatment	Total energy input (× 10^3 MJ/ha)	Energy ratio	Energy productivity (Kg/MJ)	Energy use efficiency	Energy intensity (MJ/ ₹)	Energy output efficiency (× 10^3 MJ/ha/day)
T_1	16.98^b	8.1^a	2.25^a	7.09^a	0.42	6.5^a
T_2	16.94^b	6.7^{ab}	1.85^{ab}	6.67^{ab}	0.41	5.4^{ab}
T_3	19.48^a	5^b	1.38^b	4.98^b	0.32	4.6^b
T_4	16.96^b	5.7^b	1.58^b	5.68^b	0.35	4.6^b
T_5	16.99^b	6.1^{ab}	1.69^{ab}	6.09^{ab}	0.34	4.9^{ab}
T_6	16.99^b	5.7^b	1.57^b	5.66^b	0.34	4.6^b
T_7	16.82^b	4.9^b	1.35^b	4.87^b	0.31	3.9^b
T_8	19.13^a	5.9^b	1.64^b	5.89^b	0.41	5.4^{ab}
T_9	19.18^a	6.5^b	1.81^b	6.5^b	0.43	4.6^b
CD ($p \leq 0.05$)	2.42	2.092	0.58	2.092	NS	0.201

Treatment details are given under Materials and Methods.

Table 3 Economic indices of upland taro cultivation under different water saving techniques

Treatment	Cost of inputs (₹)	Net income (₹)	B:C ratio	Productivity/ ha/day	Profit-ability/ ha/day
T_1	329850	1103650	4.34	136.5	5255.5
T_2	275450	908050	4.29	113.0	4324.0
T_3	307650	523850	2.70	79.0	2494.5
T_4	275850	582900	3.11	82.0	2775.5
T_5	307650	691350	3.24	95.5	3292.0
T_6	280650	680100	3.42	91.5	3238.5
T_7	267450	542800	3.02	77.5	2584.5
T_8	275450	809050	3.93	103.5	3853.0
T_9	227400	650800	3.80	83.0	3099.0
CD ($p\leq 0.05$)	217.4	296400	1.11	32.542	1612.28

Treatment details are given under Materials and Methods.

mat followed by bio-mulching and were comparable with irrigation at 100% ETc. Productivity ranged from 77 kg/ha/day (T_7) to 137 kg/ha/day (T_1). T_1 significantly differed from other treatments in terms of productivity, except T_2. Other water saving technologies were not found economic, compared to irrigation at 100% ETc in terms of profitability/ha/day also. Based on the economic analysis, drip irrigation at 50% ETc along with ground cover mulching or bio-mulching were found to be economic, in comparison to drip irrigation at 100% ETc.

Mulching may incur a higher cost initially, but the environmental benefits associated with proper mulching can have long term economic gains in crop production (Demo and Asefa 2024).

The present study focused on reducing the water requirement of taro by way of water saving technologies when grown in uplands of tropical conditions of India. From the field studies conducted over two seasons, drip irrigation @50% ET_c along with porous ground cover mat is found promising for maximising the cormel yield, water and energy use efficiency and profitability. Taro being a promising choice for food security in developing countries, judicious and sustainable use of resources, especially 'water', predicted as the most costliest input in farming, could be ensured based on the findings.

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