Water smart technologies for irrigation water management of elephant foot yam in tropical zones of India

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ABSTRACT

Water is the most crucial input in agriculture and declared to become the most scarce input in the near future, hence, judicious management of irrigation water is the need of the hour in tropical countries. In this study, a comparison of different water smart technologies, namely, porous ground cover mat, super absorbent polymer, partial root zone drying technique, bio mulching and foliar application of antitranspirant was made for enhancing water productivity in tuber crops using elephant foot yam as the test crop. Elephant foot yam (*Amorphophallus paeoniifolius*) is an important tropical tuber crop in India, and has attained commercial status in many states under assured irrigation. Mulching with ground cover mat and soil application of cassava starch-based super absorbent polymer recorded higher water productivity, reduced irrigation water requirement to 50% and enhanced the corm yield of elephant foot yam by 8–12% and energy use efficiency by 24–28% as compared to 100% irrigation. In the context of expected climate change and water scarcity, water smart technologies such as ground cover mats and super absorbent polymers would help in the cultivation of the tuber crop elephant foot yam with less irrigation, without adversely affecting the corm yield under humid tropical situations.

Key words | elephant foot yam, energy use efficiency, ground cover mats, super absorbent polymer, water productivity, water smart technology

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INTRODUCTION

It is a fact that the future of agriculture-based economies are most vulnerable with respect to the anticipated climate change effects. More than five billion people could suffer water shortages by 2050 due to climate change, increased demand and polluted supplies, according to a UN report on the state of global water (Watts 2018). The key for change will be agriculture, the biggest source of water consumption and pollution, which provides food and nutritional security, as well as inputs to industries contributing towards national economies. The report calls for 'conservation agriculture', which would make greater use of rainwater with minimum irrigation. To cope with the water shortage expected in the near future, the water requirement of each crop should be worked out and irrigation designed accordingly, and it is necessary to adopt suitable water-saving measures also.

Conventional water conserving measures mainly include efficient irrigation systems, mulching, antitranspirants, organic farming and conservation agriculture. The role of organic mulching in lowering soil temperature and reducing water requirement of crops has been thoroughly investigated (Ranjan *et al.* 2017). Antitranspirants are substances applied on leaves to reduce the transpiration loss, thereby the water loss from plants. Application of

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antitranspirants in improving leaf water status and yield in different crops has been reported by earlier studies (Srinivasa Rao 1985; Faralli *et al.* 2016). The development of novel water saving irrigation techniques such as partial root zone drying (PRD) technique represents an option to increase water use efficiency and is found to be promising in field crops, fruit trees, tomato and potato. PRD technique resulted in 61% increase in irrigation water use efficiency in potato without significant reduction in tuber yield (Shahnazari *et al.* 2008). The modern water saving techniques also include the use of ground cover mats and soil application of super absorbent polymers.

Amorphophallus paeoniifolius (Dennst.) Nicolson, commonly known as elephant foot yam, is considered as an important tropical tuber crop in India and is gaining popularity not only as a food security crop, but also as a cash crop due to its production potential and preference as a starchy vegetable having high nutritive and medicinal values. Its cultivation is mainly concentrated in India, Philippines, Indonesia, Sri Lanka and South East Asia. It is extensively grown throughout North India, North Eastern India, Konkan region of Maharashtra, Gujarat, Upper Gangetic plains and in peninsular India. It is basically an underground stem tuber and is consumed mostly as a cooked vegetable. It has a higher dry matter production capability per unit area than most other vegetables (Kundu *et al.* 1998). Until recent times, the crop was cultivated under rainfed conditions, like other tuber crops utilising the monsoon showers. Presently, its cultivation is attempted in non-traditional areas also due to its perennial demand as well as the attractive prices, which quite often necessitates assured irrigation in many places. In states like Andhra Pradesh, Odisha, Bihar and West Bengal, where the crop is grown on a commercial basis, farmers resort to flood irrigation (Nedunchezhiyan *et al.* 2008). Recently, micro-irrigation has also been adopted by commercial farmers, but without any rationale. Studies carried out in elephant foot yam revealed that drip irrigation results in more corm yield than flood irrigation, and irrigation given during 13–24 weeks after planting corms, coinciding with corm development phase, is more critical than the initial stages of establishment of the crop (Sunitha *et al.* 2018).

In the present study, an attempt was made to compare the different water smart technologies, namely, PRD technique, use of ground cover mats, bio mulching, application of super absorbent polymer and antitranspirant for reducing the consumptive use of elephant foot yam, for attaining optimum yield and enhancing water and energy use efficiencies.

METHODS

Field experiments were conducted at ICAR – Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, India during two growing seasons, 2015 and 2016. The location lies between 8.54° north latitude and 76.91° east longitude and comes under the humid tropical climatic zones of India with an altitude of 50 m above mean sea level (Figure 1). The soil in the experimental area was deep, well drained, sandy clay loam, moderately acidic in reaction (Table 1). The maximum temperature during the season varied between 30 and 34 °C and the minimum temperature 22 and 25 °C, having a relative humidity of 64–81%.

The trial was laid out of elephant foot yam with drip irrigation at the rate of 50% cumulative pan evaporation (CPE) in combination with five different sets of water

Figure 1 | Location map of the experimental site.

Table 1 | Physical and chemical properties of the soil (top 30 cm) in the experimental plot

Physical						Chemical					
									Available nutrients (kg/ha)		
Sand (%)	Silt (%)	Clay (%)	FC (%)	WP (%)	BD (g/cc)	pH	EC (ds/m)	OC (%)	N	P	K
69	7	24	14.5	5.8	1.3	5.2	0.08	0.6	365	55	160

FC, field capacity; WP, wilting point; BD, bulk density; EC, electrical conductivity; OC, organic carbon; N, nitrogen; P, phosphorus; K, potassium.

saving techniques in a randomised block design (RBD). The water saving techniques included PRD technique (T1), bio mulching (T2), plastic porous ground cover mulching (T3), foliar application of antitranspirant, kaolinite 0.5% (T4), soil application of cassava starch-based super absorbent polymer (SAP) at 0.5 g/plant (T5). Drip irrigation at 100% CPE (T6) and a rainfed crop (T7) were kept as controls for comparison. The leading variety of *Amorphophallus* in India, 'Gajendra' was used for the study by planting 500 g each of the seed corms uniformly at a spacing of 90 × 90 cm. Planting was undertaken during the first week of March, in both years. Drip irrigation was given once in 2 days up to six months. The quantity of irrigation was fixed based on the daily open pan evaporation and pan factor, in mm, and irrigation was given at 50% CPE. Crop factor was taken into account at different stages of growth as suggested by Allen & Pruitt (1991).

Observations on sprouting of corms and soil moisture status of top soil were recorded by gravimetric method, at monthly intervals. Biometric observations such as height of plants, height of pseudo stem, girth of pseudo stem, number of leaves, number, length and breadth of leaflets and canopy spread were recorded at three and five months after planting (MAP). Leaf area was calculated according to Ravi *et al.* (2010). Destructive sampling was done at five MAP to assess the biomass production under each treatment. The crop was harvested after ten months, during December, and corm yield per ha was estimated. Based on the corm yield and the total water used, water productivity was worked out (Heydari 2014). Corm bulking efficiency was also worked out based on the increase in corm yield compared to the initial corm size of 500 g planted. Energy equivalents of various inputs and outputs were computed (Singh & Mittal 1992; Devasenapathy *et al.* 2009) and energy efficiency indices were worked out as per Dazhong & Pimental (1984). All the data pertaining to two years were pooled and analysed using Indian NARS (National Agricultural Research System) Statistical Computing Portal, Indian Agricultural Statistics Research Institute (IASRI) 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

Sprouting of planted corms

There was variation in the pattern of sprouting of planted corms with different treatments. The corms took 19–56 days for initiating sprouting while 50% sprouting was achieved within 37–61 days and 100% sprouting within 56–73 days. The rainfed control took 56 days for first sprouting. Full sprouting was achieved earlier under 50% irrigation along with porous ground cover mulching and bio mulching (56 days) followed by 100% irrigation (64 days). PRD technique and use of antitranspirant took 56 days for 50% sprouting and 67–73 days for full sprouting. Rainfed crop took 69–73 days for 100% germination. In elephant foot yam, sprouting is highly influenced by the soil moisture availability. Although the normal planting season is February to March, the crop starts sprouting with pre-monsoon showers during April–May or with the commencement of the south west monsoon in June under rainfed conditions. About 75–80% of the sprouting of planted corms and development of first leaf occurs during two to three months and this crop growth period requires adequate soil moisture through irrigation or rainfall (Ravi *et al.* 2011). In cocoyam also, plastic-film mulching enhanced sprouting of corms and reduced the number of days required to achieve 60–80% emergence by 7 days, probably because of the higher temperature and superior volumetric moisture characteristics (Anikwe *et al.* 2007). Similar effects of early emergence of seedlings by plastic film-mulched treatments than unmulched plots in spring wheat has been reported (Li *et al.* 1999). Early sprouting observed in the present study under drip irrigation along with suitable conservation of moisture, is due mainly to the availability of enough moisture exactly in the planting zone. Moreover, 50% irrigation with mulching retained more soil moisture than 100% irrigation, and enhanced the sprouting to more than 50% within 37–40 days. Early sprouting and establishment of the crop with micro-irrigation compared to surface irrigation is reported in *Amorphophallus* (Sunitha *et al.* 2018).

Crop growth

The morphological observations recorded during the two years at three and five MAP as well as pooled data analysis revealed that crop growth was significantly affected only during the initial stage, i.e., 3 MAP. Maximum plant height as well as psuedostem height was recorded by 50% irrigation with antitranspirant spray, whereas girth of stem and canopy spread were maximum with 100% irrigation. The number of leaves was statistically the same with all the treatments including control. Leaf area index values ranged from 1.9 to 3.3 and rainfed crop recorded the lowest value of 1.5 at 3 MAP. There was no significant difference in growth attributes at 5 MAP except plant height and the treatment with antitranspirant retained maximum height at 5 MAP also. The data suggest that once the corm has sprouted and the canopy is established, the crop retains its rate of growth for a further period up to five to six months, until senescence starts. Once the sprouting is initiated, further leaf development is completed within 30 days provided sufficient soil moisture is available (Ravi *et al.* 2011). Hence, early sprouting with irrigation resulted in more canopy spread during initial months than rainfed crop.

Similarly, the number of leaves was uniform under different treatments both at 3 and 5 MAP. Although the difference was insignificant, 50% irrigation through PRD technique recorded more leaves at 3 MAP and 100% irrigation at 5 MAP. Rainfed crop recorded fewer number of leaves at both stages. Consequently, leaf area index also showed the same trend, but the difference was significant only at 3 MAP. The number and size of leaves which develop during the growing season is dependent on the quantity of planting material used, soil fertility, soil moisture and developing corm age (Das *et al.* 1997). In the present study, 500 g corms were used as planting material with uniform nutrition except for water saving treatments. Irrigation and conservation of soil moisture during the initial stages produced a greater number of leaves by triggering the cormal buds, compared to rainfed crop. However, a significant difference was not observed accordingly in the leaf area or leaf area index during later stages, since the canopy spread and number of leaflets remained almost uniform.

Biomass production and partitioning

Biomass yield per plant was estimated based on the below ground root and corm dry matter, and the above ground dry matter, which was mainly the leaf and petiole at peak growth stage of the crop, i.e., at 5 MAP. There was no significant difference in biomass production of plants among the irrigation treatments. However, the control, rainfed crop was significantly inferior with respect to total dry matter yield per plant. A similar trend was observed in biomass partitioning also. Rainfed crop recorded the minimum tuber, leaf and pseudostem dry matter. Dry matter partitioning efficiency was also found to be greater with irrigation and water saving techniques (Figure 2). The optimum moisture level together with ideal soil conditions might have contributed to the greater growth rate of the plants and subsequent biomass production. Biomass contribution for tuber bulking was 80–87%, whereas in rainfed crop, the contribution was 76% towards corm development. Irrigation at 100% CPE showed 82.4% dry matter partitioning towards corm bulking. The source-sink relationship determines crop yield, and it is largely regulated by water and nutrients in agricultural production. Unlike cereals, tuber yield is more likely to be source-limited than sink-limited during the tuber bulking stage. In potato, sufficient nitrogen and adequate irrigation increased yield mainly by enhancing the source capacity (Li *et al.* 2016). In the present study also, satisfactory vegetative growth and subsequent dry matter production led to more partitioning towards corm development. Corm yield was significantly reduced due to water deficit stress (WDS)

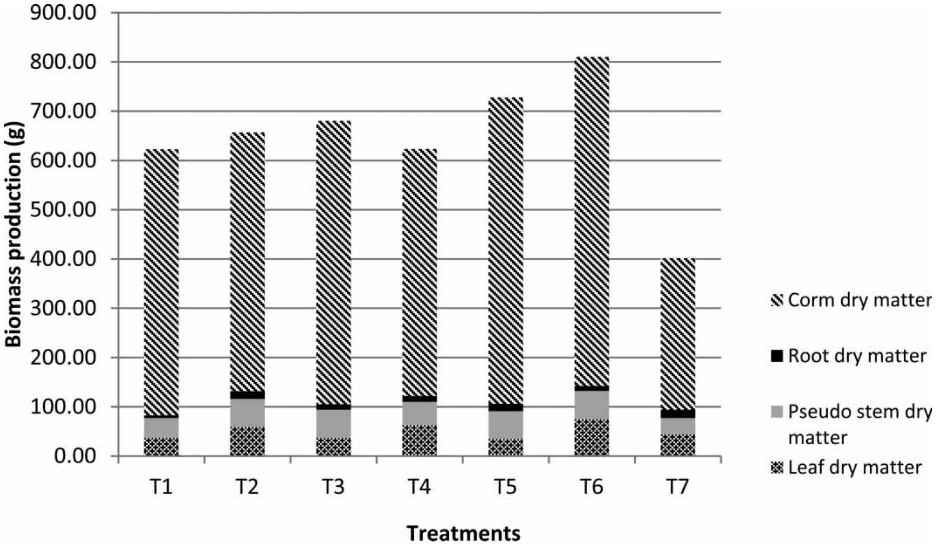

Figure 2 | Biomass partitioning in elephant foot yam under water saving techniques.

during 4–5 MAP as well as 5–6 MAP in elephant foot yam (Ravi *et al.* 2015), which indicates that soil moisture plays an important role in tuber bulking. The water requirement of elephant foot yam during 13–24 weeks after planting, coinciding with tuber development phase, was found to be more critical and assuring enough moisture either through rainfall or supplementary irrigation enhances corm yield in elephant foot yam (Sunitha *et al.* 2018).

Corm yield

The corm yield of elephant foot yam was the highest when the crop was irrigated at the rate of 50% CPE along with porous ground cover mulching (38.36 tha^{-1}) (Table 2). Retention of adequate soil moisture in the active root zone along with better weed control with ground cover mulching might have created a favourable condition for active plant growth, biomass production and partitioning which ultimately resulted in maximum corm yield. Similar increase in corm yield with plastic mulching in cocoyams due to reduced crop emergence time, improved soil moisture status, reduced weed competition and improved general edaphic conditions of the plant is reported (Anikwe *et al.* 2007). However, this was on a par with other water smart techniques such as bio mulching, soil application of super absorbent polymer and also irrigation at 100% CPE. PRD technique and antitranspirant spray did not perform better

Table 2 | Corm yield of *Amorphophallus* under different water saving techniques

Treatments	Corm yield (tha^{-1})
T1: Drip irrigation at 50% CPE through PRD	25.88
T2: Drip irrigation at 50% CPE with bio mulching	35.33
T3: Drip irrigation at 50% CPE with porous ground cover mulching	38.36
T4: Drip irrigation at 50% CPE with antitranspirant spray	29.00
T5: Drip irrigation at 50% CPE with super absorbent polymer	37.18
T6: Drip irrigation at 100% CPE	34.25
T7: Rainfed crop	19.50
SEd	4.38
CD (0.05)	**9.29**

in terms of corm yield. In all water saving techniques, though the level of irrigation was reduced to 50%, the soil moisture was retained for a longer period in the active root zone and assured effective use of soil available water. Maximum corm yield was recorded under 50% irrigation with porous ground cover mulching, followed by 50% irrigation with the application of cassava starch-based hydro gel. Super absorbent polymers (SAP) are functional macromolecules with the ability to absorb water and act as miniature water reservoirs releasing water into the soil maintaining moisture balance. Cassava starch-based SAP has an absorbency of 42,500 g kg^{-1} and is established as a hydro gel when used as a soil conditioner (Parvathy *et al.* 2014). In *Amorphophallus*, application of the hydro gel retained more soil moisture (8.4–12.8%) throughout the growth and enhanced the corm yield with saving of irrigation water. Bio mulching as soil cover in basins also could retain enough moisture in the root zone (7–10.5%) throughout the growth and tuberisation. Studies on the effects of hay, compost, plastic and paper mulches on soil temperature, soil moisture and yield of tomato indicated that mulch treatments apparently affected early tomato yield by influencing the soil temperature regime, but affected later yields by modifying soil moisture levels (Schonbeck & Evanylo 1998).

Plants sprayed with kaolinite at 0.5% recorded 24% less corm yield than the maximum. Since the spray was given on the undersurface of leaves, the plants would continue to have the normal photosynthetic rate. However, soil moisture retention was not as good as a physical ground cover in other techniques (6.6–9.5%). PRD was not found to be a promising water saving treatment, as reported in potato (Shahnazari *et al.* 2008). In *Amorphophallus*, when corms are planted, roots emerge initially from the junction of the sprout and as the sprout elongates, roots also elongate with laterals with tuber initiation occurring at the junction, just beneath the root system. Once the corm initiation occurs, adventitious roots are produced from the developing corm which is actually the modified underground stem. Adventitious roots are produced uniformly throughout its surface with branching through lateral roots. Root branching helps to increase the surface area of the root system enabling the plant to trap more distant reserves of water and minerals and improve soil anchorage, which is reported in potato (Joshi *et al.* 2016). In *Amorphophallus*, maximum root development occurs during the initial time of 10–12 weeks, and slows with the onset of tuberisation. In fact, PRD technique has reduced the corm yield by 32% compared to the ground cover mulching. PRD technique and spraying antitranspirant resulted in 24.4% and 15.3% decrease in corm yield, respectively, compared to irrigation at 100% level (Figure 3). However, significant enhancement in corm yield could be recorded with supplemental irrigation compared to rainfed situations (Figure 4).

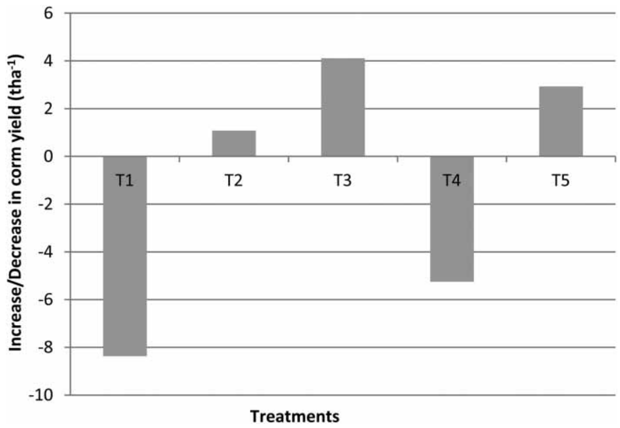

Figure 3 | Increase/decrease in corm yield with water saving techniques compared to 100% irrigation.

Trials carried out through All India Coordinated Research Project on Tuber Crops across the country indicated that *Amorphophallus* under drip irrigation at 100% CPE recorded maximum corm yield in different agro-climatic locations in India (George *et al.* 2013) compared to lower irrigation levels, namely, 75%, 50% and 25% of pan evaporation. Assuring enough soil moisture by way of suitable water conservation measures could give a corm yield on a par with 100% irrigation in the present study, which indicates the significance of water saving technologies resulting in 50% water economy.

Corm bulking efficiency

Corm bulking efficiency (corm yield per plant/weight of corm planted) followed the same trend as that of total corm yield. Maximum corm bulking was recorded under drip irrigation at 50% CPE with porous ground cover mulch (6.2 times) followed by drip irrigation at 50% with the use of SAP (6.0). Under 100% irrigation, the efficiency was only 5.5 times of the planted corms. Corm bulking efficiency mainly depends upon the size and nature of planting material (cut/whole corm), crop spacing and the management conditions (Ravi *et al.* 2011). In the present study, whole corms of 500 g were planted uniformly, so the difference observed in bulking across irrigation treatments could be attributed to the efficient water saving techniques and soil moisture availability during the crop growth.

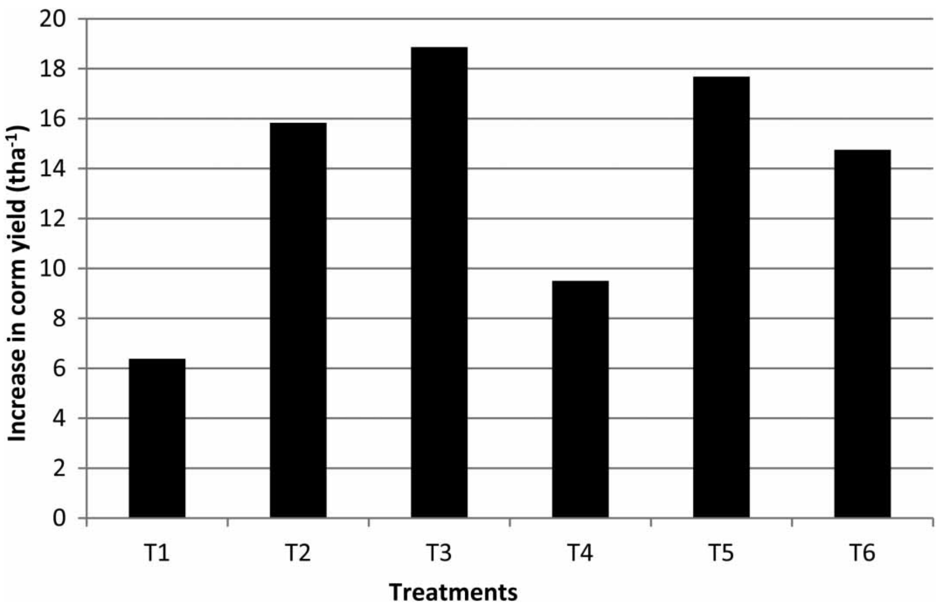

Figure 4 | Increase in corm yield under different treatments compared to rainfed crop.

Water productivity

Water productivity is the ratio of crop output and the input water. In the present study, water productivity was worked out based on the corm yield obtained and water used under different treatments through irrigation as well as effective rainfall. The ratio ranged from 2.8 to 4.4 kg/m^3. The productivity was maximum when porous ground cover mulch was used for moisture retention (Figure 5). Full irrigation, without any moisture saving technique recorded a water productivity of 3.3 kg/m^3. In general, water productivity was higher when suitable water conserving measures were undertaken, either by bio mulching, porous ground cover mulching or application of SAP in soil. Yang *et al.* (2015) reported 30.8% increase in water usage effectiveness (WUE) in maize by the use of plastic mulch. Similarly, a significant reduction in watering frequency due to the increase in water holding capacity of

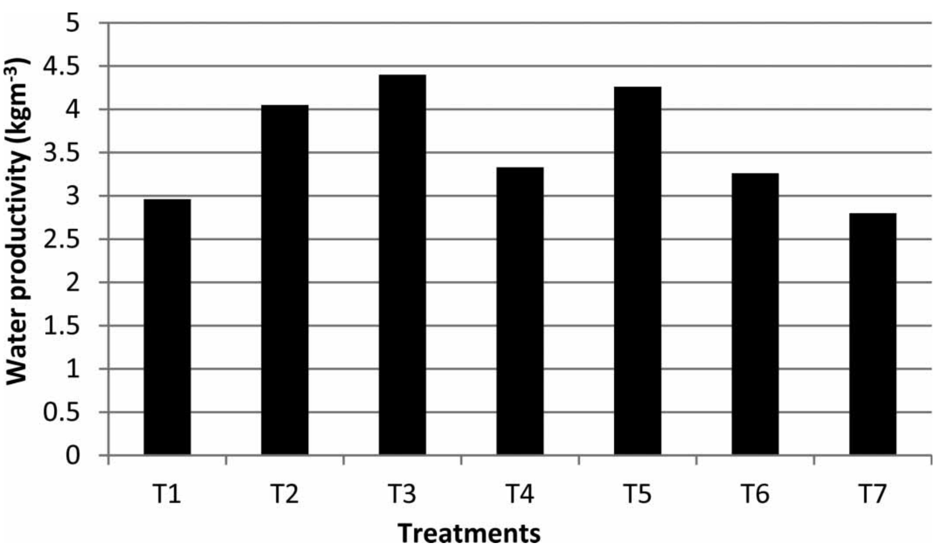

Figure 5 | Water productivity under different water saving techniques.

media by the application of SAP and thereby an increase in WUE has been reported in many crops (Cookson et al. 2001; Abedi-Koupai & Sohrab 2004; Sivalapan 2006).

One hundred per cent irrigation could not result in a corresponding increase in water productivity. 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 drip system as established in many other crops (Chouhan et al. 2014; Jha et al. 2017). Higher water productivity is an important indicator in improved water management system which shows the efficiency of irrigation. Effective utilisation of soil moisture for a prolonged time interval of crop growth was also assured in the present study.

Energy efficiency indices

Energy value of various inputs including human labour (men and women) for field preparation, planting, intercultural operations and harvesting and farm yard manure (FYM) and fertilisers applied was uniform for all the treatments and computed as 22,186 MJ/ha. Additional energy required for drip irrigation and imposing water saving technologies differed among the treatments and hence the total input energy was calculated separately. Total input energy ranged from 24,496 to 24,668 MJ/ha and was compared with the rainfed cultivation which was 22,186 MJ/ha. The total output energy computed from corm yield ranged from 93,168 to 138,096 MJ/ha and the output energy was 70,200 MJ/ha under rainfed cultivation.

The average of two years data showed that porous ground cover mulching was superior in terms of all energy efficiency indices (Table 3) and recorded maximum net energy (113,427 MJ/ha), energy use efficiency (4.6), energy productivity (1.5 kg/MJ), energy output efficiency (460.3 MJ/day) except energy intensity which was maximum under the application of super absorbent gel (0.37 MJ/Rs). Ground cover mulching resulted in 28% and 112% higher energy use efficiency and 22% and 78% higher energy productivity than 100% irrigation and rainfed crop, respectively.

Water conservation using porous ground cover mats produced significantly higher corm yield and hence total output energy was higher. Consequently, high energy use efficiency and energy productivity were recorded and it was followed by the use of super absorbent polymer. All the energy efficiency values were low under rainfed cultivation and supplemental irrigation resulted in high energy efficiency indices, although the energy input was less under rainfed cultivation. This shows the superiority of drip irrigation in *Amorphophallus* along with water conserving technologies wherein sufficient soil moisture is ensured in the active root zone of the crop, especially during the critical growth stages of the crop. Tuber crops have a higher biological efficiency and show the highest rate of dry matter production per day per unit area among all the crops. They are also recognised as the most efficient converters of solar energy (Horton & Fano 1985). In this study, energy consumption was high under drip irrigation,

Table 3 | Energy efficiency indices of *Amorphophallus* under different water saving techniques

Treatments	Energy input (×10^3 MJ/ha)	Energy output (×10^3 MJ/ha)	Energy use efficiency	Energy productivity (kg/MJ)	Energy intensity (MJ/₹)	Energy output efficiency (×10^3 MJ/ha/day
T1: Irrigation at 50% CPE + PRD	24.5	93.2	2.8	1.1	0.3	3.1
T2: Irrigation at 50% CPE + bio mulching	24.6	127.2	4.2	1.4	0.4	4.2
T3: Irrigation at 50% CPE + ground cover mulching	24.7	138.1	4.6	1.6	0.3	4.6
T4: Irrigation at 50% CPE + antitranspirant spray	24.6	104.4	3.2	1.2	0.3	3.5
T5: Irrigation at 50% CPE + SAP	24.6	133.8	4. 3	1.5	0.4	4.5
T6: Irrigation at 100% CPE	26.9	123.3	3.6	1.3	0.3	4.1
T7: Rainfed crop	22.2	72.0	2.2	0.9	0.2	2.3

however, more corm yield and high energy value of tubers resulted in high energy output.

CONCLUSIONS

The findings of the present study showed the relative advantage of water smart technologies for conserving soil moisture and reducing the water requirement of crops. Deficit irrigation along with mulching the interspaces with porous ground cover mats and soil application of cassava-based super absorbent polymer were equally effective in reducing the consumptive use of elephant foot yam, thereby reducing the irrigation water requirement by 50% without adversely affecting the corm yield. These water saving measures resulted in maximum water productivity, and water use efficiency. In the context of expected climate change and highly erratic distribution of rainfall, the effect of water scarcity will be more pronounced in the cultivation of tropical tuber crops where these crops have to compete with other high value crops. Water smart technologies such as the use of ground cover mats and soil application of super absorbent polymer would help in the cultivation of tuber crops, especially elephant foot yam (*Amorphophallus*) with less irrigation, without adversely affecting the corm yield under humid tropical situations.

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