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Drip fertigation for greater yam (*Dioscorea alata*) and maize (*Zea mays*) intercropping

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ABSTRACT

An experiment was laid out in split-plot design with three replications. Main and sub 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, F_2-N-P_2O_5-K_2O 120-90-120 kg/ha, F_3-N-P_2O_5-K_2O 140-90-140 kg/ha and F_4-N-P_2O_5-K_2O 160-90-160 kg/ha) treatments respectively. The drip irrigation treatments $I_1(F_2)$ and $I_2(F_2)$ saved 17.3% (690 m^3/ha) and 7.8% (310 m^3/ha) irrigated water over surface flood irrigation at same level of fertilizer application (N-P_2O_5-K_2O 120-90-120 kg/ha) (check). Electricity consumption saved 104 (17.4%) and 47 (7.9%) kWh/ha by adopting drip irrigation levels $I_1(F_2)$ and $I_2(F_2)$, respectively over check. The system productivity with the application of N-P_2O_5-K_2O 100-90-100 kg/ha (F_1) along with drip irrigation at I_2 was comparable with check which indicated a net saving of N-K_2O 20-20 kg/ha. The net income from drip irrigated greater yam (*Dioscorea alata* L.) + maize (*Zea mays* L.) under $I_1(F_2)$ and $I_2(F_2)$ was about 9 100 and 62 100 ₹/ha higher than the crop cultivated with surface flood irrigation (check), respectively. Greater system productivity in the treatments I_2F_4 (31.8%) and I_2F_3 (29.9%) over check indicated fertilizer responsiveness under drip fertigation. Considering environmental and economical impact, the partial deficit drip irrigation and fertigation treatment I_2F_3 could be the best for greater yam+maize intercropping system.

Keywords: Cost of cultivation, Net return, System productivity, Water productivity

Greater yam (*Dioscorea alata* L.) is a vegetatively propagated starchy tuber crop rich in minerals and dietary fibre (Nedunchezhiyan and Sahoo 2019). Irrigation is gaining importance for greater yam+maize (*Zea mays* L.) intercropping system due to its higher productivity and profitability as well as rapid changing climate. The available literature revealed that the productivity gain with drip irrigation was estimated to be in the range of 20 to 90% for different crops (Nedunchezhiyan *et al*. 2017, Jata *et al*. 2019). The benefit cost ratios (B:C) provided for different crops in INCID (1994) suggested that investment in drip irrigation was economically viable, even after excluding water saving from the calculation. There is a linear relationship between groundwater irrigated area and electricity consumption (TERI 2005). Since most of the pump sets used for lifting water from wells were being operated using electricity, the use of electricity in agriculture has been obliviously increased over the years. Though groundwater use increased the cropping intensity and productivity of crops, the electricity in agriculture was not used efficiently mainly because of cultivation of crops predominantly under surface flood irrigation (World Bank, 2001). Estimates indicated that water use efficiency under surface flood irrigation was only about 35 to 40% (Sivanappan 1994, Rosegrant and Meinzen-Dick 1996).

Surface flood irrigation is widely adopted for greater yam+maize intercropping system in India. However due to lodging of the crops at later stages [6 months after planting (MAP)], surface irrigation becomes cumbersome. Under such situations, drip irrigation could be a better option for greater system productivity. Few studies conducted on greater yam alone or along with intercrops under drip irrigation indicated higher productivity. However, studies have not analysed the relationship between drip irrigation and electricity use. Since drip irrigation reduces the working hours of pump sets through water saving, it not only reduces the consumption of electricity per ha but also increases the efficiency of electricity use to a great extent. In this study, therefore, an attempt was made to optimize the irrigation and fertigation schedule for saving agri-inputs and energy for greater yam and maize intercropping system.

MATERIALS AND METHODS

A field experiment was conducted during 2015–16 and 2016–17 cropping seasons at the Regional Centre of

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ICAR-Central Tuber Crops Research Institute, Bhubaneswar, Odisha, India. The experimental site soil was alfisols having 6.8 *p*H, 0.39% organic carbon, 196 kg/ha available N, 21.4 kg/ha available P and 265 kg/ha available K. The experiment was laid out in split-plot design with three replications. Main and sub 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, F_2-N-P_2O_5-K_2O 120-90-120 kg/ha, F_3-N-P_2O_5-K_2O 140-90-140 kg/ha and F_4-N-P_2O_5-K_2O 160-90-160 kg/ha) treatments, respectively. Control (surface irrigation at 100% of CPE without fertilizer) and check (surface irrigation at 100% of CPE; soil application of N-P_2O_5-K_2O 120-90-120 kg/ha) treatments were also included for comparing drip irrigation and fertigation treatments. 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. In the check treatment, at basal the full dose of P_2O_5 (single super phosphate) was applied. N (urea) and K (muriate of potash) were applied in three split applications, basal (40%), 45 DAP (30%) and 90 DAP (30%). Drip irrigation on alternate days and surface irrigation once in every seven days were given as per treatment based on CPE considering pan factor 0.7. The greater yam variety Da 293 cut tubers weighing about 200 g were planted at 90 cm spacing on the ridges. On the same day hybrid maize MRM 3777 seeds were sown at 30 cm spacing in between two greater yam plants in the intra-rows. Maize cobs were harvested 3 MAP and left the haulms in the field. Irrigation was withheld 20 days before harvesting of greater yam and it was harvested 290 DAP.

The rainfall received during 2015-16 was 980.0, of which the effective rainfall was 439, 396, 396, 396 and 396 mm under I_1, I_2, I_3, check and control treatments, respectively. The rainfall received 2016-17 was 1238.5 mm, of which the effective rainfall was 470, 448, 441, 441 and 441 mm under I_1, I_2, I_3, check and control treatments, respectively. The amount of water applied through drip irrigation was 383, 432, 451 and 451 mm under I_1, I_2, I_3, check and control treatments, respectively during first cropping season. The amount of water applied through drip irrigation was 274, 301, 345, 345 and 345 mm under I_1, I_2, I_3, check and control treatments, respectively during second cropping season. Soil profile moisture contribution was estimated by following the standard procedure (Reddy 2000) and it was 64, 68, 50, 52 and 51 mm during first cropping season, and 61, 66, 47, 50 and 48 mm during second cropping season under I_1, I_2, I_3, check and control treatments, respectively. The data were analysed by following the procedure as suggested by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Water saving: Partial deficit irrigation under drip further decreased consumptive use of water. However, it significantly influenced crop yields (Table 1). The effective rainfall under partial deficit drip irrigation (I_1 and I_2) was higher than surface flood irrigation (check), which substantially decreased irrigation water requirement without affecting greater yam + maize intercropping system yield at same level of fertilizer application. The drip irrigation treatments $I_1(F_2)$ and $I_2(F_2)$ saved 17.3% (690 m^3/ha) and 7.8% (310 m^3/ha) irrigated water over surface flood

Table 1 Water and electricity saving under drip irrigation and fertigation in greater yam + maize intercropping system

Parameter	I_1 (F_2)	I_2 (F_2)	I_3 (F_2)	Check
Consumptive use of water (mm)	846	856	865	868
Effective rainfall (mm)	455	422	419	419
Irrigation water (mm)	329	367	398	398
Soil profile contribution (mm)	62	67	48	51
Maize yield (t/ha)	2.5	2.8	2.8	2.5
Greater yam yield (t/ha)	29.9	33.5	31.3	28.3
System productivity(t/ha)	32.4	36.3	34.1	30.8
Water saving over check (mm); (m^3/ha)	69 (690)	31 (310)	0 (0)	
Water productivity (kg/m^3)	3.8	4.3	3.9	3.5
Water cost saving over check (₹/ha)	39330	19840		
Water application (labour) cost saving over check (₹/ha)	10600	10200	9900	
Electricity consumption (kWh/ha)	493	550	597	597
Electricity cost (₹) @ 4 ₹/ kWh	1972	2200	2388	2388
Electricity saving over check (kWh/ha)	104	47	0	
Electricity cost saving over check (₹/ha)	416	188		
Cost efficiency (₹/t) (Production cost per tonne of system yield)	5707	5245	5563	5519
Electricity efficiency (kWh/t) (Electricity used per tonne of system yield)	15.2	15.2	17.5	19.4
Weeding (labour) cost saving over check (₹/ha)	5000	4000	3000	
Total cost saving (10+11+15+18) over check (₹/ha)	55346	34228	12900	
Depreciation, interest, maintenance cost on fixed cost of drip irrigation system (₹/ha)	24833	24833	24833	
Grand total cost saving (19-20) over check (₹/ha)	30513	9395	(-) 11933	

irrigation at same level of fertilizer application (N-P_2O_5-K_2O 120-90-120 kg/ha) (check). This indicates that with the same amount of water used for irrigating one ha of greater yam+maize intercropping system under surface flood irrigation, about 1.210 or 1.084 ha of greater yam+maize intercropping system can be irrigated using partial deficit drip irrigation I_1F_2 or I_2F_2, respectively. In other words, an additional area of 0.210 or 0.078 ha can be brought under partial deficit water drip irrigation from the saving of water realised through partial deficit drip irrigation I_1F_2 or I_2F_2 respectively, when same level of fertilizer was applied (N-P_2O_5-K_2O 120-90-120 kg/ha) (Table 2). This might be due to the more water supplies at the root zone of the crop and significantly less evaporation and distribution losses (Nedunchezhiyan *et al*. 2016).

Electricity saving: Electricity consumption (Table 1) clearly showed that about 104 and 47 kWh (saving of about 17.4 and 7.9%) could be saved from each ha of greater yam+maize cultivation by adopting drip irrigation levels $I_1(F_2)$ and $I_2(F_2)$, respectively over check. Narayanamoorthy (2009) reported that electricity 350 kWh/ha was saved under drip irrigation over surface flood irrigation in cotton. Even if we assume a tariff rate of 4 ₹/kWh, the cost saving on account of electricity saving would come to about 416 and 188 ₹/ha from greater yam+maize cultivation by adopting drip irrigation levels $I_1(F_2)$ and $I_2(F_2)$, respectively. Thus, the cost as well as electricity efficiency was also found to be higher under drip irrigation when compared to the same cultivated under surface flood irrigation (Table 1).

Fertilizer saving: Application of N-P_2O_5-K_2O 120-90-120 kg/ha in soil (check) resulted in system productivity of 30.8 t/ha (Table 3). Similar level of yield or more was achieved by application of N-P_2O_5-K_2O 100-90-100 kg/ha (F_1) along with drip irrigation at I_2. This indicated greater fertilizer use efficiency under drip fertigation and a net saving of N-K_2O 20-20 kg/ha. This was due to nutrients were placed at right place and time under drip fertigation. The responsiveness to fertilizers in terms of system productivity

Table 2 Comparison of drip irrigation with surface flood irrigation in greater yam+maize intercropping system

Particular	Drip irrigation				Surface flood irrigation
	$I_1(F_2)$		$I_2(F_2)$		
	Cost of lateral, drippers, accessories	Cost of volve, pipe, filters	Cost of lateral, drippers, accessories	Cost of volve, pipe, filters	
Fixed cost (₹/ha)	50000	50000	50000	50000	
Life year	6	20	6	20	
Depreciation (₹/ha)	8333	2500	8333	2500	
Interest (12%) (₹/ha)	6000	6000	6000	6000	
Repair & maintenance (2%) (₹/ha)	1000	1000	1000	1000	
Total (B, C and D) (₹/ha)	15333	9500	15333	9500	
Grand total (₹/ha)	24833		24833		
Cost of cultivation (₹/ha)	184900		190400		170000
Irrigation water (mm)	329		367		398
Irrigation water saving over flood irrigation (mm)	69 (690 m^3; 17.3%)		31 (310 m^3; 7.8%)		
System yield (t)	32.4		36.3		30.8
Yield increase over surface flood irrigation (t)	1.6 (5.2%)		5.5 (17.9%)		
Gross return (₹) (sale price 15000 ₹/t)	486000		544500		462000
Net return (₹)	301100		354100		292000
Additional area cultivable with saving of water (ha)	0.210		0.084		
Additional expenditure (₹)	38800		16000		
Yield (t)	6.8		3.05		
Additional return (₹)	102000		45800		
Additional net return (₹)	63200		29800		
Total cost of cultivation (₹)	223700		206400		170000
Total gross return (₹)	588000		590300		462000
Total net return (₹)	364300		383900		292000
B:C ratio	2.63		2.86		2.72
Net return ₹/mm of water used	915		965		734

Table 3 Drip irrigation and fertigation effects on system and water productivity, and economics of greater yam+maize intercropping system

Treatment	Maize yield (t/ha)	Greater yam yield (t/ha)	System productivity (t/ha)	Cost of cultivation (×10^3 ₹/ha)	Gross return (×10^3 ₹/ha)	Net return (×10^3 ₹/ha)	Water productivity (kg/m^3)
I_1F_1	2.2	24.8	27.0	177.0	405.0	228.0	3.2
I_1F_2	2.5	29.9	32.4	184.9	486.0	301.1	3.8
I_1F_3	2.7	32.4	35.1	190.1	526.5	336.4	4.1
I_1F_4	2.7	32.9	35.6	193.1	534.0	340.9	4.2
I_2F_1	2.5	29.6	32.1	183.7	481.5	297.8	3.7
I_2F_2	2.8	33.5	36.3	190.4	544.5	354.1	4.3
I_2F_3	3.0	37.0	40.0	196.6	600.0	403.4	4.7
I_2F_4	3.1	37.5	40.6	199.7	609.0	409.3	4.7
I_3F_1	2.5	27.3	29.8	182.9	447.0	264.1	3.5
I_3F_2	2.8	31.3	34.1	189.7	511.5	321.8	3.9
I_3F_3	3.1	34.2	37.3	195.4	559.5	364.1	4.3
I_3F_4	3.1	35.3	38.4	199.0	576.0	377.0	4.5
Check	2.5	28.3	30.8	170.0	462.0	292.0	3.5
Control	1.2	14.9	16.1	135.3	241.5	106.2	1.9
CD (P=0.05)	0.1	2.4	2.4	1.9	21.2	19.5	0.2

varied with levels of drip irrigation. The fertilizers applied through higher level of drip irrigation (I_3) resulted in lesser response than I_2. This might be due to favouring more vegetative growth than yield in greater yam+maize intercropping system. The treatments I_2F_4 and resulted in 31.8, 14.0 and 5.8% higher system productivity than check, I_1F_4 and I_3F_4, respectively. Similarly, the treatment I_2F_3 resulted in 29.9, 14.0 and 6.8% higher system productivity than check, I_1F_3 and I_3F_3, respectively. The system productivity, gross and net returns, and water productivity difference between I_2F_4 and I_2F_3 was non-significant. Hence, the treatment I_2F_3 could be considered as the optimized treatment which saved fertilizers considerably.

Productivity gains: The partial deficit drip irrigation treatments I_1F_2 and I_2F_2 resulted in system productivity of 32.4 and 36.3 t/ha, respectively, whereas check resulted in 30.8 t/ha at same level of fertilizer application (Table 3). The system productivity gain of I_1F_2 and I_2F_2 was 5.2 and 17.9% respectively over check. The reason for the above was attributed as follows: First, the growth and development of greater yam+maize intercropping system was very good under drip irrigation treatments primarily due to less moisture stress. Secondly, the weed growth was less because of supplying of water only at the root zone of the crop. Thirdly, since fertilisers were supplied through water (fertigation) near the plants, the efficiency of fertiliser use was highly effective as losses occurring through evaporation and leaching with water are less under drip irrigation. Higher productivity of greater yam+maize intercropping system under drip irrigation has indicated that water and fertilizers were used efficiently. Higher system productivity was noticed with the increase of fertigation levels. The treatments I_2F_3 and I_2F_4 resulted in maximum system productivity of 40.0 and 40.6 t/ha, respectively, which were 29.9 and 31.8% higher than check and 148.4 and 152.2% higher than control.

The treatments I_1F_2 and I_2F_2 resulted in water productivity of 3.8 and 4.3 kg/m^3 which was 8.6 and 22.9% higher respectively, over check. Increase in water productivity was observed with the increase of fertigation levels. Maximum water productivity of 4.7 kg/m^3 was noticed in both I_2F_3 and I_2F_4, which were 34.3% higher than check and 147.4% higher than control. Application of drip irrigation at 100% CPE throughout crop growing period (I_3F_3 and I_3F_4) could not resulted in a corresponding increase in water productivity compared to I_2F_3 and I_2F_4. This indicated the wastage of water for non-productive uses.

Economics: The water cost saving under partial deficit irrigation treatments I_1F_2 and I_2F_2 was 39 330 and 19 840 ₹/ha, respectively over check (Table 1). The water cost saving was calculated based on the amount of water saved by the treatment and their water productivity per unit quantity of water. The above treatments saved water 690 and 310 m^3/ha, respectively over check. The partial deficit irrigation treatments I_1F_2 and I_2F_2 were also saved water application cost and weeding cost over check. Overall, the cost saving after deducting variable cost of drip irrigation was 30 513 and 9 395 ₹/ha in treatments I_1F_2 and I_2F_2, respectively over check. The net return was 3 01 100 and 3 54 100 ₹/ha under the partial deficit drip irrigation treatments $I_1(F_2)$ and $I_2(F_2)$, respectively, whereas the same was only about 2 92 000 ₹/ha for surface flood irrigation at same level of fertilizer application (check) (Table 3). This means that the net income from drip irrigated greater yam+maize under $I_1(F_2)$ and $I_2(F_2)$ was about 9 100 and 62 100 ₹/ha higher than the crop cultivated with surface flood irrigation (check), respectively. This higher net income is purely because of yield effect though cost of cultivation was higher due to capital cost of drip irrigation. Similar report in sugarcane was reported by Narayanamoorthy (2005). However, cost of irrigation (both labour and other costs) was substantially less under drip irrigation because of the requirement of labour was less and water saving was high, and it substantially reduced the working hours of pumpset which extensively reduced the cost on electricity.

Partial deficit drip irrigation (I_2) saved water (310-690 m^3/ha) and electricity (47-104 kWh/ha), fertigation (F_2) through partial deficit drip irrigation also saved fertilizers over surface flood irrigation along with soil application of fertilizers in greater yam+maize intercropping system. Partial deficit drip irrigation also reduced the working hours of pump sets, through saving water it not only reduced the consumption of electricity but also improved the efficiency of electricity use to a greater extent. The partial deficit drip irrigation along with fertigation (I_1F_2 and I_1F_2) also saved weeding, water application and water cost thereby increased net income over surface flood irrigation along with soil application of fertilizers. Greater system productivity in the treatments I_2F_4 and I_2F_3 indicated fertilizer responsiveness under drip fertigation. Considering environmental and economical impact, the partial deficit drip irrigation and fertigation treatment I_2F_3 could be the best option for greater yam+maize intercropping system.

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