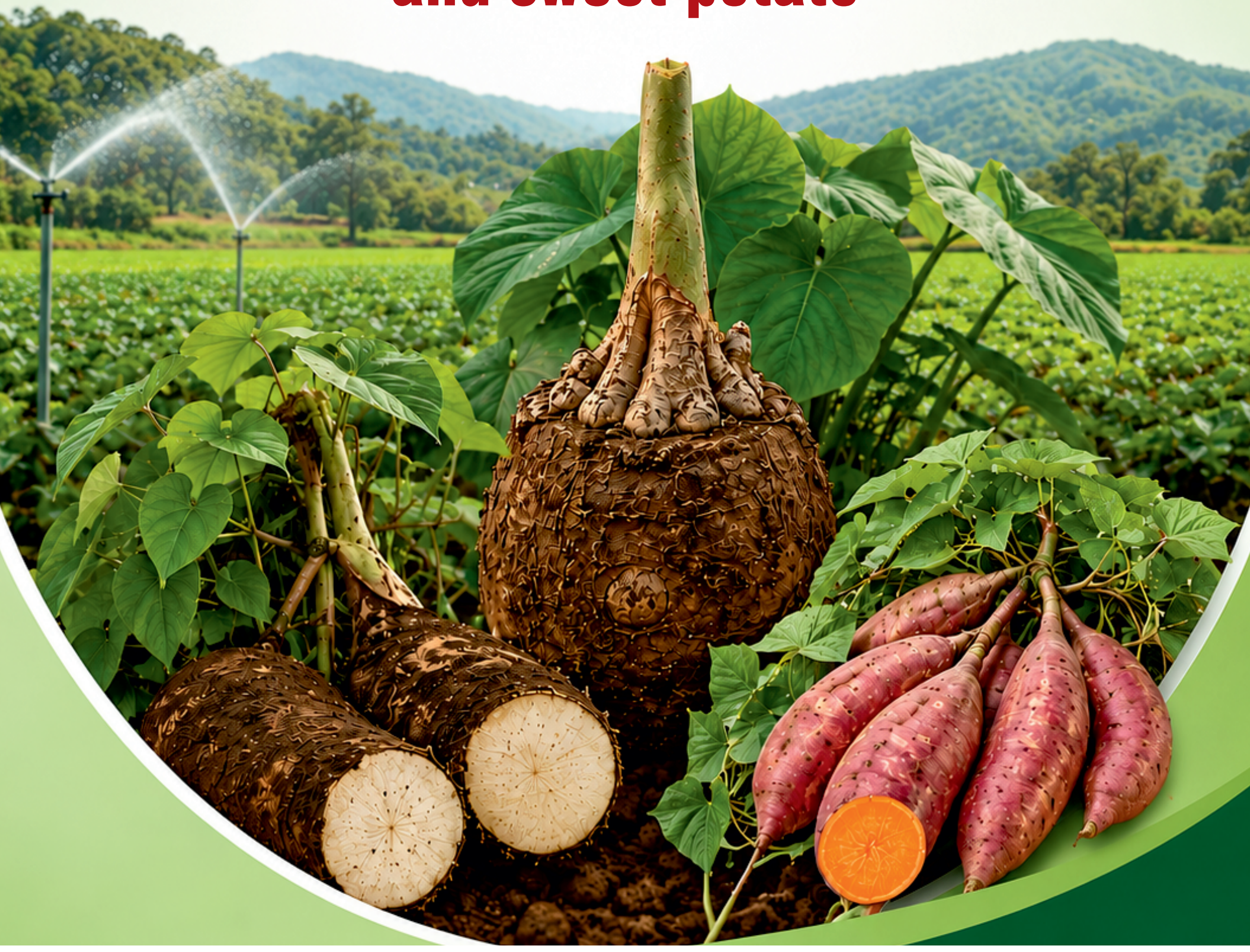
Water management in greater yam, elephant foot yam and sweet potato



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From the Director

Tropical tuber crops are the third most important food crops after cereals and grain legumes and served as staple food for millions of people in the world and in India, it is considered as secondary staple. The most important tropical tuber crops are cassava (*Manihot esculenta*), sweet potato (*Ipomoea batatas*), greater yam (*Dioscorea alata*), taro (*Colocasia esculenta*), elephant foot yam (*Amorphophallus paeoniifolius*), yam bean (*Pachyrhizus erosus*) and arrowroot (*Maranta arundinacea*) etc.

Tropical tuber crops grow well in marginal soil with fewer inputs where other crops usually fail to grow. Being high yielder with considerable period of storability, they are commercially grown in many parts of the world particularly in India. Tropical tuber crops are tolerant to drought at various degrees, however they respond very well to irrigation. The ICAR-Central Tuber Crops Research Institute has studied water requirement and water productivity (quantity m^{-3} of water) of important tuber crops. The water requirement (consumptive use) of greater yam is 670 mm with the WUE of 56 kg $ha.mm^{-1}$ and its water productivity is 5.6 kg m^{-3}. The greater yam+maize intercropping system requires 900 mm of water (consumptive use) with the WUE of 50 kg $ha.mm^{-1}$ and its water productivity is 5.0 kg m^{-3}. Elephant foot yam is water loving crop. Hence, well drained clay loam soils are highly suitable for this crop. The water requirement (consumptive use) of elephant foot yam is 1200 mm with the WUE of 25 kg $ha.mm^{-1}$ and its water productivity is 2.5 kg m^{-3}. Sweet potato is harvested 110-120 days after planting and it can tolerate mid-season drought. The water requirement (consumptive use) of sweet potato is 200 mm with the WUE of 55 kg $ha.mm^{-1}$ and its water productivity is 5.5 kg m^{-3}. The water productivity of the tuber crops (greater yam, elephant foot yam and sweet potato) was higher than most commonly cultivated cereals and pulses.

The information given in this publication is very useful to students, researchers and policy makers. I congratulate Dr. M. Nedunchezhiyan and his team for their sincere efforts in bringing out this highly useful publication.

July 2026

G. Byju
Director

Preface

Water for irrigation is becoming both scarce and expensive and necessitates to be utilized in a scientific manner. At present the crops are irrigated by flooding. The water use efficiency is very less in such system. Irrigation through drip saves lot of water (scarce commodity). Drip irrigation is an efficient method of providing water directly in to the root zone of plants. It checks unwanted weed growth and reduces water requirements. Drip irrigation has proved to be a success in terms of water and increased yield in a wide range of crops. Its ability of small and frequent irrigation applications has created interest because of decreased water requirements, possible increased production and better-quality produce. Further nutrient use efficiency of soil applied fertilizers are very less. Fertigation is a method of application of fertilizer through irrigation and supply the nutrients in the feeding zone. Application of fertilizers along with water through drip irrigation system increases crop yield and nutrient use efficiency. Now soluble fertilizers are available. When we use the same through drip irrigation nutrient use efficiency will be further increased.

In this publication, detailed studies on water management along with nutrients on greater yam, greater yam+maize intercropping, elephant foot yam, elephant foot yam+green gram and sweet potato were given. The information given in this publication is very useful to students, researchers and policy makers.

M. Nedunchezhiyan
Principal Scientist

1. Introduction

Tropical tuber crops are the third 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.), yams (*Diosocrea* spp.), elephant-foot yam (*Amorphophallus paeoniifolius* (Dennst.) Nicolson), taro (*Colocasia esculenta* Schott), yam bean (*Pachyrrhizus erosus* (L) Urban), Chinese potato (*Solenostemon rotundifolius* L.), arrowroot (*Maranta arundinacea* L.) etc. Tropical tuber crops are the most important staple or subsidiary food to about 500 million global population. It is estimated that tuber crops provide about 6% of the world's dietary energy, apart from being good sources of vitamins, anti-oxidants, dietary fibres and minerals.

Worldwide, a considerable quantity of tropical roots and tubers are utilized for feed and fuel purposes. Tropical tuber crops serve as raw material for poultry and animal feed. For cassava, Nigeria and Brazil account for about 50% of its production for use as feed, whereas China imports cassava, mainly from Thailand, mostly for use in biofuel production. It was projected that the use of cassava for biofuel would increase from 1-8 million tonnes in 2019 (Alexandratos and Bruinsma, 2012). For sweet potatoes, China accounts for about 50% of the world production and for about 80% of world feed use, whereas Nigeria accounts for about 15% of world feed use. They also have immense industrial uses, in the production of starch, sago, alcohol, liquid glucose, vitamin C, besides medicinal properties.

2. Greater yam

Greater yam (*Dioscorea alata* L.) is a starchy tuber crop grown widely in African, Asian and Latin American countries (Photo 1). In India, it is a subsistence food crop in tribal and hilly areas and in other parts; it is a vegetable cash crop (Nedunchezhiyan and Sahoo, 2019). 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, can suffer from insufficient moisture at later stages. Though greater yam relatively tolerant to drought, yield is affected if drought occurs during initial stages of growth and during the tuber bulking phase.

Photo 1. Greater yam

Water is the scarcest commodity and its use efficiency is increased in agriculture by drip irrigation system. Drip irrigation supplies water directly to the root zone of the crop instead of land, as followed in the flood method of irrigation. The available research results revealed that the productivity gain due to drip method of irrigation was estimated to be in the range of 20 to 90% for different crops (INCID, 1994; Nedunchezhiyan et al., 2017). Further, surface irrigation becomes cumbersome at later stages [6 months after planting (MAP)] due to trailing of greater yam on the ground or stake. Under such situations, drip irrigation could be a better option for greater yam.

A field experiment was conducted for three years (2020-21, 2021-22 and 2022-23) at the Regional Centre of ICAR-Central Tuber Crops Research Institute, Bhubaneswar, Odisha to study effect of levels of drip irrigation and fertigation on greater yam. The experiment was laid out in split plot design with levels of irrigation in main plots (I_1-60% CPE, I_2-80% CPE and I_3-100% CPE) and in sub plots fertigation levels (F_1- N- P_2O_5-K_2O 60-60-60 kg ha^{-1}, F_2- N- P_2O_5-K_2O 80-60-80 kg ha^{-1} and F_3- N- P_2O_5-K_2O 100-60-100 kg ha^{-1}). Check: (surface irrigation IW/CPE: 1.0; P_2O_5 60 kg ha^{-1} basal application; N-K_2O 80-80 kg ha^{-1} soil application at basal (40%), 30 (30%) and 60 (30%) days after planting) and control: (surface irrigation IW/CPE: 1.0; No fertilizer) also included to compare the treatments. The treatments were replicated thrice. In fertigation treatments, Water soluble fertilizer N- P_2O_5-K_2O through fertigation as per treatment at basal (40%), 30 (30%) and 60 (30%) days after planting (DAP). In control/check P_2O_5 was applied in the last plough. N and K was applied in 3 splits at basal (40%), 30 DAP (30%) and 60 DAP (30%). Farmyard manure 10 t/ha was incorporated in the last plough in all the treatments except control/check (2). The greater yam weighing 200 g cut tubers were planted on ridge formed at 90 cm spacing. The plant to plant distance of 90 cm was maintained. The crop was harvested 300 days after planting.

Photo 2. Greater yam under drip fertigation

Table 1. Greater yam tuber yield, water and nutrient use efficiency as influenced by drip irrigation and fertigation levels

Treatments	Tuber yield (t ha^{-1})	Water use efficiency (kg ha-mm^{-1})	Fertilizer use efficiency (kg kg^{-1})
I_1F_1	22.9	35.2	127
I_1F_2	27.0	41.5	150
I_1F_3	30.1	46.3	167
I_2F_1	31.0	45.8	141
I_2F_2	35.3	52.1	160
I_2F_3	37.6	55.5	171
I_3F_1	33.9	48.2	131
I_3F_2	37.0	52.6	142
I_3F_3	38.1	54.1	146
C (NPK)	25.7	36.5	117
C	14.0	19.8	-
CD @ 5 %	2.6	3.3	11

Photo 3. Greater yam growth at different drip irrigation levels

The results revealed that increasing irrigation level increased greater yam tuber yield. The treatment I_3 resulted in higher tuber yield of 36.2 t ha^{-1} and it was followed by I_2 with 34.2 t ha^{-1}. Among fertigation, the treatment F_3 resulted in significantly higher tuber yield of 34.7 t ha^{-1}. The interaction was found between irrigation and fertigation levels. The treatment I_3F_3 resulted in higher tuber yield and it was statistically on par with I_2F_3 and I_3F_2 (Table 1). The treatment I_2F_3 resulted in higher water use efficiency (Table 1). The treatment I_2F_3 resulted in higher fertilizer use efficiency (Table 1). The consumptive use of water (water requirement) of greater yam was 650 mm (I_2F_3) (Table 2). The irrigation water required during pre and post monsoon period was 89 mm (I_2F_3) (Table 2). The treatment I_3F_3 resulted in higher gross and net returns as well as B:C ratio and it was statistically on par with I_2F_3 and I_3F_2 (Table 3).

Table 2. Consumptive use/water requirement of greater yam

Consumptive use/ water requirement	Drip irrigation			Surface/flood irrigation 100% CPE
	I_1: 60% CPE	I_2: 80% CPE	I_1: 100% CPE	
Irrigation water (mm)	66.8	89.1	111.2	111.2
Effective rainfall (mm)	547.3	547.3	547.3	547.3
Soil profile contribution (mm)	15.4	14.2	12.6	14.8
Total (mm)	629.5	650.6	671.1	673.3

Table 3. Economics of greater yam cultivation as influenced by drip irrigation and fertigation levels

Treatments	Cost of cultivation (₹ ha^{-1})	Gross return (₹ ha^{-1})	Net return (₹ ha^{-1})	B:C ratio
I_1F_1	179800	343100	163300	1.91
I_1F_2	186400	405200	218800	2.17
I_1F_3	192000	451400	259400	2.35
I_2F_1	188500	465400	276800	2.47
I_2F_2	195000	529400	334400	2.72
I_2F_3	200800	564600	363700	2.81
I_3F_1	192000	509200	317200	2.65
I_3F_2	198300	555700	357400	2.80
I_3F_3	201700	572200	370500	2.83
C (NPK)	171300	385100	213800	2.25
C	135100	209300	74200	1.55
CD @ 5 %	3200	38700	35700	0.17

A field experiment was laid out for three years (2022-23, 2023-24 and 2024-25) at the Regional Centre of ICAR-Central Tuber Crops Research Institute, Bhubaneswar, Odisha to study effect of fertigation interval and number of splits on greater yam. The experiment was laid out in split plot design with fertigation interval in main plots (I_1-2 days, I_2-3 days and I_3-4 days) and in sub plots number of splits (S_1-40 splits, S_2-50 splits and S_3-60 splits). A control treatment [soil application of N-P_2O_5-K_2O @ 100-60-100 kg ha^{-1} at NK basal (40%), 45 (30%) and 90 (30%) days after planting) and full P at basal] also included. The treatments were replicated thrice. Drip irrigation was given at 80% CPE. Fertigation of N-P_2O_5-K_2O 100-60-100 kg ha^{-1} was adopted. In fertigation treatments, water soluble fertilizer N- P_2O_5-K_2O was applied. Farmyard manure 10 t/ha was incorporated in the last plough in all the treatments. The greater yam weighing 200 g cut tubers were planted on ridge formed at 90 cm spacing. The plant to plant distance of 90 cm was maintained. The crop was harvested 300 days after planting.

Table 4. Yield and economics of fertigation interval and number of splits on greater yam

Treatments	Greater yamtuber yield (t ha^{-1})	Cost of cultivation (₹ ha^{-1})	Gross return (₹ ha^{-1})	Net return (₹ ha^{-1})	B:C ratio
I_1S_1	29.0	197500	435300	237800	2.20
I_1S_2	31.3	199800	469800	270000	2.35
I_1S_3	32.3	200800	484500	283700	2.41
I_2S_1	33.8	202300	506700	304400	2.51
I_2S_2	36.8	205300	552500	347200	2.69
I_2S_3	40.8	209500	614300	404900	2.93
I_3S_1	37.7	206200	565300	359100	2.74
I_3S_2	35.8	202500	536800	332600	2.63
I_3S_3	33.3	201800	500000	298200	2.48
C (NPK)	29.9	198400	449200	250700	2.27
C	14.6	156300	218500	62200	1.40
CD @ 5 %	1.2	1100	17200	16100	0.07

The results revealed that in greater yam, application of drip fertigation (N-P_2O_5-K_2O @ 100-60-100 kg ha^{-1}) at 3 days interval resulted in higher tuber yield (37.1 t ha^{-1}). Among number of splits, application of fertigation in 60 splits (N-P_2O_5-K_2O @ 100-60-100 kg ha^{-1}) resulted in higher tuber yield (35.5 t ha^{-1}). The interaction effects showed that fertigation at 3 days interval with 60 number of splits resulted in higher tuber yield (40.8 t ha^{-1}), cost of cultivation (₹ 209500 ha^{-1}), gross return (₹ 614300 ha^{-1}), net return (₹ 404900 ha^{-1}) and B:C ratio (2.93) (Table 4). In greater yam, response to fertigation was found up to 190 days.

3. Greater yam+maize intercropping

Greater yam+maize (Zea mays L) is a popular intercropping system in high rainfall regions of India. 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 reduces anthracnose incidence by 60.0% and increases yield by 26.3% in greater yam compared to un-stalked greater yam (Nedunchezhiyan et al. 2006). Maize, being a short duration (90-100 days) crop, can be successfully cultivated in high rainfall regions under rainfed conditions. However, 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 most commonly used method of irrigation is surface flood irrigation which ensures uniform spreading, high evaporation and seepage loss. Greater yam+maize intercropping system develops huge canopy 3 months after planting and causes difficult for application of surface flood irrigation. Further, water is a scarce resource which needs to be preserved. Drip irrigation is an efficient method of providing water directly to the plant root zone. Irrigation efficiency in drip irrigation is as high as 90% compared to 30-50% in surface irrigation with a saving of water of 40-80%. Greater crop yields with saving of water and higher water use efficiency in vegetables occurs with drip irrigation systems. The dense foliage develops in greater yam+maize intercropping system will not interfere in irrigation under drip system. At an early stage of greater yam+maize intercropping system, the demand for water was more due to simultaneous growth of maize and greater yam. After harvest of maize cobs, the water demand was only for greater yam.

A field experiment was conducted for two seasons (2015-16 and 2016-17) on greater yam+maize intercropping system at the Regional Centre of ICAR-Central Tuber Crops Research Institute, Bhubaneswar, Odisha. The climate of the location is a hot and humid summer, and a cool and dry winter. The experimental site soil was alfisols having pH 6.8, organic carbon 0.39%, available N 196 kg ha^{-1}, available P 21.4 kg ha^{-1} and available K 265 kg ha^{-1}. The experiment was laid out in split plot design with three replications. Main plots consisted of drip irrigation [I_1- at 80% of cumulative pan evaporation (CPE) during 1-270 days after planting (DAP), I_2-at 100% of CPE during 1-90 DAP + at 80% of CPE during 91-270 DAP and I_3-at 100% of CPE during 1-270 DAP] and fertigation (F_1-N-P_2O_5-K_2O 100-90-100 kg ha^{-1}, F_2-N-P_2O_5-K_2O 120-90-120 kg ha^{-1}, F_3-N-P_2O_5-K_2O 140-90-140 kg ha^{-1} and F_4-N-P_2O_5-K_2O 160-90-160 kg ha^{-1}) in sub plots. Water soluble N, P and K fertilizers (urea, urea phosphate and potassium sulphate) applied in five equal splits (basal, 30, 60, 90 and 120 DAP) through drip irrigation in fertigation treatments. Drip irrigation on alternate days was given as per treatment based on CPE considering pan factor 0.7.

Table 5. Effect of drip irrigation and fertigation on yield, CU, WUE and water required per kg of TEY of greater yam+maize intercropping system

Treatment	Maize yield (t ha^{-1})		Greater yam yield (t ha^{-1})		TEY (t ha^{-1})		CU of water (mm)		WUE (kg TEY ha-mm^{-1})		Water required per kg of TEY (litre)	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Drip irrigation												
I_1-80% of CPE during 1-270 DAP	2.6	2.4	31.0	28.9	33.7	31.3	886	805	38.0	38.9	267	261
I_2-100% of CPE during 1-90 DAP+ 80% of CPE during 91-270 DAP	2.9	2.8	34.9	33.8	37.9	36.5	896	815	42.2	44.8	239	227
I_3-100% of CPE during 1-270 DAP	3.0	2.7	33.4	30.6	36.3	33.3	897	833	40.5	40.1	250	252
SEm±	0.05	0.04	0.44	0.36	0.46	0.37	0.9	0.7	0.05	0.43	3.2	2.7
CD (P=0.05)	0.2	0.2	1.7	1.4	1.8	1.5	3	3	2.0	1.7	13	11
Fertigation (N-P2O5-K2O)												
100-90-100 kg ha^{-1} (F_1)	2.5	2.3	28.0	26.3	30.5	28.6	891	816	34.2	35.1	294	289
120-90-120 kg ha^{-1} (F_2)	2.8	2.6	32.8	30.2	35.6	32.8	892	817	39.9	40.2	251	250
140-90-140 kg ha^{-1} (F_3)	3.0	2.8	35.5	33.5	38.5	36.2	894	818	43.1	44.4	233	227
160-90-160 kg ha^{-1} (F_4)	3.0	2.9	36.1	34.3	39.1	37.2	894	819	43.7	45.4	229	222
SEm±	0.02	0.03	0.51	0.49	0.52	0.50	0.2	0.3	0.59	0.60	4.6	4.4
CD (P=0.05)	0.1	0.1	1.5	1.5	1.5	1.5	1	1	1.7	1.8	14	13

Source: Nedunchezhiyan et al., 2021a

Table 6. Drip fertigation influence on yield, CU, WUE and water required per kg of TEY of greater yam+maize intercropping system

Treatment	Maize yield (t ha^{-1})		Greater yam yield (t ha^{-1})		TEY (t ha^{-1})		CU of water (mm)		WUE (kg TEY ha-mm^{-1})		Water required per kg of TEY (litre)	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
I_1F_1	2.3	2.1	25.4	24.1	27.6	26.2	885	804	31.2	32.6	292	308
I_1F_2	2.6	2.5	30.8	28.9	33.4	31.3	886	805	37.8	39.0	252	257
I_1F_3	2.8	2.4	33.8	31.0	36.6	33.4	887	806	41.2	41.7	230	240
I_1F_4	2.8	2.7	34.2	31.5	37.0	34.1	887	806	41.7	42.3	225	236
I_2F_1	2.6	2.4	30.6	28.5	33.2	30.9	895	814	37.0	38.0	270	268
I_2F_2	2.9	2.7	34.9	32.0	37.8	34.7	895	814	42.2	42.7	237	235
I_2F_3	3.1	2.9	36.9	37.0	40.0	39.9	896	815	44.6	49.0	224	205
I_2F_4	3.1	3.0	37.3	37.5	40.4	40.6	897	816	45.0	49.7	223	202
I_3F_1	2.6	2.4	28.2	26.3	30.8	28.7	895	831	34.4	34.7	321	290
I_3F_2	2.9	2.7	32.8	29.7	35.5	32.4	896	832	39.8	39.0	265	257
I_3F_3	3.1	2.9	35.8	32.4	38.9	35.4	898	834	43.4	42.5	243	236
I_3F_4	3.2	3.0	36.7	33.9	39.9	36.9	899	834	44.4	44.2	240	227
Control	2.7	2.4	29.0	27.5	31.8	29.9	899	835	35.3	35.8	283	280
SEm±	0.05	0.06	0.86	0.80	0.88	0.81	0.8	0.7	0.99	0.98	7.4	7.0
CD (P=0.05)	0.2	0.2	2.5	2.3	2.6	2.4	2	2	2.9	2.8	22	21

Source: Nedunchezhiyan et al., 2021a

Photo 4a

Photo 4b

Photo 4a and b. Greater yam+maize intercropping under drip fertigation

Increasing drip irrigation level increased tuber equivalent yield (TEY) up to 100% of cumulative pan evaporation (CPE) during 1-90 days after planting (DAP) + at 80% of CPE during 91-270 DAP which afterwards decreased. This was due to both maximum maize and greater yam yield in 100% of CPE during 1-90 DAP + at 80% of CPE during 91-270 DAP (Table 5). The drip irrigation at 100% of CPE during 1-90 DAP + at 80% of CPE during 91-270 DAP has coincided with the water requirement of greater yam and maize. In this treatment drip irrigation at 100% of CPE during 1-90 days could meet the water requirement of maize and greater yam. Subsequently drip irrigation at 80% of CPE during 90-270 days was sufficient for greater yam growth and yield. Hence, drip irrigation at 100% of cumulative pan evaporation (CPE) during 1-90DAP + at 80% of CPE during 91-270 DAP was found optimum for greater TEY (Nedunchezhiyan et al., 2021a). The consumptive use of water by greater yam+maize intercropping system was increased with increase in water application. However, about 900 mm was found optimum for greater yam+maize intercropping system

(Table 5) (Nedunchezhiyan et al., 2024b).

Fertilizers applied directly to soil are generally not utilized efficiently by crops. In fertigation, nutrients are applied along with water directly into the zone of maximum root activity (Patel and Rajput 2000). Nutrient management for greater yam+maize intercropping is necessary to achieve high yields. For the greater yam+maize intercropping system, a fertilizer dose of N-P_2O_5-K_2O 100-75-100 kg ha^{-1} along with mulching (2 t ha^{-1} dried farm waste) is recommended for economic yield (Nedunchezhiyan et al. 2010). Application of N-P_2O_5-K_2O 120-90-120 kg ha^{-1} to the greater yam+maize intercropping system resulted in improved greater yam tubers and maize yield. Top dressing of fertilizers in greater yam+maize intercropping is very difficult due to spreading canopy development after the third month. Hence, fertigation is an option for nutrient management for the greater yam+maize intercropping system. Fertigation at 160-90-160 kg ha^{-1} of N-P_2O_5-K_2O resulted in maximum TEY whereas the minimum TEY was noticed in plants under the treatment 100-90-100 kg ha^{-1} of N-P_2O_5-K_2O (Table 5). This was due to more maize and greater yam yield (Table 5). The treatment 160-90-160 kg ha^{-1} of N-P_2O_5-K_2O resulted in 1.6-2.5, 10.0-13.1 and 28.2-30.1% greater TEY than the treatments 140-90-140 kg ha^{-1}, 120-90-120 kg ha^{-1} and 100-90-100 kg ha^{-1} of N-P_2O_5-K_2O, respectively. The TEY difference between 160-90-160 kg ha^{-1} of N-P_2O_5-K_2O and 140-90-140 kg $ha^{-1}$of N-P_2O_5-K_2O was negligible. Hence, fertigation of 140-90-140 kg $ha^{-1}$of N-P_2O_5-K_2O was considered optimum for greater yam+maize intercropping system (Table 5) (Nedunchezhiyan et al., 2021a).

Photo 5. Greater yam+maize intercropping under drip fertigation

Surface irrigation at 100% of CPE with soil application of N-P_2O_5-K_2O 120-90-120 kg ha^{-1} (control) and drip fertigation at 80% of CPE during 1-270 DAP with fertigation of same level of nutrients (N-P_2O_5-K_2O 120-90-120 kg ha^{-1}) resulted in same level of TEY

(Table 6). Thus, drip irrigation saved 0.684-0.710 million litre (17.9-25.9%) of water per ha. Same level of TEY with the treatments i.e. surface irrigation at 100% of CPE with soil application of N-P_2O_5-K_2O 120-90-120 kg ha^{-1} and drip fertigation at 100% of CPE during 1-90 DAP + at 80% of CPE during 91-270 DAP with 100-90-100 kg ha^{-1} of N-P_2O_5-K_2O as well as 100% of CPE during 1-270 DAP with 100-90-100 kg ha^{-1} of N-P_2O_5-K_2O also indicated a saving of nutrients N-K_2O 20-20 kg ha^{-1} (20%) under drip fertigation (Table 6) (Nedunchezhiyan et al., 2023a). Thus drip irrigation and fertigation not only saves water but also applied fertilizers than traditional surface flood irrigation and soil application of fertilizers. The treatments drip fertigation at 100% of CPE during 1-90 DAP + at 80% of CPE during 91-270 DAP with 160-90-160 kg ha^{-1} of N-P_2O_5-K_2O and drip fertigation at 100% of CPE during 1-90 DAP + at 80% of CPE during 91-270 DAP with 140-90-140 kg ha^{-1} of N-P_2O_5-K_2O resulted in greater TEY, WUE and NUE, and minimum water required per kg of TEY than control. The treatment 100% of CPE during 1-90 DAP + at 80% of CPE during 91-270 DAP with 140-90-140 kg ha^{-1} of N-P_2O_5-K_2O was at par with the treatment 100% of CPE during 1-90 DAP + at 80% of CPE during 91-270 DAP with 160-90-160 kg ha^{-1} of N-P_2O_5-K_2O in all the above parameters (Table 6). Hence, the treatment drip fertigation at 100% of CPE during 1-90 DAP + at 80% of CPE during 91-270 DAP with 140-90-140 kg ha^{-1} of N-P_2O_5-K_2O was recommended considering greater TEY, WUE and NUE, and minimum water required per kg of TEY (Nedunchezhiyan et al., 2021a). Nedunchezhiyan et al. (2023a) further reported that when same quantity of water and fertilizer was applied through drip, it increased 21.1% higher tuber equivalent yield, 21.1 and 24.7% higher gross and net returns, respectively than soil application (Table 7 and 8). When same quantity of fertilizer was drip fertigated, it saved 21.2% water and resulted in 5.2 and 3.1% higher gross and net returns, respectively. Thus, drip fertigation increased water and fertilizer-use efficiency 20% (Table 7 and 8).

Table 7. Comparison of drip fertigation vs control at same level of greater yam+maize intercropping system yield

Particulars	Treatment (I_1F_2)	Control
Tuber equivalent yield (t ha^{-1})	32.4	30.8
Irrigation water application (mm)	328.5	398.0
Fertilizer application (N-P_2O_5-K_2O kg ha^{-1})	120-90-120	120-90-120
Cost of cultivation (₹ x 10^3 ha^{-1})	184.9	170.0
Gross return (₹ x 10^3 ha^{-1})	486	462
Net return (₹ x 10^3 ha^{-1})	301.1	292
B:C ratio	2.63	2.72

Source: Nedunchezhiyan et al. (2023a)

Table 8. Comparison of drip fertigation vs control at same level of water and fertilizer application in greater yam+maize intercropping system

Particulars	Treatment (I_1F_2)	Control
Tuber equivalent yield (t ha^{-1})	37.3	30.8
Irrigation water application (mm)	398.0	398.0
Fertilizer application (kg ha^{-1})	120-90-120	120-90-120
Cost of cultivation (₹ ha^{-1})	195.4	170.0
Gross return (₹ ha^{-1})	559.5	462
Net return (₹ ha^{-1})	364.1	292
B:C ratio	2.86	2.72

Source: Nedunchezhiyan et al. (2023a)

The field experiment on greater yam+maize intercropping was laid out for three years (2017-18, 2018-19 and 2019-20) at the Regional Centre of ICAR-Central Tuber Crops Research Institute, Bhubaneswar, Odisha in split plot design with fertigation interval in main plots (I_1-2 days, I_2-3 days and I_3-4 days) and in sub plots number of splits (S_1-40 splits, S_2-50 splits and S_3-60 splits). Control (soil application at basal (40%), 45 (30%) and 90 (30%) days after planting) also included to compare the treatments. In greater yam+maize intercropping system, application of drip irrigation (100% of CPE during 1-90 DAP + at 80% of CPE during 91-270 DAP) at 2 days interval resulted in significantly higher maize seed yield compared to other treatments. However, maximum greater yam tuber and tuber equivalent yield was noticed in the treatment 3 days interval (Table 9). The treatment 60 splits of recommended dose of fertilizer (140-90-140 kg ha^{-1} of N-P_2O_5-K_2O) resulted in lower maize seed yield and higher greater yam tuber, and tuber equivalent yield (Table 9). The interaction effect was found significant (Table 9). The treatment I_1S_1 resulted in greater maize seed yield (3.2 t ha^{-1}) compared to other treatments. However, the treatment I_2S_3 resulted in higher greater yam tuber yield (37.0 t ha^{-1}) and tuber equivalent yield (39.4 t ha^{-1}). The treatment I_3S_1 was statistically on par with I_2S_3 with regard to greater yam tuber (35.9 t ha^{-1}) and tuber equivalent yield (37.9 t ha^{-1}). The drip fertigation treatments I_2S_3 resulted in higher nutrient use efficiency of 106.5 kg of greater yam tuber equivalent yield per kg of nutrient (NPK) application. The treatment I_2S_3 resulted in higher gross (₹ 5,91,000 ha^{-1}) and net (₹ 3,80,000 ha^{-1}) returns compared to other treatments (Table 9). Thus, fertigation of N-P_2O_5-K_2O @ 140-90-140 kg ha^{-1} in 60 splits at 3 days interval was recommended for greater yam+maize intercropping system for higher system yield, nutrient use efficiency, gross and net returns (Nedunchezhiyan et al., 2023b).

Table 9. Interaction effects of fertigation interval and number of splits on maize, greater yam and tuber equivalent yields

Treatment	Maize yield (t ha^{-1})	Greater yam yield (t ha^{-1})	TEY (t ha^{-1})	Nutrient use efficiency (kg kg^{-1})
I_1S_1	3.2	30.0	33.2	89.7
I_1S_2	2.9	31.6	34.5	93.2
I_1S_3	2.8	33.4	36.2	97.8
I_2S_1	2.6	32.7	35.3	95.4
I_2S_2	2.5	34.5	37.0	100.0
I_2S_3	2.4	37.0	39.4	106.5
I_3S_1	2.0	35.9	37.9	102.4
I_3S_2	1.7	33.2	34.9	94.3
I_3S_3	1.5	32.5	34.0	91.9
C (NPK)	2.5	28.6	31.1	84.1
SEm±	0.06	0.52	0.52	1.45
CD @5%	0.1	1.5	1.5	4.2

Source: Nedunchezhiyan et al. (2023b)

4. Elephant foot yam

Elephant foot yam is a member of Araceae family grown for underground tuberous vegetable botanically known as corm. In India, elephant foot yam is cultivated in Andhra Pradesh, West Bengal, Bihar, Uttar Pradesh, Tamil Nadu, Kerala, Maharashtra, Odisha and Karnataka (Nedunchezhiyan and Byju, 2005). Recently, interest has been increasing as a commercial cash crop in India due to its high productivity and profit (Nedunchezhiyan *et al*., 2010). The pseudostem and corm is consumed after chopping and boiling (Nedunchezhiyan *et al*., 2006a). The corms are also eaten after baking and frying. The corms are rich in minerals (calcium and phosphorus) and vitamins (vitamin A and C) (Nedunchezhiyan *et al*., 2008). It is also used as medicine in many preparations (Mondal *et al*., 2012; Nedunchezhiyan *et al*., 2016a).

Nutrient use efficiency of fertilizers applied to soil especially nitrogenous fertilizer was very low. Hence, improved methods and timings of application are called for higher nutrient use efficiency. Fertigation is an innovative cultural method by which fertilizers are applied along with irrigation water. Fertigation through drip system enables adequate supply of water and nutrients with precise timing and uniform distribution to meet the crop demand so as to get maximum yield (Fanish *et al*., 2011). Phene *et al*. (1979) reported 25-50% reduction in fertilizer requirement under drip fertigation compared to surface broadcasting without yield reduction. Drip fertigation not only improves the yield but also saves water and nutrients (Behera *et al*., 2013). Elephant foot yam is a long duration (8-10 months) crop with continues nutrient uptake up to 7th MAP (Kabeerathumma *et al*., 1987). The present recommendation for this crop is soil application of fertilizers up to 3rd month because the crop canopy structure/orientation does not permit intercultural activities afterwards. However, without damaging the canopy, elephant foot yam can be fertigated through drip. Furthermore, many of the researchers reported that multiple application of small quantity of fertilizers increases fertilizer use efficiency. In potato, fertigation of nutrients with very great dilution in each irrigation increased the fertilizer use efficiency far beyond the previously possible level (Menzel and Obe, 1990).

Photo 6. Elephant foot yam

A field experiment on elephant foot yam was laid out for three years (2009-2011) in split plot design with three replications at the Regional Centre of ICAR-Central Tuber Crops Research Institute, Bhubaneswar, Odisha. The experiment consisted of three drip irrigation levels I_1 60% CPE, I_2 80% CPE and I_3 100% CPE in main plots and three fertigation levels F_1 N-K_2O @ 80-80 kg ha^{-1}, F_2 N-K_2O @ 100-100 kg ha^{-1} and F_3 N-K_2O @ 120-120 kg ha^{-1} in sub plots. A control treatment (flood irrigation and soil application of N-P_2O_5-K_2O @ 100-60-100 kg ha^{-1}) was also included for comparison. Soil application of P_2O_5 @ 60 kg ha^{-1} was done in all the fertigation treatments and farmyard manure @ 10 t ha^{-1} was applied to all the treatments during last ploughing and incorporated into the soil. The result revealed that the higher corm length, diameter and yield/plant were with drip irrigation at 100% CPE. However, it was statistically on par with drip irrigation at 80% CPE (Table 10). Among fertigation, maximum corm length, diameter and yield/plant were with fertigation of N-K_2O 120-120 kg ha^{-1}. However, it was statistically on par with N-K_2O 100-100 kg ha^{-1}(Table 10).

Table 10. Drip irrigation and fertigation effects on yield attributes, yield, water use efficiency (WUE) and fertilizer use efficiency(FUE) in elephant foot yam

Treatments	Corm length (cm)	Corm diameter (cm)	Corm yield plant^{-1} (g)	Corm yield (t ha^{-1})	WUE (kg mm- ha^{-1})	FUE (kg kg^{-1})
Drip irrigation levels						
60% CPE	19.4	20.3	2280	28.1	22.3	135.7
80% CPE	21.0	22.1	2610	32.2	24.6	154.9
100% CPE	21.8	22.9	2750	33.9	24.9	163.3
SEm±	0.28	0.36	50	0.61	0.46	2.89
CD (P=0.05)	1.1	1.4	194	2.4	1.8	11.3
Fertigation levels (N-K_2O kg ha^{-1})						
80-80	19.2	20.1	2220	27.4	20.9	158.9
100-100	20.9	22.0	2630	32.4	24.7	155.0
120-120	22.1	23.2	2790	34.3	26.2	139.9
SEm±	0.29	0.39	52	0.65	0.49	3.09
CD (P=0.05)	0.9	1.2	160	2.0	1.5	9.5
Control (Flood irrigation and soil application of N-P_2O_5-K_2O @ 100-60-100 kg ha^{-1})	20.4	21.6	2480	30.5	17.7	146.1

Source: Nedunchezhiyan, 2017

The result also revealed that drip fertigation treatment I_3F_3 resulted in maximum growth attributes and corm yield. However, it was at par with I_3F_2 and I_2F_3. The dry matter accumulation in corm was greater than in shoot at 3, 5 and 8 MAP (months after planting) (Nedunchezhiyan et al., 2016). The higher corm length, diameter and yield/plant was with drip irrigation at 100% CPE with fertigation of N-K_2O 120-120 kg ha^{-1} (Table 11). The highest corm yield (37.0 t ha^{-1}) was obtained due to drip irrigation at 100% CPE and fertigation of N-K_2O @ 120-120 kg ha^{-1} (Table 11). However, maximum water use efficiency (WUE) was obtained with drip irrigation at 80% CPE and fertigation of N-K_2O @ 120-120 kg ha^{-1} (Table 11). This treatment resulted in optimum corm yield (35.7 t ha^{-1}) with net saving of 43,41,000 litre (434.1 mm) of water per ha of land per season, net income of 154 x 10^3 Rs ha^{-1} and net profit Rs 701 mm^{-1} of water applied (Table 12) (Nedunchezhiyan, 2017). The consumptive use of 1258.1 mm water was observed with drip irrigation, whereas in surface irrigation it was 1721.4 mm (Nedunchezhiyan et al., 2016). At 5 and 8 MAP, nutrient uptake by corm was greater than in shoot. The total K uptake of elephant foot yam was greater than N and P. The total N, P and K uptake was maximum at 8 MAP (at harvest) in all the treatments. The treatment I_3F_3 resulted in maximum total N, P and K uptake at all the stages. The water requirement of elephant foot yam reduced from 6.1 to 4.4 litres day^{-1} plant^{-1} and saved water

58.0-66.4% through drip irrigation. Drip fertigation (three splits) saved fertilizer N-K_2O 20-20 kg ha^{-1} (20%) and increased corm yield up to 15.1% (Nedunchezhiyan et al., 2016).

Table 11. Interaction effect of drip irrigation and fertigation on yield attributes, yield, WUE and FUE in elephant foot yam

Drip irrigation levels	Fertigation levels (N-K_2O) (kg ha^{-1})			Sem±	CD (P=0.05)
	80-80	100-100	120-120		
			Corm length (cm)		
60% CPE	18.6	19.4	20.3	0.49	1.5
80% CPE	19.1	21.2	22.7		
100% CPE	19.8	22.1	23.5		
			Corm diameter (cm)		
60% CPE	18.9	20.5	21.6	0.62	1.9
80% CPE	20.2	22.4	23.8		
100% CPE	21.1	23.3	24.4		
			Corm yield per plant (g)		
60% CPE	2040	2330	2460	86	264
80% CPE	2230	2700	2900		
100% CPE	2390	2850	3010		
			Corm yield (t ha^{-1})		
60% CPE	25.2	28.7	30.3	1.07	3.3
80% CPE	27.5	33.3	35.7		
100% CPE	29.4	35.1	37.0		
			FUE (kg ha^{-1})		
60% CPE	146.3	137.5	123.3	5.11	15.7
80% CPE	159.7	159.3	145.6		
100% CPE	170.7	168.3	150.9		

Source: Nedunchezhiyan, 2017

Photo 7. Elephant foot yam under drip fertigation

Table 12. Economic comparison of best drip irrigation and fertigation treatment vs control in elephant foot yam

Sl. No.	Particulars	Best drip irrigation and fertigation treatment (80% CPE and N-K$_2$O @120-120 kg ha^{-1})		Control (IW/CPE: 1.0; soil application of N-P2O5-K$_2$O @ 100-60-100 kg ha^{-1})
		Cost of lateral, drippers, accessories	Cost of valve, pipe, filters	
1	Fixed cost (x 10^3 ₹ ha^{-1})	50.0	50.0	
A	Life year	6	20	
B	Depreciation (x 10^3 ₹ ha^{-1})	8.3	2.5	
C	Interest (12%) (x 10^3 ₹ ha^{-1})	6.0	6.0	
D	Repair & maintenance (2%) (x 10^3 ₹ ha^{-1})	1.0	1.0	
	Total (B, C and D) (x 10^3 ₹ ha^{-1})	15.3	9.5	
	Grand total (x 10^3 ₹ ha^{-1})	24.8		
2	Cost of cultivation (x 10^3 ₹ ha^{-1})	203.0		175.6
3	Irrigation water (mm)	219.7 (80% CPE)		653.8
3a	Irrigation water saving over flood irrigation (mm)	434.1 (43,41,000 litre)		
4	Yield at 80% CPE and N-K$_2$O @ 120-120 kg ha^{-1} (t ha^{-1})	35.7		30.5
4a	Yield increase over flood irrigation (t ha-1)	5.2 (17.0%)		
5	Selling price (₹10,000 ha^{-1}) (x 10^3 ₹ ha^{-1})	357.0		305.0
6	Net income (x 10^3 ₹ ha^{-1})	154.0		129.4
7	Addl. area cultivable with 434.1 mm of water	1.98 ha		
8	Addl. expenditure (x 10^3 ₹1.98 ha^{-1})	402.0		
9	Addl. yield (t 1.98 ha^{-1})	70.7		
10	Addl. income (x 10^3 ₹ 1.98 ha^{-1})	707.0		
11	Addl. net income (x 10^3 ₹ 1.98 ha^{-1})	305.0		
12	Gross cost of cultivation (x 10^3 ₹ 2.98 ha^{-1})	605.0		
13	Total net income (x 10^3 ₹ 2.98 ha^{-1})	459.0		
14	B:C ratio	1.76		1.74
15	Net profit ₹ mm^{-1} of water used	701		198

Source: Nedunchezhiyan, 2017

Photo 8. Root development in elephant foot yam under drip irrigation

A field experiment was laid out on elephant foot yam during 2013 and 2014 in split plot design at the Regional Centre of ICAR-Central Tuber Crops Research Institute, Bhubaneswar, Odisha. The treatment consisted of different fertigation intervals (T_1:2, T_2:3 and T_3:4 days intervals) in the main plots and recommended dose of fertilizers (soluble fertilizer N-P_2O_5-K_2O @ 120-60-120 kg ha^{-1}) applied in splits (S_1:30, S_2:40 and S_3:50) through drip irrigation in sub plots. A check [surface irrigation with P_2O_5 60 kg ha^{-1} as basal and N-K_2O @ 120-120 kg ha^{-1} during 1st(40%), 2nd (30%) and 3rd (30%) month after planting (MAP) applied to soil] and control (surface irrigation without fertilizer) treatments were also included. All the treatments had three replications. The results revealed that the plant height, canopy spread and pseudostem (leaf petiole) girth at 3rd and 5th MAP was maximum in treatments which received maximum nutrients (Table 13). The growth was negligible between 5-7 months and then decline/senescence started (Nedunchezhiyan et al., 2017). Maximum corm diameter and corm length was recorded with the treatment T_2S_3 (fertigation in 50 split doses at 3 days interval) (Table 13). The corm yield was increased with increasing fertigation interval from 3 to 4 days with 40 to 50 split applications (Table 13). However, the crop was not responded to fertigation beyond 180 DAP (Nedunchezhiyan et al., 2017). The treatments T_3S_2 (fertigation in 40 split doses at 4 days interval) and T_2S_3 (fertigation in 50 split doses at 3 days interval) resulted in greater corm yield, dry matter and starch content, nutrient (N, P and K) uptake and use efficiency (agronomic efficiency, recovery efficiency and partial factor productivity) but the difference between the two treatments were not statistically significant (Table 13, 14 and 15). Control (surface irrigation without fertilizer) resulted in lower calcium oxalate content in corm. Dilution effect of calcium oxalate content was recorded in treatments that resulted in maximum corm yield (Nedunchezhiyan et al., 2018). Thus, for elephant foot yam, fertigation of water-soluble fertilizers *viz*., N- P_2O_5-K_2O 120-60-120 kg ha^{-1} in 40 split doses at 4 days interval (N-P_2O_5-K_2O 3-1.5-3 kg ha^{-1} dose^{-1}) or 50 split doses at 3 days interval (N-P_2O_5-K_2O 2.4-1.2-2.4 kg ha^{-1} dose^{-1}) can be recommended for greater productivity, quality and nutrient uptake and use efficiency (Nedunchezhiyan et al., 2017; Nedunchezhiyan et al., 2018).

Photo 9a

Photo 9b

Photo 9a and b. Root development in elephant foot yam influenced by levels and frequency of drip irrigation

Table 13. Growth and yield of elephant foot yam as influenced by fertigation interval and number of splits

Treatment	Plant height (cm)		Canopy spread (cm)		Pseudo stem girth (cm)		Corm diameter (cm)	Corm length (cm)	Corm yield plant^{-1} (g)
	3 MAP	5 MAP	3 MAP	5 MAP	3 MAP	5 MAP			
T_1S_1	78	90	90	118	15.2	18.2	17.7	16.0	2020
T_1S_2	82	91	94	120	15.4	18.5	19.4	17.5	2280
T_1S_3	80	94	90	122	15.2	18.6	21.4	18.1	2440
T_2S_1	82	89	93	119	15.3	18.4	21.2	17.7	2440
T_2S_2	78	92	91	123	15.2	18.7	22.3	18.9	2710
T_2S_3	75	97	89	126	15.1	18.9	23.5	20.1	2850
T_3S_1	77	92	91	124	15.0	18.9	22.2	18.8	2640
T_3S_2	74	93	86	123	14.7	18.7	23.6	20.3	2910
T_3S_3	71	92	83	122	14.5	18.7	22.5	19.0	2660
Check	72	92	83	120	14.7	18.3	19.4	17.3	2140
Control	64	82	79	98	13.9	17.2	13.4	12.1	1410
SEm±	1.7	3.1	1.0	1.7	0.14	0.20	0.24	0.21	61
CD (5%)	5	9	3	5	0.4	0.6	0.7	0.6	180

Source: Nedunchezhiyan et al., 2017

Table 14. Effect of fertigation schedule on dry matter, starch and calcium oxalate content in elephant foot yam corm

Treatment	Dry matter content (%)		Starch content (%)		Calcium oxalate (mg 100 g^{-1})	
	2013	2014	2013	2014	2013	2014
T_1S_1	19.2	18.8	15.6	15.2	81.4	81.0
T_1S_2	19.5	19.3	15.7	15.7	83.4	83.0
T_1S_3	19.8	20.0	16.1	16.5	83.6	84.0
T_2S_1	20.0	19.6	16.3	16.1	83.8	83.6
T_2S_2	20.3	20.1	16.5	16.4	84.5	84.3
T_2S_3	20.6	20.8	16.8	16.6	84.0	83.8
T_3S_1	20.2	20.0	16.7	16.5	84.6	84.4
T_3S_2	20.8	20.6	16.9	16.4	83.4	84.2
T_3S_3	20.5	20.1	16.4	16.3	84.0	84.4
Check	19.4	19.2	15.6	15.2	81.5	81.3
Control	19.0	18.8	15.2	14.6	80.5	80.3
CD (5%)	0.8	1.1	0.4	0.6	3.8	3.6

Source: Nedunchezhiyan et al., 2018

Table 15. Effect of fertigation schedule on NPK uptake, RE, AE, PE and PFP in elephant foot yam

Treatment	NPK uptake (kg ha^{-1})		AE		PE		RE		PFP	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
T_1S_1	274.9	241.7	27.7	22.0	85.5	96.8	32.4	25.8	88.3	77.7
T_1S_2	294.4	291.0	33.3	38.0	85.8	97.8	38.9	42.3	94.0	93.7
T_1S_3	304.2	322.8	38.0	46.3	90.2	87.6	42.1	52.9	98.7	102.0
T_2S_1	320.1	292.5	43.7	40.7	92.0	95.1	47.4	42.8	104.3	96.3
T_2S_2	354.3	324.5	53.7	52.7	91.2	98.6	58.8	53.4	114.3	108.3
T_2S_3	360.2	370.2	56.3	61.7	92.7	89.8	60.8	68.7	117.0	117.3
T_3S_1	346.3	328.1	49.3	51.3	87.8	94.0	54.6	54.6	110.0	107.0
T_3S_2	396.6	345.0	67.0	56.3	92.3	93.5	72.6	60.3	127.7	112.0
T_3S_3	370.2	315.6	55.3	44.3	86.3	87.8	64.1	50.5	116.0	100.0
Check	272.5	250.7	31.0	28.3	98.2	98.3	31.6	28.8	91.7	84.0
Control	177.8	164.2	-	-	-	-	-	-	-	-
CD (5%)	37.4	30.2	3.1	2.8	8.7	9.1	4.3	3.9	9.6	9.2

Source: Nedunchezhiyan et al., 2018
AE (agronomic efficiency), RE (recovery efficiency), PE (Physiological efficiency),
PFP (partial factor productivity)

5. Elephant foot yam+green gram

A field experiment was conducted during 2012 and 2013 at the Regional Centre of ICAR-Central Tuber Crops Research Institute, Bhubaneswar, Odisha to study the effects of cropping system and irrigation on nutrient use efficiency and quality of elephant foot yam. The experiment was laid out in split plot design with elephant foot yam+green gram (*Vigna radiata* L.) and elephant foot yam sole crop in main plots and surface irrigation, drip irrigation at 100% cumulative pan evaporation (CPE), drip irrigation at 80% CPE and drip irrigation at 60% CPE in sub-plots. The treatments were replicated five times. Elephant foot yam+green gram resulted in greater corm yield compared to other treatments (Table 16). The drip irrigation at 100, 80 and 60% CPE resulted in 16.7 and 14.9%, 16.4 and 14.6%, 12.3 and 11.5% higher yield over surface irrigation during 2012 and 2013, respectively (Jata et al., 2015; Jata et al., 2018a). The greater nitrogen, phosphorus and potassium uptake as well as nutrient use efficiency were noticed in elephant foot yam+green gram intercropping. Drip irrigation at 100% CPE resulted in higher nitrogen, phosphorus and potassium uptake as well as nutrient use efficiency followed by drip irrigation at 80% CPE (Table 16). The elephant foot yam+green gram resulted in greater protein and sugar content in the corms than sole cropping. But, starch and oxalate content were higher in sole elephant foot yam corms. Surface irrigation resulted in higher protein, sugar, starch and oxalate content in the coms (Table 17). The lowest protein, sugar and starch content in the corms were noticed in drip irrigation at 100% CPE, whereas the lowest oxalate content was noticed in drip irrigation at 80% CPE (Table 17). The minerals P, K, Ca, Mg and Zn content in the corms of sole elephant foot yam crop were higher than elephant foot yam+green gram intercropping (Table 18). Surface irrigation resulted in higher P and K content in the corms, whereas drip irrigation at 60% resulted in higher Ca, Mg and Zn content in the corms (Table 18). However, optimum elephant foot yam corm yield and nutrient use efficiency with mineral nutrition can be obtained under elephant foot yam+green gram intercropping with the application of drip irrigation at 80% CPE (Jata et al., 2018b).

Table 16. Effect of green gram intercropping and drip irrigation on nutrient uptake and nutrient use efficiency of elephant foot yam

Treatment	Corm yield (t ha^{-1})		Nitrogen uptake (kg ha^{-1})		Phosphorous uptake (kg ha^{-1})		Potassium uptake (kg ha^{-1})		Nutrient use efficiency (kg ha^{-1})	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
Cropping system										
EFY+GG intercropping	31.4	33.2	34.6	35.0	7.7	7.7	66.9	62.3	115	122
EFY sole	28.3	30.3	33.5	33.4	7.3	7.4	60.8	59.0	101	108
SEm±	0.2	0.3	0.2	0.3	0.1	0.03	1.2	0.9	0.77	1.0
CD (P=0.05)	1.0	1.2	0.8	1.3	0.3	0.1	4.6	NS	3.04	3.7
Irrigation										
Surface	26.8	28.8	33.6	34.0	7.1	7.3	60.2	58.8	97	104
Drip at 100% CPE	31.3	33.1	35.0	34.8	8.1	8.0	68.6	61.6	113	120
Drip at 80% CPE	31.2	33.0	34.2	34.5	7.7	7.7	64.3	62.1	113	120
Drip at 60% CPE	30.1	32.1	33.4	33.4	7.2	7.2	62.4	60.1	109	116
SEm±	0.3	0.3	0.3	0.3	0.1	0.1	1.3	0.9	1.0	0.9
CD (P=0.05)	1.0	0.8	0.9	0.9	0.3	0.4	3.8	NS	3.0	2.7
Interaction	*	*	NS	*	*	NS	*	*	*	*

EFY: Elephant foot yam, GG: Green gram, CPE: Cumulative pan evaporation

Source: Jata et al., 2018a

Table 17. Effect of green gram intercropping and drip irrigation on quality of elephant foot yam corm

Treatment	Protein (%)		Sugar (%)		Starch (%)		Oxalate (mg 100 g^{-1})	
	2012	2013	2012	2013	2012	2013	2012	2013
Cropping system								
EFY+GG intercropping	1.91	1.91	0.85	0.86	15.5	15.3	83.0	83.1
EFY sole	2.18	2.00	0.93	0.94	15.6	15.6	84.7	84.7
SEm±	0.02	0.03	0.01	0.01	0.05	0.1	0.7	0.7
CD (P=0.05)	0.09	NS	0.04	0.03	NS	NS	NS	NS
Irrigation								
Surface	2.35	2.19	1.01	1.00	16.4	16.9	84.4	84.3
Drip at 100% CPE	1.92	1.87	0.77	0.78	14.6	14.6	84.2	84.2
Drip at 80% CPE	1.93	1.88	0.84	0.85	15.3	15.1	82.9	83.0
Drip at 60% CPE	1.97	1.87	0.95	0.96	16.0	15.9	83.8	83.9
SEm±	0.03	0.05	0.01	0.02	0.2	0.2	1.0	1.0
CD (P=0.05)	0.10	0.13	0.04	0.05	0.5	0.5	NS	NS
Interaction	*	NS	*	*	NS	NS	NS	NS

EFY: Elephant foot yam, GG: Green gram, CPE: Cumulative pan evaporation, IC: Intercropping

Source: Jata et al., 2018b

Table 18. Effect of green gram intercropping and drip irrigation on mineral content of elephant foot yam corm

Treatment	Corm yield (t ha^{-1})		Nitrogen uptake (kg ha^{-1})		Phosphorous uptake (kg ha^{-1})		Potassium uptake (kg ha^{-1})		Nutrient use efficiency (kg ha^{-1})	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
Cropping system										
EFY+GG IC	0.081	0.077	0.91	1.08	95.3	95.5	45.3	45.4	0.98	0.99
EFY sole	0.085	0.082	0.97	1.13	96.3	96.4	46.4	46.5	1.04	1.04
SEm±	0.001	0.001	0.02	0.02	0.8	0.9	0.6	0.6	0.003	0.01
CD (P=0.05)	NS	0.005	NS	NS	NS	NS	NS	NS	0.01	NS
Irrigation										
Surface	0.088	0.086	1.02	1.16	95.3	95.3	45.8	45.9	0.97	0.96
Drip at 100% CPE	0.082	0.078	0.94	1.07	95.9	95.9	45.7	45.7	1.03	1.03
Drip at 80% CPE	0.082	0.079	0.90	1.09	96.2	96.5	45.9	46.0	0.97	0.97
Drip at 60% CPE	0.079	0.074	0.90	1.11	96.0	96.1	46.0	46.1	1.06	1.09
SEm±	0.002	0.002	0.03	0.03	1.1	1.1	1.0	1.0	0.005	0.02
CD (P=0.05)	0.006	0.005	0.08	NS	NS	NS	NS	NS	0.013	0.06
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	*	NS

EFY: Elephant foot yam, GG: Greengram, CPE: Cumulative pan evaporation, IC: Intercropping

Source: Jata et al., 2018b

Photo 10. Elephant foot yam+green gram intercropping under drip fertigation

A field experiment was conducted during 2013 and 2014 at the Regional Centre of ICAR-Central Tuber Crops Research Institute, Dumuduma, Bhubaneswar, Odisha to study the effects of fertigation on elephant foot yam [*Amorphophallus paeoniifolius* (Dennst.) Nicolson]+green gram (*Vigna radiata* L.) intercropping system. The experiment was laid out in randomized complete block design with four replications. The experiment consisted of six treatments Soil application of fertilizers T_1-N-K_2O @ 100-100 kg ha^{-1} (control), T_2-Fertigation of N-K_2O @ 60-60 kg ha^{-1}, T_3-N-K_2O @ 80-80 kg ha^{-1}, T_4-N-K_2O @ 100-100 kg ha^{-1}, T_5-N-K_2O @ 120-120 kg ha^{-1} and T_6-N-K_2O @ 140-140 kg ha^{-1}. Phosphorus 60 kg ha^{-1} was uniformly applied in to the soil in all the treatments. The result revealed that the numbers of pods plant^{-1}, seed and haulm yield of green gram were greater in fertigation treatments than soil application (Table 19) (Jata et al., 2019). However, green gram responded to fertigation upto T_3-N-K_2O @ 80-80 kg ha^{-1} (Table 19). The elephant foot yam yield attributes were influenced by fertigation treatments (Table 20). Increasing fertigation level upto T_6-N-K_2O @ 140-140 kg ha^{-1} resulted in higher corm diameter and average corm weight. However, number of corms per heap was found in control (T_1) (Table 20). The elephant foot yam corm yield increased with fertigation upto T_6-N-K_2O @ 140-140 kg ha^{-1} (Table 20). The corm yield of elephant foot yam and corm equivalent yield of elephant foot yam+green gram intercropping system with fertigation of T_4-N-K_2O @ 100-100 kg ha^{-1} was comparable with T_6-N-K_2O @ 140-140 kg ha^{-1} (Table 20). The fertigation of T_4-N-K_2O @ 100-100 kg ha^{-1} resulted in increase of 20.1-22.4% corm yield, 19.8-22.3% corm equivalent yield and 19.9-24.4% nutrient use efficiency over soil application (T_1) of the same quantity of nutrients. The fertigation of elephant foot yam+green gram intercropping system with N-K_2O @ 100-100 kg ha^{-1} (T_4) was also resulted in 26.7-28.7% greater net return and higher benefit: cost ratio over soil application of the same quantity of nutrients (Table 21). The study indicated that fertigation of N-K_2O @ 100-100 kg ha^{-1} was sufficient for obtaining optimum yield, returns and nutrient use efficiency in elephant foot yam+green gram intercropping system (Jata et al., 2020).

Table 19. Fertigation effects on plant height, yield attributes and yield of green gram in elephant foot yam+green gram intercropping.

Treatments	Plant height (cm)		Number of Pods per plant		Seed yield (kg ha^{-1})		Haulm yield (kg ha^{-1})	
	2013	2014	2013	2014	2013	2014	2013	2014
T_1	25.3	25.8	25.8	24.8	0.40	0.36	1.76	1.60
T_2	26.7	26.6	29.5	28.5	0.45	0.42	1.98	1.88
T_3	27.5	27.4	31.5	31.0	0.47	0.48	2.10	2.13
T_4	27.9	27.6	29.8	30.0	0.46	0.47	2.03	2.07
T_5	28.7	26.9	25.8	28.3	0.43	0.41	1.90	1.83
T_6	28.3	27.0	28.8	28.8	0.44	0.44	1.97	1.96
SEm±	0.3	0.2	1.3	1.1	0.02	0.02	0.07	0.10
CD (P=0.05)	1.0	0.7	NS	3.4	NS	0.06	NS	0.29

Source: Jata et al., 2019

Table 20. Fertigation effects on yield attributes and yield of elephant foot yam, and corm equivalent yield in elephant foot yam+green gram intercropping.

Treatments	Number of Corms per heap		Corm diameter (cm)		Average corm weight (kg)		Corm yield (t ha^{-1})		Corm equivalent yield (t ha^{-1})	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
T_1	1.2	1.1	18.6	18.8	2.2	2.4	29.4	29.5	29.8	30.0
T_2	1.1	1.2	21.2	22.0	2.5	2.5	32.3	32.7	32.7	33.4
T_3	1.1	1.1	23.0	24.5	2.8	2.8	34.1	35.2	34.5	36.0
T_4	1.0	1.1	24.5	25.3	3.0	2.9	35.3	36.1	35.7	36.7
T_5	1.0	1.1	24.8	25.4	3.1	3.2	36.0	36.6	36.4	37.4
T_6	0.9	0.9	25.4	25.8	3.7	3.6	36.2	36.7	36.6	37.4
SEm±	0.04	0.03	0.3	0.6	0.1	0.1	0.4	0.6	0.4	0.6
CD (P=0.05)	0.1	0.1	1.0	1.9	0.3	0.3	1.1	1.9	1.1	1.9

Source: Jata et al., 2019

Table 21. Fertigation effects nutrient use efficiency and economics of elephant foot yam+green gram intercropping.

Treatments	Nutrient use efficiency (kg kg^{-1})		Total cost ($x10^5$ ₹ ha^{-1})		Gross return ($x10^5$ ₹ ha^{-1})		Net return ($x10^5$ ₹ ha^{-1})		B:C ratio	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
T_1	106.3	107.2	1.71	1.71	4.56	4.57	2.85	2.86	1.7	1.7
T_2	163.6	166.8	1.81	1.81	5.02	5.07	3.21	3.27	1.8	1.8
T_3	143.8	150.1	1.82	1.82	5.30	5.47	3.48	3.65	1.9	2.0
T_4	127.5	133.4	1.86	1.86	5.47	5.57	3.61	3.68	1.9	1.9
T_5	113.7	114.6	1.89	1.89	5.56	5.67	3.67	3.81	1.9	2.0
T_6	101.7	104.0	1.92	1.92	5.60	5.69	3.68	3.77	1.9	2.0
SEm±	1.3	2.4	0.03	0.03	0.06	0.10	0.06	0.10	0.03	0.1
CD (P=0.05)	3.8	7.2	0.09	0.09	0.17	0.29	0.17	0.29	0.1	0.2

Source: Jata et al., 2020

6. Sweet potato

The sweet potato (*Ipomoea batatas* L.) is a plant of high rusticity with easy maintenance, good climatic adaptation, high tolerance to dryness, low crop production cost (Silva et al., 2002). It is also one of the highest calorie producers per area (370 Kcal 100 g^{-1} on a dry basis, Franco, 1996) and it is a root easy to transport and to storage. It is a crop cultivated in the tropic places where live most of the poor people, constituting an excellent human and animal food supply. Also, it is industrialized as powder, amid and even alcohol (Silva et al., 2002).

Sweet potato, a mid-season drought tolerant crop is grown throughout India, but mainly in eastern India. Odisha rank number one in area and production. Jharkhand, Chhattisgarh, West Bengal, Bihar and Eastern Uttar Pradesh are the other eastern states grow sweet potato. During *kharif*, it is grown in uplands and during *rabi* in lowlands with protective irrigation. It grows well in pH 5.5-6.5. Sandy loam soils are best suited for sweet potato (Nedunchezhiyan et al., 2006b).

Photo 11. Sweet potato

A field experiment was conducted for two *rabi* seasons (2002-03 and 2003-04) at the Instructional Farm, Krishi Vigyan Kendra, Orissa University of Agriculture and Technology, Barachana, Odisha to study the effect of irrigation and fertilizer levels on dry matter production and partitioning, yield, quality and nutrient uptake of sweet potato. The experiment was conducted in split plot design with three replications. The irrigation levels were assigned to main plots (I_1 = IW/CPE 0.6, I_2 = IW/CPE 0.8, I_3 = IW/CPE 1.0 and I_4 = IW/CPE 1.2) and fertility levels to sub plots (F_1 = N-P_2O_5-K_2O 0-0-0 kg ha^{-1}, F_2 = N-P_2O_5-K_2O 50-50-50 kg ha^{-1}, F_3 = N-P_2O_5-K_2O 50-50-75 kg ha^{-1}, F_4 = N-P_2O_5-K_2O 75-50-75 kg ha^{-1}, F_5 = N-P_2O_5-K_2O 75-50-100 kg ha^{-1} and F_6 = N-P_2O_5-K_2O 75-50-125 kg ha^{-1}). The results revealed that different growth parameters (vine length, number of leaves and LAI) and vine yield were greater with frequent irrigation at IW/CPE 1.2 (I_4) (Biswal et al., 2017a). Application of N-P_2O_5-K_2O 75-50-125 kg ha^{-1} (F_6) resulted in greater vine length, leaf number, LAI and vine yield (Table 22 and 24). Application of irrigation at IW/CPE 0.8 (I_2) resulted in greater yield attributes (tuber length, girth and weight per plant), tuber yield, harvest index and water use efficiency Table 23, 24 and 25). Irrigation and fertility levels significantly influenced sweet potato dry matter production, partitioning, tuber yield, quality and nutrient uptake (Table 26 and 27). The dry matter accumulation in leaves and stems was greater with irrigation at IW/CPE 1.2 and N-P_2O_5-K_2O 75-50-125 kg ha^{-1} (Table 26). The dry matter accumulation in tuber was greater with irrigation at IW/CPE 0.8. The application of N-P_2O_5-K_2O 75-50-75 kg ha^{-1} resulted in greater tuber yield (Table 24). The maximum tuber yield and nutrient uptake (NPK) were obtained with the application of N-P_2O_5-K_2O 75-50-75 kg ha^{-1} at IW/CPE 0.8. The starch and protein contents increased with increase in irrigation levels up to IW/CPE 1.0. The starch content in tuber increased up to N-P_2O_5-K_2O 75-50-100 kg ha^{-1} and that of protein content up to N-P_2O_5-K_2O 75-50-75 kg ha^{-1}. The sugar content, vitamin C and β- carotene contents were found progressively declined with added irrigation and fertility levels (Table 27). The treatment irrigation at IW/CPE 0.8 with application of N-P_2O_5-K_2O 75-50-75 kg ha^{-1} resulted in greater gross return, net return and B: C ratio (Table 26) (Biswal et al., 2017b).

Table 22. Effect of irrigation schedule and fertilizer levels on growth of sweet potato

Treatments	Vine length (cm)		Number of leaves $plant^{-1}$		LAI	
	2002-03	2003-04	2002-03	2003-04	2002-03	2003-04
Irrigation (IW/CPE)						
I_1=0.6	80	85	58	60	2.33	2.39
I_2=0.8	99	103	78	81	2.41	2.47
I_3=1.0	123	129	90	91	3.09	3.18
I_4=1.2	138	144	106	106	3.21	3.30
SEm ±	0.24	0.20	0.25	0.19	0.01	0.01
CD (0.05)	0.82	0.69	0.85	0.67	0.04	0.03
Fertility level (N-P_2O5-K_2O kg ha^{-1})						
F_1=0-0-0	42	42	54	47	1.97	2.01
F_2=50-50-50	83	85	64	68	2.45	2.51
F_3=50-50-75	112	117	84	87	2.71	2.87
F_4=75-50-75	133	139	95	97	2.95	3.20
F_5=75-50-100	140	146	98	101	3.13	3.21
F_6=75-50-125	153	160	102	106	3.35	3.21
SEm ±	0.46	0.35	0.36	0.25	0.01	0.01
CD (0.05)	1.32	1.00	1.03	0.72	0.02	0.02

Source: Biswal et al., 2017a

Table 23. Effect of irrigation schedule and fertilizer levels on yield attributes of sweet potato

Treatments	Tuber length (cm)		Tuber girth (cm)		Tuber weight (g plant^{-1})	
	2002-03	2003-04	2002-03	2003-04	2002-03	2003-04
Irrigation (IW/CPE)						
I_1=0.6	8.80	8.92	5.12	5.25	150	153
I_2=0.8	10.29	10.88	6.45	6.57	195	199
I_3=1.0	10.07	10.46	6.25	6.37	194	197
I_4=1.2	9.95	10.04	6.07	6.19	175	178
SEm ±	0.09	0.06	0.02	0.01	0.93	0.77
CD (0.05)	0.32	0.21	0.08	0.02	3.22	2.67
Fertility level (N-P_2O5-K_2O kg ha^{-1})						
F_1=0-0-0	6.89	6.92	4.16	4.24	83	84
F_2=50-50-50	8.75	9.23	5.47	5.58	175	178
F_3=50-50-75	10.29	10.61	5.94	6.05	192	195
F_4=75-50-75	11.99	12.32	7.27	7.44	209	215
F_5=75-50-100	10.93	11.25	6.79	6.93	207	211
F_6=75-50-125	9.83	10.11	6.21	6.32	207	209
SEm ±	0.08	0.04	0.04	0.02	0.79	0.57
CD (0.05)	0.23	0.10	0.11	0.07	2.26	1.64

Source: Biswal et al., 2017a

Table 24. Effect of irrigation schedule and fertilizer levels on tuber and vine yield of sweet potato

Treatments	Tuber yield (t ha^{-1})		Vine yield (t ha^{-1})	
	2002-03	2003-04	2002-03	2003-04
Irrigation (IW/CPE)				
I_1=0.6	11.88	12.10	14.35	15.36
I_2=0.8	15.44	15.71	16.59	17.78
I_3=1.0	15.29	15.57	17.64	18.82
I_4=1.2	13.84	14.02	19.96	21.14
SEm ±	0.18	0.16	0.16	0.13
CD (0.05)	0.62	0.55	0.55	0.45
Fertility level (N-P_2O5-K_2O kg ha^{-1})				
F_1=0-0-0	6.53	6.63	7.66	7.82
F_2=50-50-50	13.79	14.02	16.91	17.83
F_3=50-50-75	15.14	15.39	18.49	19.66
F_4=75-50-75	16.49	16.95	19.36	20.86
F5=75-50-100	16.38	16.63	19.78	21.24
F_6=75-50-125	16.35	16.47	20.16	21.74
SEm ±	0.15	0.11	0.04	0.09
CD (0.05)	0.43	0.31	0.12	0.26
Interaction (I x F)				

I_1F_1	5.20	5.29	6.95	7.11
I_1F_2	11.83	12.06	14.66	15.55
I_1F_3	12.77	13.01	15.60	16.84
I_1F_4	14.05	14.31	15.75	17.23
I_1F_5	13.79	14.04	16.55	17.90
I_1F_6	13.62	13.88	16.50	17.44
I_2F_1	6.07	6.19	7.73	7.99
I_2F_2	14.82	15.09	17.01	18.08
I_2F_3	16.63	16.93	18.06	19.35
I_2F_4	18.73	19.05	18.69	20.12
I_2F_5	18.32	18.64	18.96	20.14
I_2F_6	18.05	18.37	19.00	20.90
I_3F_1	6.29	6.41	7.27	7.31
I_3F_2	14.55	14.81	17.05	17.83
I_3F_3	16.41	16.70	18.95	19.96
I_3F_4	18.46	18.78	20.42	22.01
I_3F_5	18.09	18.42	20.69	22.35
I_3F_6	17.96	18.28	21.38	23.34
I_4F_1	8.54	8.63	8.74	8.95
I_4F_2	13.95	14.13	19.09	20.05
I_4F_3	14.74	14.93	21.44	22.71
I_4F_4	15.47	15.67	22.99	24.43
I_4F_5	15.20	15.42	23.43	24.91
I_4F_6	15.15	15.34	23.93	25.62
SEm ±	0.30	0.22	0.08	0.18
CD (0.05)	0.86	0.62	0.23	0.52

Source: Biswal et al., 2017a

Table 25. Effect of irrigation schedule and fertilizer levels on consumptive use, water use efficiency and harvest index of sweet potato

Treatments	Consumptive use (mm)		Water use efficiency (kg ha^{-1} mm)		Harvest index (%)	
	2002-03	2003-04	2002-03	2003-04	2002-03	2003-04
Irrigation (IW/CPE)						
I_1=0.6	92	115	129	105	45.29	44.06
I_2=0.8	120	143	129	109	48.20	46.91
I_3=1.0	138	155	110	101	46.43	45.27
I_4=1.2	152	183	91	77	40.95	39.87
SEm ±	1.90	2.00	1.90	1.70	0.34	0.23
CD (0.05)	6.50	6.90	6.60	5.90	1.19	0.78
Fertility level (N-P_2O5-K_2O kg ha^{-1})						
F_1=0-0-0	121	145	54	46	46.02	45.88
F_2=50-50-50	124	147	111	95	44.92	44.02
F_3=50-50-75	126	149	120	103	45.02	43.91

F_4=75-50-75	127	150	130	113	46.00	44.83
F_5=75-50-100	128	151	128	110	45.30	43.91
F_6=75-50-125	128	152	128	108	44.78	43.10
SEm ±	0.10	0.10	1.10	0.90	0.05	0.16
CD (0.05)	0.30	0.30	3.30	2.60	0.13	0.46

Source: Biswal et al., 2017a

The consumptive use of water was significantly influenced by irrigation and fertility levels (Table 25). Application of irrigation at IW/CPE 1.2 resulted in maximum consumptive use of water (153 mm during rabi 2002-03 and 183 mm during rabi 2003-04) (Table 25). It was 10.1 to 65.2% greater than that of the other ratios during rabi 2002-03 and 18.0 to 59.1% greater than that of the other ratios during rabi 2003-04. High moisture status in the root zone due to frequent irrigations increased evaporation and enhanced consumptive use (Biswal et al., 2017a). At low irrigation level the soil moisture stress caused increase in resistance to the flow of water, which reduced the consumptive use. Increase in consumptive use of water with increase in irrigation frequency has also been reported by Biswas et al. (1980). Maximum consumptive use of water noticed in F_6 and minimum was observed in F_1 (control) (Table 25). This might be due to higher vegetative (vine) growth. The WUE was significantly influenced by irrigation and fertility levels (Table 25). The WUE increased with the increase in irrigation level from IW/CPE 0.6 to IW/CPE 0.8 (Table 25). Further increase of frequency of irrigation (beyond at IW/CPE 0.8) reduced the WUE. Thus, maximum WUE was noticed at IW/CPE 0.8 and minimum at IW/CPE 1.2 (Table 25). Increasing fertility level increased WUE up to N-P_2O_5-K_2O @ 75-50-75 kg ha^{-1} (F_4), further increasing the fertility level decreased WUE. This might be due to decrease in tuber yield (Table 24) and increase in consumptive use of water (Table 25) at higher fertility levels (F_5 and F_6) (Table 25).

Table 26. Effect of irrigation and fertilizer levels on tuber and vine yield, nutrient uptake and economics of sweet potato

Treatments	Dry matter (t ha^{-1})	Tuber yield (t ha^{-1})	NPK uptake (kg ha^{-1})	Gross return (Rs ha^{-1})	Net return (Rs ha^{-1})	B:C Ratio
Irrigation (IW/CPE)						
I_1=0.6	6.243	11.99	172	35963	18285	2.03
I_2=0.8	7.505	15.57	226	46720	28542	2.57
I_3=1.0	7.496	15.43	233	46291	27113	2.41
I_4=1.2	7.263	13.93	216	41792	21864	2.10
SEm ±	0.053	0.17	3.0	329	327	0.01
CD (0.05)	0.182	0.59	9.0	1124	1118	0.03

Fertility level ($N-P_2O5-K_2O$ kg ha^{-1})						
F_1=0-0-0	3.188	6.58	66	19734	2921	1.17
F_2=50-50-50	6.952	13.91	187	41715	23023	2.23
F_3=50-50-75	7.649	15.26	224	45793	26900	2.42
F_4=75-50-75	8.284	16.72	273	50163	31015	2.62
F_5=75-50-100	8.288	16.51	269	49519	30170	2.56
F_6=75-50-125	8.398	16.41	249	49224	29676	2.52
SEm ±	0.043	0.13	3.0	358	359	0.01
CD (0.05)	0.122	0.37	7.0	1023	1013	0.03
Interaction (I x F)						
I_1F_1	2.810	5.25	55	15736	-14	1.00
I_1F_2	6.246	11.94	154	35833	18203	2.03
I_1F_3	6.742	12.89	183	38667	20837	2.17
I_1F_4	7.130	14.18	216	42551	24465	2.35
I_1F_5	7.208	13.91	222	41742	23456	2.28
I_1F_6	7.323	13.75	201	41244	22758	2.23
I_2F_1	3.130	6.13	67	18393	2143	1.13
I_2F_2	7.354	14.95	201	44860	26730	2.47
I_2F_3	8.096	16.78	241	50343	32013	2.75
I_2F_4	8.855	18.89	297	56665	38079	3.05
I_2F_5	8.769	18.48	285	55439	36653	2.95
I_2F_6	8.826	18.21	264	54630	35644	2.88
I_3F_1	3.022	6.35	64	19049	1799	1.10
I_3F_2	7.115	14.68	202	44047	24917	2.30
I_3F_3	8.003	16.55	243	49658	30328	2.57
I_3F_4	8.923	18.62	308	55857	36271	2.85
I_3F_5	8.873	18.25	299	54762	34976	2.77
I_3F_6	9.043	18.12	280	54360	34374	2.72
I_4F_1	3.789	8.59	77	25757	7757	1.43
I_4F_2	7.094	14.04	191	42120	22240	2.12
I_4F_3	7.757	14.83	228	44503	24423	2.22
I_4F_4	8.230	15.57	272	46707	26371	2.30
I_4F_5	8.301	15.31	272	45935	25399	2.24
I_4F_6	8.399	15.24	253	45735	24999	2.21
SEm ±	0.085	0.26	5	716	718	0.01
CD (0.05)	0.244	0.74	15	2046	2026	0.04

Source: Biswal et al., 2017b

Table 27. Effect of irrigation and fertilizer levels on quality of sweet potato tubers

Treatments	Starch (%)*	Sugar (%)*	Protein (%)*	B-carotene (mg 100 g^{-1})*	Vitamin C (mg 100 g^{-1})*
Irrigation (IW/CPE)					
I_1=0.6	58.60	12.78	6.14	2.39	66.89
I_2=0.8	61.56	12.30	6.50	2.37	66.18

I_3=1.0	62.53	12.11	6.61	2.34	65.05
I_4=1.2	60.09	11.56	6.19	2.34	64.56
SEm ±	0.46	0.07	0.02	0.02	0.40
CD (0.05)	1.60	0.25	0.07	NS	1.39
Fertility level ($N-P_2O5-K_2O$ kg ha^{-1})					
F_1=0-0-0	51.04	13.64	4.79	2.46	66.66
F_2=50-50-50	60.21	12.60	5.70	2.45	66.33
F_3=50-50-75	61.98	12.11	6.17	2.43	65.55
F_4=75-50-75	62.85	11.97	7.01	2.39	65.35
F_5=75-50-100	64.80	11.67	6.83	2.34	65.30
F_6=75-50-125	63.88	11.15	6.67	2.10	64.81
SEm ±	0.42	0.09	0.01	0.02	0.52
CD (0.05)	1.20	0.27	0.02	0.05	1.48

*Dry weight basis
Source: Biswal et al., 2017b

Puddling, which is done to reduce percolation rate in rice causes soil compaction. This poses problem to the following arable crops (Peeyush Sharma et al., 2005). Sweet potato being root crop, may respond differently in puddled lowland rice field. Soil compaction may affect root bulking. Hence, an investigation on minimum tillage, irrigations and nutrient levels on sweet potato were carried out in rice-sweet potato cropping system during 2007-08 and 2008-09 at the Regional Centre of ICAR-Central Tuber Crops Research Institute, Bhubaneswar, Odisha. The experiment was conducted in split-split plot design with three replications. Minimum tillage and conventional tillage in main plots, 3, 5 and 7 supplemental irrigations in sub plots and 0-0-0, 37.5-25-37.5 and 75-50-75 $N-P_2O_5-K_2O$ kg ha^{-1} in sub-sub plots.

Sweet potato tends to grow continuously at varying rate depending up on the growing conditions. Reduction in leaf area at harvesting was noticed due to maturity of the crop. Number of irrigations had significant influence on vine length and LAI (Table 28). The longest vines and maximum LAI were noticed with highest frequency of irrigation (7 irrigations) during both the years of study. The shortest vines and lower LAI were observed with minimum irrigation level (3 irrigations). Under moisture stressed conditions (3 irrigations) photosynthesis rate was reduced which in turn decreased the growth parameters. Increasing frequency of irrigation increased the yield attributes in both the years of study. Significantly higher number of roots per plant, root length, root diameter (N-S and E-W) and root yield per plant were found with 7 irrigations compared to other irrigation levels (Nedunchezhiyan et al., 2012). However, it was at par with 5 irrigations with respect to root diameter (N-S and E-W). Application of 5 irrigations recorded significantly higher number of roots per plant, root length, root diameter (N-S and E-W) and root weight per plant than 3 irrigations. Soil moisture stressed conditions restrict the yield forming processes. Under stress free conditions, soil rhizosphere favour yield attributes development.

Table 28. Effect of tillage, irrigation and nutrient levels on growth of sweet potato in ric-sweet potato system

Treatment	Vine length (cm)		LAI			
	2007-08	2008-09	2007-08		2008-09	
			90 DAP	Harvest	90 DAP	Harvest
Tillage						
Minimum tillage	102.3	100.6	2.51	2.38	2.42	2.33
Conventional tillage	110.1	115.6	2.74	2.50	2.64	2.51
LSD (P=0.05)	8.1	7.7	NS	NS	0.19	0.15
No. of irrigations						
3	97.8	96.7	2.31	2.11	2.26	2.12
5	107.1	111.3	2.68	2.50	2.61	2.53
7	114.8	117.3	2.88	2.72	2.72	2.61
LSD (P=0.05)	4.6	3.5	0.08	0.05	0.05	0.04
Nutrient levels ($N-P_2O_5-K_2O$ kg ha^{-1})						
0-0-0	91.9	96.4	2.50	2.31	2.36	2.26
37.5-25-37.5	110.3	112.3	2.63	2.46	2.58	2.42
75-50-75	116.5	116.6	2.74	2.57	2.65	2.58
LSD (P=0.05)	3.8	3.4	0.07	0.07	0.07	0.06

Source: Nedunchezhiyan et al., 2013

Photo 12. Sweet potato under different method of planting and irrigation levels

Table 29. Effect of tillage, irrigation and nutrient levels on root and fodder yield of sweet potato in rice – sweet potato system

Treatment	Root yield (kg ha^{-1})		Fodder yield (kg ha^{-1})	
	2007-08	2008-09	2007-08	2008-09
Tillage				
Minimum tillage	11100	9210	10370	10530
Conventional tillage	11600	12000	10810	12820
LSD (P=0.05)	470	410	NS	380
No. of irrigations				
3	9320	8360	8390	9770
5	11640	10710	10860	11640
7	13100	12750	12510	13630
LSD (P=0.05)	500	330	250	330
Nutrient levels ($N-P_2O_5-K_2O$ kg ha^{-1})				
0-0-0	9990	9040	9670	10190
37.5-25-37.5	11530	10610	10770	11700
75-50-75	12540	12180	11330	13140
LSD (P=0.05)	340	240	390	260

Source: Nedunchezhiyan et al., 2013

Table 30. Interaction effect of tillage and number of irrigations on sweet potato root yield (kg ha^{-1}) in rice – sweet potato system

Method of tillage	Number of irrigations			CD (P=0.05)
	3	5	7	
		2007-08		
Minimum	8990	11530	12770	610
Conventional	9650	11750	13430	
		2008-09		
Minimum	7140	9240	11250	430
Conventional	9590	12180	14240	

Source: Nedunchezhiyan et al., 2013

Increasing irrigation frequency increased sweet potato root yield (Table 29). However, the rate of increase between 3 and 5 irrigations was higher than between 5 and 7 irrigations. Between 3-5 irrigation the root yield increase was 24.9% and 28.1%, whereas the increase of root yield between 5 and 7 irrigations was 24.5% and 19.0% during the year 2007-08 and 2008-09, respectively. The number of roots, root length and diameter were found increasing with levels of irrigation. Soil penetration resistance decreased with increased levels of irrigation. Due to smaller size of yield attributes lower root yield was recorded at 3 irrigations. Sweet potato vine is used as a green fodder for livestock. Increasing the frequency of irrigation increased the green fodder yield (Table 29). Significantly higher green fodder yield was registered with 7 irrigations. It was 49.2% over 3 irrigations and

15.2% over 5 irrigation during 2007-08, whereas 39.5% higher over 3 irrigations and 17.1% over 5 irrigations during 2008-09. Increased moisture availability favoured higher crop growth

Minimum tillage sweet potato crop responded very well to irrigation (Table 30). Under minimum tillage the yield increase rate was higher with increasing level of irrigation and continued up to 7 irrigations. In less frequently irrigated treatment (3 irrigations) under zero tillage crop establishments highly flattened and irregular shaped roots were observed. This might be due to soil compactness. With the increasing the frequency of irrigation the compactness was reduced and roots bulked uniformly. Irrigation brings changes in soil physical properties, basically acting as soil lubricant and influence soil compaction (Nedunchezhiyan et al., 2013). Soil compaction and soil moisture are known to influence tuberous root growth in sweet potato (Nedunchezhiyan et al., 2012). In conventional system of planting uniform response for irrigation frequency was observed and highest yield was noticed at 7 irrigations. Irrigation level improved the efficiency of fertilizer utilization. Increasing fertilizer levels at lower level of irrigation frequency increased the root yield at lower rate compared to higher level of irrigation frequencies. It indicated that plant requires sufficient moisture to fully utilize applied nutrients. Maximum root yield was noticed when higher dose of fertilizer was applied along with maximum number of irrigations.

The effective root depth of sweet potato appears to be in the range of 0.4 to 0.6 m, although roots can extend to at least one meter (Gomes and Carr, 2003). Hence, soil moisture profile studies were carried out up to 0.6 m soil depth. Profile moisture contribution from 0-15, 15-30, 30-45 and 45-60 cm indicated that 78% of water extracted from top 0.45 m of the soil profile (Table 31 and 32). Increasing irrigation frequency, the percentage of moisture contribution between 0-45 and 0.6 m soil depth was decreased. At 3 irrigations, the maximum contribution of 23.2% and 23.0% soil moisture at 0.45-0.6 m soil depth was noticed during 2007-08 and 2008-09. The consumptive use of water was markedly higher with increase in irrigation levels than that with reduced irrigations. Significantly higher consumptive use of water was observed with 7 irrigations than other irrigation levels in both the years of study. The lowest consumptive use of water noticed at 3 irrigations, which was 24.5% and 55.6% lower than 3 and 7 irrigations respectively in 2007-08 and 35.3% and 79.6% lower than 3 and 7 irrigations respectively in 2008-09. The consumptive use of water by sweet potato in rice-sweet potato cropping system was ranged from 200-250 mm (Nedunchezhiyan et al., 2012). Reduction in WUE was found with increasing number of irrigations. Maximum WUE was found with 3 irrigations.

Table 31. Effect of different treatments on consumptive use of water by sweet potato in rice – sweet potato system during 2007-08

Treatment	Moisture contribution from profile storage (mm)					Evaporation (mm)	Effective rainfall (mm)	Consumptive use (mm)	Water use efficiency (kg mm^{-1})
	0-15 cm	15-30 cm	30-45 cm	45-60 cm	Total				
Method of tillage									
Minimum tillage	34.4	31.9	29.1	26.3	121.6	24.8	58.2	204.6	54.6
	(28.3)*	(26.2)	(23.9)	(21.6)	(100.0)				
Conventional	28.9	28.8	28.2	25.6	111.5	22.7	58.2	192.4	60.6
	(25.9)	(25.8)	(25.3)	(23.0)	(100.0)				
CD (P=0.05)	-	-	-	-	-	-	-	13.5	NS
No. of irrigation									
3	21.7	21.5	21.4	19.5	84.1	14.4	58.2	156.7	59.5
	(25.8)	(25.6)	(25.4)	(23.2)	(100.0)				
5	29.0	31.1	29.0	24.3	113.4	23.5	58.2	195.1	59.5
	(25.6)	(27.4)	(25.6)	(21.4)	(100.0)				
7	40.1	40.8	39.1	32.3	152.3	33.4	58.2	243.9	53.8
	(26.3)	(26.8)	(25.7)	(21.2)	(100.0)				
CD (P=0.05)	-	-	-	-	-	-	-	5.0	3.6
Nutrient levels (kg ha^{-1})									
0-0-0	27.3	29.2	27.6	24.5	108.6	23.8	58.2	190.6	52.8
	(25.1)	(26.9)	(25.4)	(22.6)	(100.0)				
37.5-25-37.5	31.1	30.8	30.2	25.1	117.2	23.8	58.2	199.2	58.4
	(26.5)	(26.3)	(25.8)	(21.4)	(100.0)				
75-50-75	33.8	32.7	31.2	26.1	123.9	23.8	58.2	205.9	61.7
	(27.3)	(26.4)	(25.2)	(21.1)	(100.0)				
CD (P=0.05)	-	-	-	-	-	-	-	3.4	2.4

*Percentage values are given within parentheses
NS: Not significant
Source: Nedunchezhiyan et al., 2013

Table 32. Effect of different treatments on consumptive use of water by sweet potato in rice – sweet potato system during 2008-09

Treatment	Moisture contribution from profile storage (mm)					Evaporation (mm)	Effective rainfall (mm)	Consumptive use (mm)	Water use efficiency (kg mm^{-1})
	0-15 cm	15-30 cm	30-45 cm	45-60 cm	Total				
Method of tillage									
Minimum tillage	39.1	33.9	33.3	28.9	135.2	26.7	5.9	167.8	55.7
	(28.9)*	(25.1)	(24.6)	(21.4)	(100.0)				
Conventional	34.9	31.7	30.5	28.5	125.7	25.2	5.9	156.8	77.5
	(27.8)	(25.2)	(24.3)	(22.7)	(100.0)				
CD (P=0.05)	-	-	-	-	-	-	-	11.0	3.7
No. of irrigation									
3	25.1	24.9	24.5	22.2	96.7	14.8	5.9	117.4	71.2
	(26.0)	(25.7)	(25.3)	(23.0)	(100.0)				
5	34.5	33.1	32.2	28.5	128.3	24.6	5.9	158.8	67.6
	(26.9)	(25.8)	(25.1)	(22.2)	(100.0)				
7	45.2	43.6	40.9	36.6	166.3	38.6	5.9	210.8	60.8
	(27.2)	(26.2)	(24.6)	(22.0)	(100.0)				
CD (P=0.05)	-	-	-	-	-	-	-	4.7	2.8
Nutrient levels (kg ha^{-1})									
0-0-0	32.2	31.4	30.9	27.8	122.3	26.0	5.9	154.2	60.0
	(26.3)	(25.7)	(25.3)	(22.7)	(100.0)				
37.5-25-37.5	34.7	33.8	32.9	29.6	131.1	26.0	5.9	163.0	66.7
	(26.5)	(25.8)	(25.1)	(22.6)	(100.0)				
75-50-75	37.5	36.3	35.0	29.1	137.9	26.0	5.9	169.8	73.0
	(27.2)	(26.3)	(25.4)	(21.1)	(100.0)				
CD (P=0.05)	-	-	-	-	-	-	-	2.8	1.7

*Percentage values are given within parentheses
Source: Nedunchezhiyan et al., 2013

7. Conclusion

Tropical tuber crops grow well in marginal soil with fewer inputs where other crops usually fail to grow. Being high yielder with considerable period of storability, they are commercially grown in many parts of the world particularly in India. Tropical tuber crops are tolerant to drought at various degrees, however they respond very well to irrigation. The ICAR-Central Tuber Crops Research Institute has studied water requirement and water productivity (quantity m^{-3} of water) of important tuber crops which are given in the Table 33. Greater yam is also highly drought tolerant crop. The water requirement (consumptive use) of greater yam is 670 mm with the WUE of 56 kg $ha.mm^{-1}$ and its water productivity is 5.6 kg m^{-3}. The greater yam+maize intercropping system requires 900 mm of water (consumptive use) with the WUE of 50 kg $ha.mm^{-1}$ and its water productivity is 5.0 kg m^{-3}. Elephant foot yam is water loving crop. Hence, well drained clay loam soils are highly suitable for this crop. The water requirement (consumptive use) of elephant foot yam is 1200 mm with the WUE of 25 kg $ha.mm^{-1}$ and its water productivity is 2.5 kg m^{-3}. Sweet potato is harvested 110-120 days after planting and it can tolerate mid-season drought. The water requirement (consumptive use) of sweet potato is 200 mm with the WUE of 55 kg $ha.mm^{-1}$ and its water productivity is 5.5 kg m^{-3}. The water productivity of the tuber crops (greater yam, elephant foot yam and sweet potato) was higher than most commonly cultivated cereals and pulses.

Table 33. Water productivity of tropical tuber crops

Crop	Water productivity (kg m^{-3})
Greater yam	5.6
Greater yam+maize	5.0
Elephant foot yam	2.5
Sweet potato	5.5

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Annexure-I

Drip irrigation controlling valves

Filter system

Drip fertigation sensor control panel

Fertilizer mixing tank

Photo 13. Sensor based drip irrigation and fertigation system

Photo 14. Venturi based drip fertigation system

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