Journal of Root Crops
Indian Society for Root Crops
ISSN 0378-2409, ISSN 2454-9053 (online)
Journal homepage: https://journal.isrc.in

Climate resilient technologies for sustainable production of root and tuber crops

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Abstract

Root and tuber crops are mostly grown in uplands under rainfed conditions. Uncertain weather is the major constraint in rainfed farming. Root and tuber crops are propagated vegetatively by using cut tubers/stems/vines. The cut surface loses moisture quickly and is subjected to drying and decaying. Being widely spaced long duration crops, weed menace at early stage and moisture stress at later stage affect growth and development of tubers. Cowdung cap on cassava setts improved the sprouting and establishes quickly under rainfed conditions. Storing sweet potato vine cuttings with intact leaves in bundles under shade for two days prior to planting in the main field improved sprouting and establishes quickly. Ridge height of 45 cm for sweet potato and broad bed and furrow system (20 cm height) for elephant foot yam resulted in higher yield. Mulching in yams, elephant foot yam and taro conserved soil moisture, improved sprouting and establishment, suppressed weeds and increased soil fertility apart from increased tuber yield. Growing maize as intercrop in greater yam served as livestaking and added organic matter into the soil apart from higher yield and return. Green gram intercropping in elephant foot yam increased income and improved soil fertility. Grain or vegetable crops intercropping in taro increased biological efficiency of the cropping system. Drip irrigation and fertigation in greater yam, elephant foot yam and greater yam+maize intercropping system not only produced higher yield and income but also saved water and nutrients. Thus, sustainable yield and income can be obtained by following suitable climate resilient technologies.

Keywords: Cowdung slurry sett treatment, Drip irrigation, Fertigation, Intercropping, Mulching

Introduction

Tropical tuber crops are the most important food crops after cereals and grain legumes. They are used for food, medicine, animal feed and raw material for starch-based industries. The commonly cultivated tropical tuber crops are cassava (*Manihot esculenta* Crantz), sweet potato (*Ipomoea batatas* (L.) Lam.), elephant foot yam (*Amorphophallus paeoniifolius* (Dennst.) Nicolson), taro-eddoe (*Colocasia esculenta* var. *anticorum* (L.) Schott.), taro-dasheen (*Colocasia esculenta* var. *esculenta* (L.) Schott.), swamp taro (*Colocasia esculenta* var. *stoloniferum* (L.) Schott.), tannia (*Xanthosoma sagittifolium* (L.) Schott.), lesser yam (*Dioscorea esculenta* (Lour.) Burk.), greater yam (*Dioscorea alata* L.), white yam (*Dioscorea rotundata* Poir.), aerial yam (*Dioscorea bulbifera* L.), yam bean (*Pachyrhizus erosus* (L.) Urb.), Chinese potato (*Solenostemon rotundifolius* (Poir.) Spreng.) and arrowroot (*Maranta arundinacea* L.).

Tropical tuber crops are rich sources of energy and carbohydrates although each of them also provides other important nutrients as well. Tropical tuber crops

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Received: 19 March 2023; Revised: 01 April 2023; Accepted: 04 April 2023

are rich in minerals and vitamins too. As per FAOSTAT (2020), globally cassava is cultivated in 28.2 million ha with a production of 302.7 million t and productivity of 10.7 t ha^{-1}. Sweet potato is cultivated in 7.4 million ha with production of 89.5 million t and productivity of 12.1 t ha^{-1}. Yams are cultivated in 8.8 million ha with production of 74.8 million t and productivity of 8.5 t ha^{-1}. Taro is cultivated in 1.8 million ha with production of 12.8 million t and productivity of 7.1 t ha^{-1}. Cocoyam is cultivated in 0.03 million ha with production of 0.4 million t and productivity of 12.4 t ha^{-1}. In terms of percentage contribution of world, it is as follows: cassava (63.0%), sweet potato (18.6%), yams (15.6%) and taro (2.7%) and cocoyams (0.1%). Cassava is mostly grown in Africa, Asia and South America while sweet potatoes are heavily concentrated in Asia. Africa dominates in the production of yams and taro.

Tropical tuber crops are having varied growth habits, drought and flood resistance and crop duration. Though tropical tuber crops are perennial in nature but domesticated as seasonal or annual. This provides an opportunity for staggered harvesting as per household and market needs. Tropical tuber crops have great flexibility in planting and can fit into any cropping/farming system. This is possible because the propagating material is an asexual stem or vine or tuber cuttings. As the economic part is swollen roots or modified stem, photoperiod has no significant effect on yield forming factors in most of the tropical tuber crops. Thus, tropical tuber crops are both thermo and photo insensitive. However, extreme high and low temperature affects the growth and yield. Tropical tuber crops grow well in marginal soils with fewer inputs where other crops usually fail to grow. They are tolerant to drought and some of them grow fast and provide a wide soil cover to prevent erosion. It also produces a high amount of dry matter per unit area per unit time compared to cereals. They are most efficient in converting solar energy, for example cassava producing 250×10^3 kcal ha^{-1} day^{-1} and sweet potato 240×10^3 kcal ha^{-1} day^{-1} as compared to on 76×10^3 kcal ha^{-1} day^{-1} for rice, 110×10^3 kcal ha^{-1} day^{-1} by wheat and 200×10^3 kcal ha^{-1} day^{-1} for maize. Tuber crops are capable of utilizing available resources more efficiently especially in partial sunlight and residual moisture (Nedunchezhiyan and Laxminarayana, 2006).

Inter-Governmental Panel on Climate Change has projected that by the end of this century, global earth temperature is likely to increase by 1.8 to 4.0°C. This would lead to more frequent hot extremes, floods, droughts, cyclones, and recession of glaciers. Frequent severe droughts and floods are attributed to climate change that are making millions of people, particularly in resource-poor areas, vulnerable, when their livelihood and food security is depending on agriculture (IAASTD, 2009). The projected increase in these events will result in greater instability in food production and will threaten farmers' livelihood security. Producing enough food for increased demand against the background of changing climate scenario is a challenging task for agricultural research. This would require increased adaptation and mitigation research.

FAO has recognized cassava (*Manihot esculenta*; Euphorbiaceae), quinoa (*Chenopodium quinoa*; Chenopodiaceae), yams (*Dioscorea* spp.; Dioscoreaceae) and grain amaranthus (*Amaranthus* spp.; Amaranthaceae) are climate resilient crops. Among four climate resilient crops, two (cassava and yams) are from root and tuber crops. In addition to climate resilient crops, climate resilient production systems that are based on the sustainable use of natural resources must be promoted as a prevention and mitigation measure against climate change related crises (FAO, 2018).

Climate resilient technologies

Cassava

Cow dung cap sett treatment

Cassava is a starchy root tuber crop. It is popularly known as tapioca, produces more calories/unit area. It is grown in Asia, Africa, South America and Latin America. In India, cassava is being cultivated in an area of 0.16 m ha with a production of 5.04 m t (FAOSTAT, 2020). Cassava is an important crop in South India (Kerala, Tamil Nadu and Andhra Pradesh) and is slowly spreading to Western (Maharastra) as well as Eastern (Odisha) and Northeastern (Assam, Meghalaya and Tripura) India. Cassava tubers are utilized primarily as human food after boiling, frying, baking or steaming. The other uses of cassava are in industry where it is used for production of starch, liquid glucose, dextrin, high fructose syrup, monosodium glutamate, alcohol and preparation of biodegradable plastics. The starch is also used in textile industries in warping and to produce plywood. Cassava produces huge foliages. Leaves and tubers also form an important component of animal feed and are extensively used in feed for cattle, poultry and swine. Green foliage is used for silage making. Culled tubers and thippi are used as animal feed as well as fuel in starch industries. Cassava is a long duration crop. Once it establishes there is no death for this crop. Hence, it is also called crop camel in horticultural crops. However, the establishment phase is crucial for this crop. Stem is the propagule of the cassava crop. Stems are cut in to 20-25 cm length setts and planted vertically in the field.

Cassava setts take 7-10 days for sprouting and establishment. During this period, high mortality was noticed, when the setts were exposed to water stress. Under rainfed conditions, setts mortality was very high. The cut surface of the cassava sett loses moisture quickly and the auxillary buds gets dried when expose to high temperature and moisture stress. To prevent evaporation of moisture from the cut surface, fresh cow dung is applied on the cut surface like cap. This will prevent evaporation of moisture from the stem and accelerate the sprouting of the setts. This technique of cow dung cap cassava sett treatment reduces mortality of cassava setts and prevents population reduction. Under Tribal Sub Plan, cow dung cap cassava sett treatment on sprouting and establishment was demonstrated in 100 farmers field during 2022 and 200 farmers field during 2023 in Mohana block, Gajapati district, Odisha. Two treatments *viz*., cow dung cap and control were tested with each treatment in one cent area. Cow dung cap treatment recorded 98.6% and 93.3% sprouting and establishment during the year 2022 and 2023, respectively, whereas the control treatment recorded 72.3% and 68.3% sprouting and establishment, respectively. This clearly showed that cow dung cap cassava sett treatment is very effective and required to counteract climate change effects.

Greater yam

Tuber sett treatment with cow dung slurry

Greater yam is a very important tropical tuber crop. It is rich in carbohydrates, dietary fibre, vitamin C and essential minerals. Greater yams are consumed as boiled, roasted, baked or fried. Greater yam plays vital role in food and nutrition security in many of the states in India. Apart from food, yams are also sources of pharmaceutical compounds like saponins and sapogenins, which are precursors of cortisone used medically in the treatment of arthritis and some allergies. Greater yam seed tuber of 200-250 g is recommended for commercial cultivation. However, since seed tubers of 200-250 g are not available for planting, yam tubers of 1.0 kg is cut in to 4-5 pieces and used as seed materials. When the tubers are cut, they are subjected to moisture loss and invite pests and diseases. Hence, greater yam tuber setts are treated with cow dung slurry (2 kg of cow dung in 1.0 litre of water) before planting. The tuber setts treated with cow dung slurry are to be shade dried for 1 or 2 days before planting and can also be stored for 7-10 days. Cow dung slurry treatment prevent moisture loss from the cut tubers and prevent pest and diseases infestation/infection and also augment early sprouting.

Mulching with dried farm waste

Mulching is very essential under rainfed conditions due to the many benefits they impart on soil rhizosphere. It moderates the soil temperature in addition to conserving soil moisture, reducing evaporation as well as controlling weed population. Mulching is essential for high value cash crops like greater yam in high rainfall regions like Odisha where dry spells are common in the beginning of the monsoon. Long duration crops like greater yam get nutrients from mulches through slow decomposition and mineralization at later stages. Dried farm waste which is available in plenty in rainfed small holder farming systems can be used as mulch. It can also reduce fertilizer requirements which indirectly improves the financial conditions of the farmers. An investigation was carried out to find out the effect of mulch on greater yam. Two treatments were taken, *viz*., no mulch and mulch @ 2 t ha^{-1} as dried farm waste. Mulching materials were applied uniformly immediately after planting of the greater yam. The results revealed that application of mulching material resulted in significantly higher greater yam tuber yield over no mulching (Table 1).

Table 1. Effect of mulching on greater yam tuber yield

Treatment	Tuber yield (g $plant^{-1}$)
Mulching	1495
No mulching	1230
CD (5%)	152

(Source: Nedunchezhiyan et al., 2010a)

Drip irrigation and fertigation for greater yam

Water and nutrients are the most important input factors in crop production which constraint productivity of the crops. Availability of water to agriculture is decreasing due to increasing demand in industrial and allied sectors. Hence, water should be used judiciously in crop production along with rainwater. Rainfall in India is monsoon dependent and 80% of rainfall is received during southwest monsoon season (June to September). Greater yam, being a long duration (9-10 months) crop, may suffer from insufficient moisture at later stages. Supplementary irrigation to greater yam is beneficial for uniform sprouting at early stage and rapid tuber bulking during post monsoon season. The most used method of irrigation is surface flood irrigation which ensures uniform spreading, high evaporation and seepage loss. Drip irrigation and fertigation is a water and nutrient saving technique. A field experiment conducted at the Regional Station of ICAR-CTCRI, Bhubnaeswar revealed that increasing drip irrigation level increased greater yam tuber yield. The treatment 100% CPE resulted in higher tuber yield of 34.8 t ha^{-1} and it was followed by 80% CPE with 33.8 t ha^{-1}. Among fertigation tretaqments, the one with N- P_2O_5-K_2O 100-60-100 kg ha^{-1} resulted in significantly higher tuber yield of 34.2 t ha^{-1}. The interaction was found between irrigation and fertigation levels. The treatment 100% CPE with N- P_2O_5-K_2O 100-60-100 kg ha^{-1} resulted in higher tuber yield and it was statistically on par with 80% CPE with N- P_2O_5-K_2O 100-60-100 kg ha^{-1} and 100% CPE with N- P_2O_5-K_2O 80-60-80 kg ha^{-1}.

Elephant foot yam

Corm sett treatment with cow dung slurry

Elephant foot yam is a tuberous vegetable crop cultivated through out India and particularly in Andhra Pradesh, West Bengal, Bihar, Uttar Pradesh, Tamil Nadu, Kerala, Maharastra, Odisha and Karnataka (Nedunchezhiyan and Byju, 2005). Elephant foot yam seed corm of 500 g is recommended for commercial cultivation. Usually, ware corm of 2.0 kg is cut in to 4 pieces and used as seed material. Hence, elephant foot yam corm setts are treated with cow dung slurry before planting. Cow dung slurry treated corms setts are to be shade dried for 1 or 2 days before planting and can also be stored for 7-10 days. Cow dung slurry treatment prevent moisture loss from the cut corms and prevent pest and diseases infestation/ infection and also augment early sprouting. Storage study conducted during the years 2022 and 2023 indicated that treatment with cow dung slurry controlled mealybugs and prevented further infestation during the storage (Table 2).

Table 2. Effect of cow dung slurry treatment on mealybug infestation 3 months after treatment

Treatment	2022		2023	
	Sprouting (%)	No. of mealybug per corm	Sprouting (%)	No. of mealybug per corm
Cow dung	96	4.3	100	0
Control	10	47.0	100	7.3

Woven polythene mulching in elephant foot yam

Elephant foot yam is a widely spaced crop, which competes with weeds throughout its growth period. An investigation was carried out at Regional Station of ICAR-CTCRI, Bhubaneswar to find out alternatives to hand weeding. The results revealed that woven polythene mulching (weed control ground cover) resulted in significantly the lowest weed dry matter per m^2 (11.2 g) and highest corm yield (32.4 t ha^{-1}) with the weed control efficiency of 95.3% (Nedunchezhiyan et al., 2020).

Drip irrigation and fertigation for elephant foot yam

A field experiment conducted at the Regional Station of ICAR-CTCRI, Bhubnaeswar revealed that, maximum corm yield (33.9 t ha^{-1}) was noticed at highest irrigation level (100% CPE) (Table 3). However, it was comparable with 80% CPE (32.2 t ha^{-1}). Increasing the nutrient levels increased corm yield. Higher corm yield was obtained with the application of $N:K_2O$ @120:120 kg ha^{-1} through drip (Table 3). The next best treatment was application of $N:K_2O$ @ 100:100 kg ha^{-1}. Interaction effect was found significant between irrigation and fertigation levels (Table 3). The highest yield of 37.0 t ha^{-1} was recorded with the application of drip irrigation at 100% CPE along with $N:K_2O$ @ 120:120 kg ha^{-1}. However, it was on par with the application of drip irrigation at 80% CPE along with $N:K_2O$ @ 120:120 kg ha^{-1}. The control/check (IW/CPE=1) treatment recorded a corm yield of 30.5 t ha^{-1}. Yield increase in drip fertigation might be due to the efficient utilization of applied nutrients and water.

Table 3. Corm yield of elephant foot yam (t ha^{-1}) as affected by irrigation and fertigation levels

Irrigation level	Fertigation levels ($N:K_2O$ kg ha^{-1})			
	80:80	100:100	120:120	Mean
60% CPE	25.2	28.7	30.3	28.1
80% CPE	27.5	33.3	35.7	32.2
100% CPE	29.4	35.1	37.0	33.9
Mean	27.4	32.4	34.3	

CD (P=0.05): Irrigation : 2.4
Fertigation : 2.0
Interaction : 3.3
Control/Check (IW/CPE=1):30.5 t ha^{-1}
(Source: Nedunchezhiyan et al., 2017)

The average amount of water applied through drip irrigation in each treatment was computed (mean of three years). It was 164.8 mm, 219.7 mm and 274.6 mm in 60%, 80% and 100% CPE, respectively (pan factor = 0.6; crop coefficient = 0.7) (Table 4). In control treatment (IW/CPE=1) 653.8 mm of water was applied through flood irrigation. Drip irrigation at 80% CPE and 100% CPE saved 434.1 mm (43,41,000 L ha^{-1}) and 379.2 mm (3792000 L ha^{-1}) of water respectively over surface flood irrigation (IW/CPE=1). Energy consumed in drip irrigation treatments were found to be lower than surface irrigation (control) (Table 4). This might be due to the lower quantity of water was required under drip irrigation. The energy charges for pumping water were found lower in drip irrigation systems compared to check (IW/CPE=1) (Table 4).

Table 4. Irrigation water and energy required as influenced by levels of drip irrigation

Treatment	Irrigation water (mm)	Energy consumed (Unit)	Energy charge (₹)
60% CPE	164.8	530.9	2124
80% CPE	219.7	681.1	2724
100% CPE	274.6	851.3	3405
IW/CPE=1	653.8	1830.6	7322

Taro

Paddy straw mulching

Taro is grown for its modified stem tubers, which is a rich source of carbohydrate (73-80% on dry weight basis) (Arutselvan et al., 2023). An annual rainfall of 900-1200 mm spread over 5-6 months is required for taro cultivation (Nedunchezhiyan and Sahoo, 2019). Taro is cultivated both in *kharif* (rainfed) and *rabi* (irrigated) seasons. Weeds are big menace in *kharif* taro. The Regional Station of ICAR-Central Tuber Crops Research Institute, Bhubaneswar studied various options in weed management in taro. An experiment was laid out for three years under rainfed conditions in split plot design with plant density in main plots [P_1 - 55500 (60 × 30 cm) and P_2 - 74000 (45 × 30 cm) plants ha^{-1}] and in sub plots mulching (M_1 - Sunnhemp live mulching, M_2 - Daincha live mulching, M_3 - Cowpea live mulching, M_4 - Paddy straw mulching, M_5 - Hand weeding at 30, 60 and 90 days after planting (DAP) and M_6 - Control). The treatments were replicated thrice. FYM @ 25 t ha^{-1} was applied at final ploughing and then ridge and furrows were made for planting. The variety Muktakeshi (taro) was planted and harvested at165 days after planting. The results revealed that plant density of 74000 plants ha^{-1} recorded higher tuber yield of 14717 kg ha^{-1}. Paddy straw mulching recorded significantly highest tuber yield of 20152 kg ha^{-1}. Hand weeding at 30, 60 and 90 DAP was found to be the next best treatment. Live mulching suppressed the weeds considerably and increased the taro yield compared to control (weedy check). The results also revealed that live mulching alone is not enough for controlling the weeds in taro. Paddy straw mulching resulted in higher sustainable yield index (SYI), water holding capacity (WHC), porosity, earthworms count and lower bulk density. The interaction effect showed that the planting density of 74000 plants ha^{-1}along with paddy straw mulching resulted in greater taro tuber yield (21390 kg ha^{-1}) (ICAR-CTCRI, 2023).

Sweet potato

Storage of vine cuttings before planting

Sweet potato is cultivated throughout the tropics, subtropics and warmer temperate regions. Sweet potato roots and tops are highly nutritious, which can be used to combat nutritional deficiencies in many parts of the developing countries. The roots are primarily used as human food after boiling, frying, steaming and baking. Value added products like noodles, liquid glucose, sorbitol, manitol, yoghurt, wine, ethanol etc. are also prepared from sweet potato. Apart from source of energy, roots also contain significant quantities of water soluble vitamins *i.e.,* ascorbic acid, thiamin, riboflavin and niacin. The contents of pyridoxine, folic acid and pantothenic acid may be relatively high. Tender tips of fresh leaves are excellent sources of ascorbic acid and some of the B-vitamins especially riboflavin which is deficient in many Asian diets. Orange fleshed sweet potatoes contain ß-carotene as high as 14 mg100^{-1} g fresh tuber (Nedunchezhian and Ray, 2010). Regional Station of ICAR-CTCRI, Bhubaneswar has released purple colour anthocyanin (85 mg100^{-1} g fresh tuber) rich variety Bhu Krishna. Green tops and culled tubers are used as animal feed. Foliage is good for hay making.

Sweet potato is propagated through vine cuttings. Generally, vine cuttings are prepared from the nursery on the day of transplanting into the main field. Storage of sweet potato vine cuttings for 2 days before planting in shade and then transplanting into the main field resulted in higher percentage of sprouting and establishment. During storage, vines initiate root and shoot. When such vines are transplanted, it establishes quickly compared to direct transplanting, wherein high mortality was reported.

Alteration in ridge height

Generally, sweet potato is planted in ridge and furrow system. The ridge height depends on inter-row spacing. The recommended spacing of 60 cm row to row led to 30 cm ridge height only. It is not enough for tuberization especially rainfed conditions. Hence, the Regional Station of ICAR-CTCRI, Bhubaneswar has investigated and found that making 45 cm ridge height (90 cm row to row spacing) resulted in greater tuber yield (13.6 t ha^{-1}), harvest index (0.49), gross return (Rs 247600 ha^{-1}), net return (Rs 169000 ha^{-1}), and B:C ratio (3.15) (ICAR-CTCRI, 2023).

Tuber crops-based cropping systems

Greater yam+maize intercropping system

Maize was found best intercrop in greater yam cultivation, which reduces 60.0% anthracnose incidence and increases yield by 26.3% (Nedunchezhiyan et al., 2010a). Maize also replaces wooden stakes. Hence it is an ecofriendly technology.

Elephant foot yam+green gram intercropping system

Elephant foot yam is a long duration widely spaced crop. The growth of elephant foot yam is slow during initial stages and takes more than 60 days to spread the full ground. During this period, close growing pulse can be grown as intercrop. Green gram was found as a suitable intercrop in elephant foot yam due to short duration and no competition for natural resources (Nedunchezhiyan and Byju, 2005). The system productivity was higher with the introduction of green gram in elephant foot yam. In addition to additional yield from green gram, nitrogen fixation in the rhizosphere by green gram improves the fertility status of the soil. Mulching the haulms after harvest of green gram pods, improves soil organic matter content.

Taro+grain crops intercropping system

Taro, a water loving tuber crop is grown in eastern India because of high rainfall and longer crop growing period. However, mid-season and terminal droughts can reduce the yield of taro to a considerable extent. As a sole crop, taro requires a huge quantity of seed material (1.2 t ha^{-1}) causing very high initial investment. In small-holder farming systems, it may be difficult to invest and during drought, the farm economy is severely affected. Hence, intercropping with cereals and pulses under replacement series will reduce seed cost of taro. Intercropping of cereals and pulses in taro can also act as contingent crops and increase the land use efficiency apart from augmenting farm yield in upland rainfed conditions.

Research findings from the Regional Station of ICAR-CTCRI, Bhubaneswar revealed that taro corm and cormel yield per ha was found decreasing under intercropping (Table 5). The decrease in taro yield was due to a decrease in taro population apart from competition from intercrop (maize/pigeonpea) under intercropping. Taro corm yield per ha was more affected than cormel yield per ha under intercropping. The decrease of taro corm yield per ha ranged from 17.1 to 41.9% under intercropping, whereas decrease of taro cormel yield per ha ranged from 16.1 to 38.0% (Table 5). Increasing intercrop population resulted in decrease of taro corm and cormel yield per ha, however it was not in linear. When one row of taro was replaced with maize (5:1), the reduction in taro corm and cormel yield per ha was 17.1 and 16.1%, respectively (Table 5). When two rows of taro were replaced with maize (5:2), the reduction in taro corm and cormel yield per ha was 32.9 and 29.0%, respectively (Table 5). Similarly, one row of taro was replaced with pigeonpea (5:1), the reduction in taro corm and cormel yield per ha was 26.6 and 20.7%, respectively. When two rows of taro were replaced with pigeonpea (5:2), the reduction in taro corm and cormel yield per ha was 41.9 and 38.0%, respectively (Table 5).

The corm equivalent yield (CEY) revealed that, taro sole cropping recorded higher CEY and it was statistically comparable with taro+maize (5:1) and taro+pigeonpea (5:1) intercropping systems (Table 5). This was due to favourable rainfall during crop growing period of taro and its higher tonnage yield. In the three year period of the experiment, the average total rainfall received during crop growing period was 1568.2 mm with 74 rainy days, which was sufficient for raising sole taro crop. During lesser rainfall and rainy days per year, the importance of maize and pigeonpea will be realized.

Table 5. Yield components and yield of taro and seed yield of intercrops at harvest as influenced by intercropping systems

Cropping system	Corm yield (kg ha^{-1})	Cormel yield (kg ha^{-1})	Seed yield (kg ha^{-1})	Cormel equivalent yield (kg ha^{-1})
Taro	4744	15420	0	18593
Maize	0	0	4862	4862
Pigeonpea	0	0	2101	7006
Taro+maize (5:1)	3934	12934	1344	16900
Taro+maize (5:2)	3184	10945	2122	15187
Taro+pigeon-pea (5:1)	3480	12235	627	16647
Taro+pigeon-pea (5:2)	2755	9561	892	14373
SEm±	-	-	-	667
CD (P=0.05)	-	-	-	2053

(Source: Nedunchezhiyan et al., 2021b)

Taro+vegetable crops intercropping system

A field experiment was conducted at the Regional Station of ICAR-Central Tuber Crops Research Institute, Bhubaneswar to study the effect of vegetable crops intercropping in taro on yield potential in additive series. The results revealed that intercropping of vegetable crops in taro resulted in greater cormel equivalent yield than sole crops cultivation (Table 6). The treatment taro+vegetable cowpea (1:1) resulted in significantly greater cormel equivalent yield (19478 kg ha^{-1}) (Table 6). This was due to the higher yield of taro and veg. cowpea. The next best treatment was taro+okra (1:1) (16280 kg ha^{-1}). The land equivalent ratio (LER) of taro+vegetable cowpea (1:1), taro+cluster bean (1:1) and taro+okra (1:1) were found >1. This indicated that, all the above intercropping systems were biologically efficient. The LER is the most popular method of assessing intercropping systems. The treatment taro+veg. cowpea (1:1) resulted in greater LER than other two systems (ICAR-CTCRI, 2023).

Table 6. Effect of intercrops on cormel equivalent yield (CEY)

Treatment	Corm yield (kg ha^{-1})	Cormel yield (kg ha^{-1})	Intercrop yield (kg ha^{-1})	CEY (kg ha^{-1})
Sole taro	4893	12570	-	15832
Sole okra	-	-	12737	12737
Sole vegetable cowpea	-	-	10752	10752
Sole cluster-bean	-	-	9581	9581
Taro+okra	2377	4360	10336	16280
Taro+vegeta-ble cowpea	4613	7610	8792	19478
Taro+cluster-bean	3973	6373	7233	16256
CD (P=0.05)	-	-	-	1910

Corm ₹ 10 kg^{-1}; cormel ₹ 15 kg^{-1}; okra/vegetable cowpea/ cluster bean ₹ 15 kg^{-1}
(Source: ICAR-CTCRI, 2023)

Sweet potato+pigeonpea strip intercropping system

Intercropping is gaining importance because not only it provides biological insurance against risks under aberrant rainfall behavior in dryland environment but also more labour employment. In uplands, intercropping and crop substitution stabilizes crop yields. Sweet potato+pigeonpea intercropping increased number of tubers/plant, tuber length, tuber diameter and tuber yield per plant. The intercropping system recorded higher tuber equivalent yield, gross return, net return and benefit: cost ratio (Table 7). The intercropping system also enriched the soil with organic matter.

Table 7. Tuber equivalent yield and economics of sweet potato-based strip intercropping systems

Cropping system	Tuber equiv-alent yield (kg ha^{-1})	Cost of cultiva-tion (₹ ha^{-1})	Gross returns (₹ ha^{-1})	Net return (₹ ha^{-1})	B:C ratio
Sole cropping					
Sweet potato	13367	18279	40101	21822	2.19
Rice	4220	8650	12660	4010	1.46
Ragi	2963	7899	8889	990	1.13
Maize	3991	8638	11973	3335	1.38
Pigeonpea	7508	7436	22524	15088	3.03
Strip intercropping					
Sweet potato+rice	10262	13818	30786	16968	2.22
Sweet potato+ragi	9751	12914	29253	16339	2.27
Sweet potato + maize	9224	13365	27672	14307	2.07
Sweet potato+pigeonpea	13534	12527	40602	28075	3.24
CD (P=0.05)	403	-	-	-	-

Selling cost: Sweet potato ₹ 3 kg^{-1}; rice/ragi/maize ₹ 5 kg^{-1}; pigeon pea ₹ 12 kg^{-1}
(Source: Nedunchezhiyan et al., 2010b)

Drip irrigation and fertigation for greater yam+maize intercropping system

Greater yam is a trailing herb and needs staking. In greater yam+maize intercropping system, maize grain cobs are harvested at physiological maturity and haulms are left in the field to serve as live staking. Maize, being a short duration (90-100 days) crop, can be successfully cultivated as intercrop in greater yam in high rainfall regions under rainfed conditions. However, greater yam being a long duration (9-10 months) crop, may suffer from insufficient moisture at later stages. Supplementary irrigation to greater yam+maize intercropping system is beneficial for uniform sprouting at early stage and rapid tuber bulking during post monsoon season. The commonly used method of irrigation is surface flood irrigation which ensures uniform spreading, high evaporation and seepage loss. The greater yam+maize intercropping system develops thick canopy 3 months after planting and causes difficulty for application of surface flood irrigation. Further, water is a scarce resource which needs to be preserved.

The field experiments conducted at the Regional Station of ICAR-Central Tuber Crops Research Institute, Dumuduma, Bhubaneswar, Odisha revealed that the treatment drip irrigation at 100% of CPE during 1-90 DAP+80% of CPE during 91-270 DAP resulted in maximum greater yam and tuber equivalent yield (TEY). Fertigation of N-P_2O_5-K_2O @ 160-90-160 kg ha^{-1} was resulted in higher maize and greater yam yield and TEY than other treatments. Treatments drip irrigation at 100% of CPE during 1-90 DAP+80% of CPE during 91-270 DAP along with fertigation of N-P_2O_5-K_2O @ 160-90-160 kg ha^{-1} and drip irrigation at 100% of CPE during 1-90 DAP+80% of CPE during 91-270 DAP along with fertigation of N-P_2O_5-K_2O @ 140-90-140 kg $ha^{-1}$of N-P_2O_5-K_2O were on par and resulted in higher greater yam yield, TEY, nutrient and water use efficiency. Hence, the treatment drip irrigation at 100% of CPE during 1-90 DAP+80% of CPE during 91-270 DAP along with fertigation of N-P_2O_5-K_2O @ 140-90-140 kg ha^{-1} is recommended for greater yam+maize intercropping system considering greater TEY, nutrient and water use efficiency as well as minimum water requirement per kg of TEY production (Nedunchezhiyan et al., 2021a).

Conclusion

Cow dung slurry cap sett treatment and mulching are essential for combating climate change effects at early stages in root and tuber crops. Storage of vine cuttings prior to planting in main field augment early establishment of the sweet potato and planting sweet potato on 45 cm ridge height (row to row spacing 90 cm) resulted in higher marketable tuber yield. Tuber crops- based cropping systems were found biologically efficient and resulted in sustainable yield, higher returns, lower investment and dietary variation in farm family consumption. Greater yam, elephant foot yam and greater yam+maize intercropping system responded well to drip irrigation and fertigation.

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