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Enhancing factor productivity of a greater yam+maize intercropping system under drip fertigation

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Abstract

Field experiments were conducted for consecutive two years (2015-16 and 2016-17) at the Regional Sation of ICAR-Central Tuber Crops Research Institute, Dumuduma, Bhubaneswar, Odisha to study the effect of drip irrigation and fertigation levels on factor productivity of a greater yam + maize intercropping. Drip irrigation treatments: I_1=80% cumulative pan evaporation (CPE) during 1-270 days after planting (DAP); I_2=100% of CPE during 1-90 DAP+80% of CPE during 91-270 DAP and I_3=100% of CPE during 1-270 DAP were included in main plots. Fertigation treatments: F_1=100-90-100 kg ha^{-1}; F_2=120-90-120 kg ha^{-1}; F_3=140-90-140 kg ha^{-1} and F_4=160-90-160 kg ha^{-1} of N-P_2O_5-K_2O were included in sub plots. A control (surface flood irrigation at 100% of CPE and soil application of N-P_2O_5-K_2O 120-90-120 kg ha^{-1}) was included to compare drip fertigation treatments. Treatment I_3 resulted in maximum maize yield; I_2 resulted in maximum greater yam and tuber equivalent yield (TEY). Fertigation at F_4 was resulted in higher maize and greater yam yield and TEY than other treatments. Treatments I_2F_4 and I2F3 were on par and resulted in higher greater yam yield, TEY, nutrient and water use efficiency. The treatments control and I_1F_2 resulted in same level of TEY, which indicated saving of 0.684-0.710 million litre (17.9-25.9%) of water per ha under drip irrigation. Same level of TEY with the treatments *viz*., control and I_2F_1/I_3F_1 also indicated a saving of nutrients N-K_2O 20-20 kg ha^{-1} (20%) under drip irrigation over soil application. The treatment I_2F_3 (drip irrigation at 100% of CPE during 1-90 DAP+80% of CPE during 91-270 DAP along with fertigation of N-P_2O_5-K_2O 140-90-140 kg ha^{-1}) is recommended for greater yam + maize intercropping system considering greater TEY, nutrient and water use efficiency as well as minimum water requirement per kg of TEY production.

Keywords: *Dioscorea alata*, *Zea mays*, Consumptive use, Nutrient use efficiency, Tuber equivalent yield, Water use efficiency

Introduction

Greater yam (*Dioscorea alata* L.) + 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. Water and nutrients are the most important input factors in crop production which constraint productivity of the crops. Availability of water to agriculture is decreasing due to increasing demand in industrial and allied sectors. Hence, water should be used judiciously in crop production along with rainwater. Rainfall in India is monsoon dependent

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and 80% of rainfall is received during southwest monsoon season, June to September. Maize, being a short duration (90-100 days) crop, can be successfully cultivated in high rainfall regions under rainfed conditions. Greater yam, being a long duration (9-10 months) crop, may suffer from insufficient moisture at later stages. Supplementary irrigation to greater yam + maize intercropping system is beneficial for uniform sprouting at early stage and rapid tuber bulking during post monsoon season. The most used method of irrigation is surface flood irrigation which ensures uniform spreading, high evaporation and seepage loss. Greater yam + maize intercropping system develops thick 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% (Dhawan, 2002). Greater crop yields with saving of water and higher water use efficiency in vegetables occurs with drip irrigation systems (Manjunath et al., 2001; Tiwari et al., 2003; Montazar et al., 2019). The dense foliage develops in greater yam + maize intercropping system will not interfere in irrigation under drip system.

Nutrients, one of the important input factors in crop production has low use efficiency due to improper time, method and quantity of application. 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 higher greater yam and maize yields (Sahoo et al., 2006). Top dressing of fertilizers in greater yam + maize intercropping is very difficult due to canopy development after the third month. Hence, drip irrigation and fertigation is an option for water and nutrient management for the greater yam + maize intercropping system. Few studies were conducted on nutrient management for greater yam + maize intercropping system in India and elsewhere in the world, but very meager information is available on water and nutrient management through drip irrigation. Keeping in view of the above, an investigation was conducted to evaluate effects of drip irrigation and fertigation on production potential, water and nutrient use efficiency of the greater yam + maize intercropping system.

Materials and Methods

Field experiments were conducted during 2015-2016 and 2016-2017 seasons at the Regional Station of Indian Council of Agricultural Research ICAR-Central Tuber Crops Research Institute (CTCRI) (20°14'53.25" N, 85°47'25.85" E, 33 m above mean sea level) at Bhubaneswar, Odisha, India. The climate of the experimental site was characterized by a hot, humid summer, and a cool, dry, winter. The soil was an alfisol with 13.6% water content at permanent wilting point, 27.6% water content at field capacity, 1.53 g cc^{-1} bulk density, 6.8 pH, 0.39% organic carbon, 196 kg ha^{-1} available N, 21.4 kg ha^{-1} available P, and 265 kg ha^{-1} available K in the top 0.30 m. The experiment was laid out in split plot design and replicated 3 times with the drip irrigation treatments: I_1 = at 80% cumulative pan evaporation (CPE) during 1-270 days after planting (DAP); I_2 = at 100% of CPE during 1-90 DAP+80% of CPE during 91-270 DAP and I_3 = at 100% of CPE during 1-270 DAP were in main plots. The fertigation treatments: F_1 = 100-90-100 kg ha^{-1}; F_2 = 120-90-120 kg ha^{-1}; F_3 = 140-90-140 kg ha^{-1} and F_4 = 160-90-160 kg ha^{-1} of N-P_2O_5-K_2O were included in sub-plots. The greater yam + maize intercropping system responded up to 90 kg ha^{-1} phosphorus in the study location as per previous studies (Nedunchezhiyan et al., 2010) and hence held constant in all fertigation treatments. The recommended fertilizer rate for greater yam + maize intercropping system was N-P_2O_5-K_2O 120-90-120 kg ha^{-1} under soil application (Nedunchezhiyan et al., 2010). Hence, a control treatment (surface flood irrigation at 100% of CPE and soil application of N-P_2O_5-K_2O 120-90-120 kg ha^{-1}) was included to compare the treatments. During the first and second season, greater yam and maize were established on 17 April 2015 and 22 April 2016, respectively. Cut tubers, 200 g of greater yam, var. Da 293, were planted on ridge tops at 5-7 cm depth and 90 cm between plants. In intra-rows, between 2 greater yam plants 3 hybrid maize 'MRM 3777' seed were sown at 2-3 cm depth at 30 cm spacing on the same day. Plant populations of 12345 and 37037 plants ha^{-1} for greater yam and maize, respectively, were established.

Water soluble N, P and K fertilizers (urea, urea phosphate and potassium sulphate) were split into 5 equal applications (basal, 30, 60, 90 and 120 DAP) and supplied through drip irrigation with emitter spacing of 30 cm and flow rate of 4 L h^{-1}. In control treatment, the full P_2O_5 (single super phosphate) was applied to soil prior to planting. The N (urea) and K (muriate of potash) were applied to soil in 3 split applications, basal (40%), 45 DAP (30%) and 90 DAP (30%). Drip irrigation on alternate days and surface irrigation (treatment) once every 7 days were given as per treatment based on CPE based on pan factor 0.7. Weeding followed by earthing up was done at 30 and 60 DAP. Maize cobs were harvested at physiological maturity (90 DAP) and stalks and leaves left in the field to serve as staking for the greater yam. Maize cobs were harvested on 15 July 2015 and 20 July 2016, respectively. Irrigation was withheld for 20 days before harvesting of greater yam in all treatments. Greater yam was harvested 290 DAP. During first and second season, greater yam was harvested on 31 January 2016 and 5 February 2017, respectively.

Rainfall received during first (2015-2016) and second (2016-2017) cropping seasons was 980.0 and 1238.5 mm, respectively. During the first cropping season, effective rainfall (Reddy and Reddi, 2010) was 439, 396 and 396 mm at I_1, I_2 and I_3, respectively. The amount of water applied through drip irrigation was 383, 432 and 451 mm I_1, I_2 and I_3, respectively. During the second cropping season, effective rainfall was 470, 448 and 441 mm at I_1, I_2 and I_3, respectively. The amount of water applied through drip irrigation was 274, 301 and 345 mm at I_1, I_2 and I_3, respectively. In control treatment, 451 and 345 mm of water was applied surface irrigation during the first and second cropping season, respectively. Soil profile moisture contribution was calculated by gravimetric method from one metre soil depth by available soil moisture at the start of the experiment minus available soil moisture at the end of the experiment. The tuber equivalent yield (TEY), consumptive use (CU), water use efficiency (WUE), water required per kg of TEY production (litre) and nutrient use efficiency (NUE) were calculated by following standard methods.

The data collected were subjected to analysis of variance (ANOVA) in split plot as well as randomized block design using statistical software SAS (SAS, 2010). Treatment means were compared for significance at the 0.05 level of probability using the critical differences (CD) as suggested by (Gomez and Gomez, 1984).

Results and Discussion

Maize yield

Drip irrigation and fertigation levels significantly influenced maize yield (Table 1). The treatment I_3 resulted in maximum maize yield, but it was statistically at par with I_2 (Table 1). The increase in maize yield of I_3 over I_2 was negligible, because in both the treatments equal quantity of water was applied during 1-90 DAP (until the harvest of maize at physiological maturity). Better performance of maize in terms of yield in treatments I_2 and I_3 might be presumably due to less competition for water between the greater yam and maize, effective absorption and utilization of available nutrients, and better proliferation of roots with the favourable soil moisture. Increasing fertigation level increased the maize yield (Table 1). Fertigation at F_4 level resulted in significantly higher maize yield than the other treatments. Adequate supply of NPK might have increased chlorophyll formation, cell elongation and division, enzymes involved in various metabolic processes, nucleotide, protein etc. that led to more production and translocation of photosynthates towards sink (Manickasundaram et al., 2002). Drip fertigation levels revealed that maximum maize yield was recorded in I_3F_4 (Table 2). The treatments I_3F_4, I_3F_3, I_2F_4 and I_2F_3 resulted in greater maize yield of 18.5-30.4, 14.8-30.4, 14.8-30.4 and 14.8-26.1% over the control, respectively. Drip fertigation provided water and nutrients directly to the root zone of plants with apparent greater efficiency than surface irrigation with soil application of nutrients. Under surface flood irrigation weeds can be major competitors for water and nutrients. In water and nutrient stressed fields, weeds can absorb water and

Table 1. 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)	
	2015-2016	2016-2017	2015-2016	2016-2017	2015-2016	2016-2017	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Drip irrigation												
I_1	2.6	2.4	31.0	28.9	33.7	31.3	886	805	38.0	38.9	267	261
I_2	2.9	2.8	34.9	33.8	37.9	36.5	896	815	42.2	44.8	239	227
I_3	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												
F_1	2.5	2.3	28.0	26.3	30.5	28.6	891	816	34.2	35.1	294	289
F_2	2.8	2.6	32.8	30.2	35.6	32.8	892	817	39.9	40.2	251	250
F_3	3.0	2.8	35.5	33.5	38.5	36.2	894	818	43.1	44.4	233	227
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

nutrients more efficiently than the crop (Singh et al., 2014; Nedunchezhiyan, 2017).

Greater yam yield

Greater yam yield was significantly influenced by drip irrigation and fertigation levels (Table 1). The treatment I_2 resulted in maximum greater yam yield compared to other drip irrigation levels (Table 1). The greater yam yield decreased in the treatment I_3 at 4.3-9.6% compared to the treatment I_2. With excessive soil moisture conditions, plants may develop more vegetative growth by diverting photosynthates towards growing points. Increasing fertigation level increased the greater yam yields (Table 1). Fertigation at F_4 level resulted in maximum greater yam yield. The fertigation treatment F_4 was greater by 1.7-2.4, 10.1-13.6 and 28.9-30.4% than the treatments F_3, F_2 and F_1, respectively. Remya and Byju (2020) reported maximum greater yam yield at greater level of nutrient application. The treatment I_2F_4 resulted in superior greater yam yield (Table 2). The effect of drip irrigation and fertigation revealed that at favourable soil moisture without wide fluctuations along with sufficient nutrients available for absorption and utilization resulted in maximum greater yam yield.

Tuber equivalent yield (TEY)

Marked variation in TEY was noticed with respect to drip irrigation and fertigation levels (Table 1). Increasing drip irrigation increased TEY up to I_2 level which afterwards decreased. This was due to both maximum maize and greater yam yield in I_2 treatment (Table 1). The drip irrigation at I_2 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. Thus, the treatment I_2 resulted in greater TEY than other treatments. Fertigation at F_4 level resulted in maximum TEY whereas the minimum TEY was noticed in plants under the treatment F_1 (Table 1). This was due to more maize and greater yam yield (Table 1). The treatment F_4 resulted in 1.6-2.5, 10.0-13.1 and 28.2-30.1% greater TEY than the treatments F_3, F_2 and F_1, respectively. Decreased yield response to successive increase of nutrient levels have been reported in many crops (Behera and Ghosh, 2009). The drip fertigation treatments I_2F_4, I_2F_3, I_3F_4 and I_3F_3 and I_2F_2 resulted in greater TEY (Table 2) due to adequate soil moisture during the crop growing period which increased the availability of applied nutrients to the greater yam and maize. Although in the control treatment the quantity of water applied through surface irrigation was equal to I_3 and nutrients applied in soil was equal to F_2, the TEY was lower than I_3F_2. This was because of loss of water and nutrients apart from heavy weed infestation which removed considerable amount of water and nutrients from the soil. The TEY of control treatment was statistically at par with I_1F_2, I_2F_1 and I_3F_1. This indicated that surface irrigation with soil application of fertilizer (control) and drip irrigation at I_1

Table 2. 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)	
	2015-2016	2016-2017	2015-2016	2016-2017	2015-2016	2016-2017	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

with fertigation of same level of fertilizer (F_2) resulted in the similar TEY. Thus, drip irrigation I_1F_2 saved 0.684-0.710 million litre (17.9-25.9%) of water per ha. Same level of TEY in the control and in the treatments I_2F_1/ I_3F_1 indicated a saving of nutrients N-K_2O 20-20 kg ha^{-1} (20%). Patil et al. (2011) reported 30% fertilizer saving when fertilizer was applied through drip irrigation in sweet corn.

Consumptive use (CU) of water

The CU of water was greater with the increase in drip irrigation levels (Table 1). The treatment I_1 resulted in lower CU, whereas I_3 resulted in greater CU. The CU during the first season was higher than the second season. This might be due to greater temperature prevailed during the first season which caused greater evaporative demand. This was amply indicated by the quantity of irrigation water applied to the crop. The CU in greater yam + maize intercropping system increased with increase in fertigation levels (Table 1). The treatment F_4 resulted in greater CU compared with the other treatments. The effect of drip fertigation levels indicated greater CU was in the treatment I_3F_4 (Table 2). This might be due to greater quantity of water irrigated and evapo-transpiration.

Water use efficiency (WUE)

The WUE of greater yam + maize intercropping system was significantly influenced by both the drip irrigation and fertigation levels (Table 1). The WUE increased with increase in drip irrigation level up to I_2 and then decreased (Table 1). The WUE decreased at the treatment I_3 by 4.0-10.5% than the treatment I_2 due to lower TEY with the cost of higher shoot biomass. The CU of water and WUE were in quadratic relationship (Fig. 1). Increasing in CU increased WUE and then decreased. Arora et al. (2007) reported that WUE increased from no irrigation to partial irrigation regime and decreased thereafter with more irrigation. Increasing the fertigation level increased the WUE. The treatment F_4 resulted in significantly higher WUE than F_1 and F_2, but on par with F_3. The treatment F_4 resulted in greater WUE of 1.4-2.3, 9.5-12.9 and 27.8-29.3% than the treatments F_3, F_2 and F_1, respectively. The effect of drip fertigation levels on WUE of greater yam + maize intercropping system revealed that the treatments I_2F_4, I_2F_3, I_3F_4, I_3F_3, I_2F_2, I_1F_4, I_1F_3 and I_3F_2 resulted in greater WUE of 27.5-38.8, 26.3-36.9, 23.5-25.8, 18.7-22.9, 19.3-19.5, 18.1-18.2, 16.5-16.7 and 12.7% than the control, respectively (Table 2).

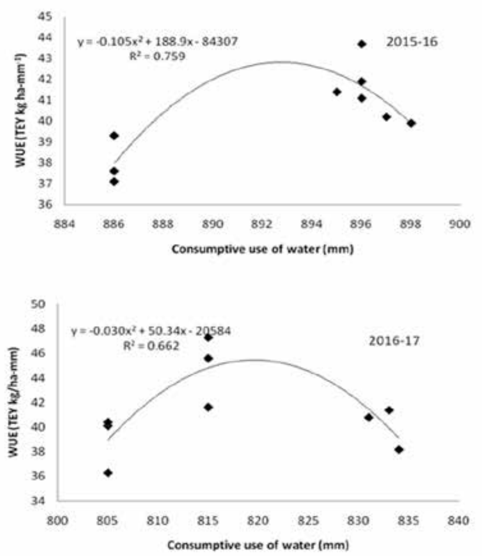

Fig. 1. Relationship between consumptive use of water and WUE in greater yam + maize intercropping system (Significant at p=0.01 in both the years)

The water required to produce a kg of TEY decreased with increasing drip irrigation level up to I_2 and then increased at I_3 (Table 1). The treatment I_2 saved 11-25 and 28-34 litre of water than the treatments I_3 and I_1, respectively to produce a kg of TEY. This might be due to greater TEY at optimum level of drip irrigation (Table 1). The water required to produce a kg of TEY decreased with increasing fertilizer level (Table 1). The treatment F_4 resulted in minimum water required per kg of TEY and saved 4-5, 22-28 and 65-67 litre of water than the treatments F_3, F_2 and F_1, respectively to produce a kg of TEY. This might be due to higher yield of maize and greater yam. The treatments I_2F_4 and I_2F_3 saved 60-78 and 59-75 litre respectively, to produce one kg. of TEY compared to the control (surface irrigation with recommended dose of fertilizer) (Table 2).

Nutrient use efficiency (NUE)

The NUE increased with increasing drip irrigation level up to the treatment I_2 and then decreased at I_3 (Fig. 2). The treatment I_2 resulted in maximum NUE owing to greater TEY. The NUE increased with increasing fertilizer level up to F_2 and then declined (Fig. 3). The treatment F_2 resulted in greater NUE. This might be due

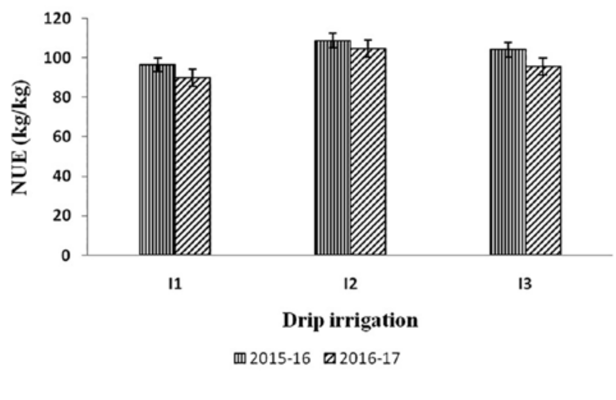

Fig. 2. Effect of drip irrigation levels on NUE [SEm±: 1.3 (2015-16) and 1.2 (2016-17); CD (P=0.05): 5.2 (2015-2016) and 4.8 (2016-2017)] in greater yam + maize intercropping system.

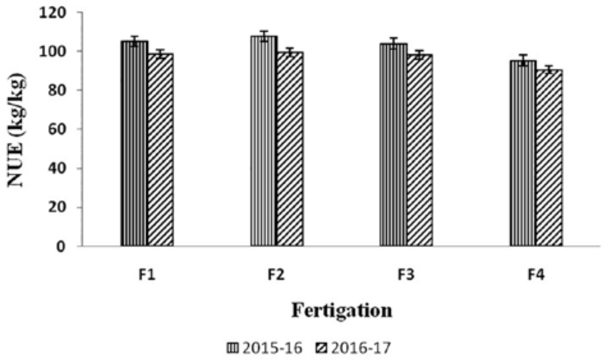

Fig. 3. Effect of fertigation levels on NUE [SEm±: 1.6 (2015-16) and 1.7 (2016-17); CD (P=0.05): 4.8 (2015-16) and 5.0 (2016-17)] in greater yam + maize intercropping system.

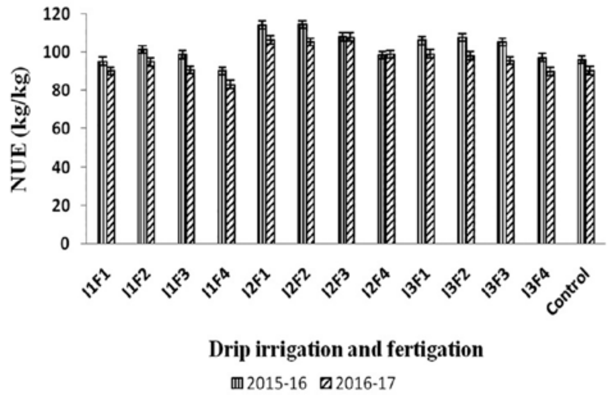

Fig. 5. Effect of drip irrigation and fertigation levels on NUE [SEm±: 2.8 and CD (P=0.05): 8.1 for both the years] in greater yam + maize intercropping system

to greater TEY. The NUE had quadratic relationship with nutrient levels (Fig. 4). This indicated that addition of nutrients increased NUE up to F_2 and further addition of nutrients decreased NUE. At higher level of nutrients

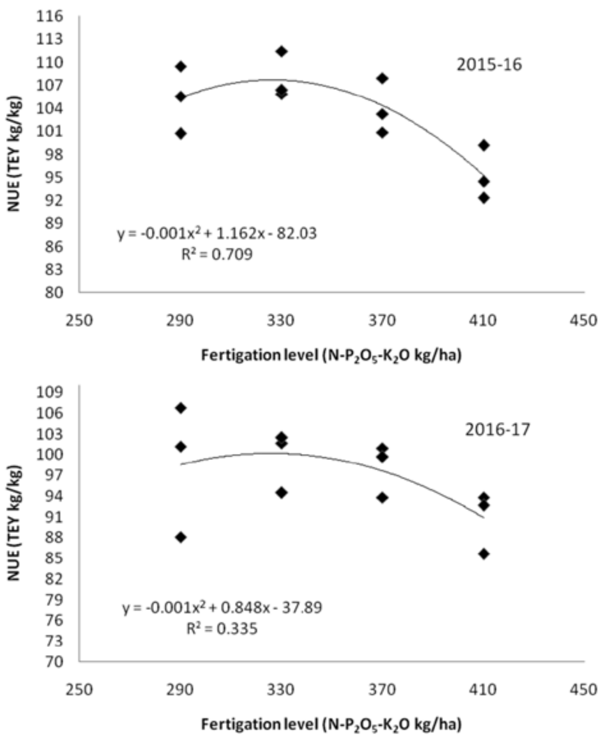

Fig. 4. Relationship between fertigation levels and NUE in greater yam + maize intercropping system (Significant at P=0.01 during 2015-16 and not significant during 2016-17)

application, yield increased at decreasing rate thereby NUE decreased. The interaction treatments I_2F_2 and I_2F_3 resulted in greater NUE (Fig.5). Application of same quantity of nutrients in soil and through drip irrigation revealed that application of nutrients along with drip irrigation at I_2 resulted in 16.5-19.0% greater NUE than soil application with the surface irrigation (control). The application of same quantity of nutrients along with drip irrigation at I_3 resulted in 8.6-12.2.0% greater NUE than soil application with the surface irrigation (control).

Thus, it can be concluded that the treatment I_2F_3 was at par with the treatment I_2F_4 in all the parameters studied. Hence, the treatment I_2F_3 (drip irrigation at 100% of CPE during 1-90 DAP+80% of CPE during 91-270 DAP along with fertigation of N-P_2O_5-K_2O 140-90-140 kg ha^{-1}) is recommended for greater yam + maize intercropping system considering greater TEY, WUE and NUE, and minimum water required per kg of TEY.

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