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Spacio-Temporal Fertigation Effects on Growth, Yield and Nutrient Use Efficiency of Elephant Foot Yam (*Amorphophallus paeoniifolius*)

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Abstract: A field experiment was conducted for two consecutive years during 2013-14 and 2014-15 at the Regional Centre of ICAR-Central Tuber Crops Research Institute, Bhubaneswar, Odisha, India. The experiment was laid out in split plot design with fertigation interval (2, 3 and 4 days) in the main plots and in sub plots the recommended fertilizer (Soluble fertilizer N- P_2O_5-K_2O 120-60-120 kg ha^{-1}) was split into 30, 40 and 50 doses and applied through drip irrigation. A Check [furrow irrigation where P_2O_5 60 kg ha^{-1} was applied as basal and N-K_2O 120-120 kg ha^{-1} were applied at 1st (40%), 2nd (30%) and 3rd (30%) month after planting (MAP) to soil] and control (no fertilizer) treatments were also included. All the treatments had three replications. The results revealed that the plant height, canopy spread and pseudostem girth at 3rd and 5th MAP were the maximum in treatments which received maximum fertigation during that period. Corm yield increased with increase in fertigation interval from 3 to 4 days along with fertilizers application in 40 to 50 split doses. However, the crop did not respond to fertigation beyond 180 days after planting (DAP). The corm yield had significant positive correlation with N, P and K uptake. The fertigation at 4 days interval with application of recommended fertilizers split into 40 doses and fertigation at 3 days interval with application of recommended fertilizers into 50 doses resulted in the maximum corm yield, nutrient (N, P and K) uptake and use efficiency (agronomic efficiency, recovery efficiency and partial factor productivity) in elephant foot yam.

Key words: Elephant foot yam · Fertigation · Nutrient use efficiency · Yield

INTRODUCTION

Elephant foot yam (*Amorphophallus paeoniifolius*) is a starchy food crop grown for its underground modified stem botanically known as corm. It is widely cultivated in tropical Asian and African countries [1, 2] and it is speculated that human activity has played an important role in its distribution [3, 4]. Elephant foot yam (EFY) is a crop of South East Asian origin. It has long been used as a staple food in many countries such as Philippines, Java, Indonesia, Sumatra, Malaysia, Bangladesh, India, China and South-eastern countries [1]. EFY is considered as famine food in the Pacific Islands [5]. In India, EFY is cultivated in Andhra Pradesh, West Bengal, Bihar, Uttar Pradesh, Tamil Nadu, Kerala, Maharashtra, Odisha and Karnataka [6]. It emerged as a commercial crop in India due to its high production [7], export potential [8] and culinary properties [9]. Long keeping quality of the corms, less pests and diseases and low labour requirement encourages farmers to grow EFY crop in spite of the long duration (8 months) [10]. The corm is consumed after boiling, baking and frying [11, 12]. Young leaves are also used as vegetable after chopping and boiling. Pickle, a delicious recipe preferred by Indians is also prepared from the corms [13]. EFY corms are rich in minerals and vitamins [14]. It is also used as medicine in many preparations. The corms are believed to have blood purifying characteristics and are used in medicines for the treatment of piles, asthma, dysentery and other abdominal disorders [15]. The paste of corms is applied externally to reduce pain in arthritis.

Nutrients are prerequisites to enhance the crop yield and improve the quality and economic return [16, 17]. The method of nutrient application is important in improving the use efficiency of nutrients. Fertilizers applied through traditional methods are generally not utilized efficiently by the crop besides causing environmental pollution and wastage of money. Fertigation is a method of application

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of fertilizer through microirrigation. Fertigation enables adequate supply of water and nutrients with precise timing and uniform distribution to meet the crop demand so as to get maximum yield [18, 19]. Drip fertigation is considered to be most efficient in improving the crop yield, saving of water and enhancing water producvtivity [20]. Phene *et al*. [21] reported 25-50% reduction in total fertilizer requirement using drip system compared to surface broadcasting without yield reduction in potato. Venkatesan *et al*. [22] also reported greater corm yield under drip fertigation. In chilli, fertigation using water soluble fertilizers increased yield by 15% than soil application [23]. Fertigation with water soluble fertilizers in French-bean saved 25% of fertilizer requirement and increased yield by 28% over soil application of fertilizers [23]. EFY is a shallow rooted crop and the feeding roots extending more than 60 cm are distributed radially around the plant exhausting water and nutrients from the topsoil of 20 cm depth [24, 25]. EFY is considered as a nutrient exhaustive crop as it requires very high amount of N-P-K fertilizers for achieving maximum yield [26]. A crop yielding 33 tonnes of corm removed 128.8 kg N, 23.6 kg P and 239.6 kg K ha^{-1} [27]. Judicious use of nutrient inputs and manipulation of microclimate is essential to maximize the corm yield [28]. Fertilizers application to soil results in very low (20-30%) nutrient use efficiency in EFY [29]. Fertigation provides the most effective way of supplying nutrients to plant roots of elephant foot yam and it increased EFY corm yield by 15-21% over soil application (Nedunchezhiyan *et al*. [25]). Furthermore, EFY requires 8 months for producing significant corm yield and the nutrient uptake continues up to 7 months after planting (MAP) [27]. Soil application of fertilizer is recommended up to three months because the crop canopy structure/orientation does not permit intercultural activities afterwards. However, through drip fertigation the crop can be fed nutrients up to 7 MAP without damaging the canopy. Several researchers reported that multiple application of small quantity of fertilizers increased fertilizer use efficiency in many crops. Menzel and Obe [30] reported that fertigation of nutrients with very great dilution in each irrigation increased the fertilizer use efficiency far beyond the previously possible level in potato. Miller *et al*. [31] observed that multiple applications of N fertilizers through drip irrigation improved the efficiency of fertilizer uptake by EFY over a single injection. Application of nitrogen through the drip irrigation in ten equal splits at 8 days interval saved 20-40% nitrogen as compared to the furrow irrigation when nitrogen was applied in two equal splits (at planting and 1 month after planting) in tomato [32]. But, Locascio *et al*. [33] recorded no difference in the yield of straw berry when N and K were applied either daily or at weekly intervals along with the drip irrigation. At present, there is no drip fertigation technology available for EFY. Hence, expansion of the crop in water limited areas is hindering. Keeping the above facts in view, the present study was therefore, conducted to find-out the effect of spatio-temporal drip fertigation on EFY corm yield, water and fertilizer use efficiency.

MATERIALS AND METHODS

Experimental Site and Design: A field experiment was conducted for two consecutive years during 2013-14 and 2014-15 at the Regional Centre of ICAR-Central Tuber Crops Research Institute (20°14'53.25'' N and 85°47'25.85'' E and 33 m above mean sea level), Bhubaneswar, Odisha, India. The physico-chemical feature of the soil at experimental site was as under: The water holding capacity of the soil 26.8%, bulk density 1.54 g cc^{-1}, pH 6.4, organic carbon 0.36%, available N 184 kg ha^{-1}, available P 21.2 kg ha^{-1} and available K 243 kg ha^{-1}. The experiment was laid out in split plot design with fertigation interval in main plots: T_1- 2 days, T_2- 3 days and T_3- 4 days and in sub plots number of split application of the recommended dose of fertilizer (water soluble fertilizer N- P_2O_5-K_2O 120-60-120 kg ha^{-1}): S_1- 30 splits (N- P_2O_5-K_2O 4-2-4 kg $ha^{-1}dose^{-1}$), S_2- 40 splits (N-P_2O_5-K_2O 3-1.5-3 kg $ha^{-1}dose^{-1}$) and S_3- 50 splits (N-P_2O_5-K_2O 2.4-1.2-2.4 kg $ha^{-1}dose^{-1}$). The fertigation was given through drip irrigation. A Check [furrow irrigation where P_2O_5 60 kg ha^{-1} was applied as basal and N-K_2O 120-120 kg ha^{-1} were applied at 1st (40%), 2nd (30%) and 3rd (30%) month after planting (MAP) to soil] and control (no fertilizer) treatments were also included. All the treatments had three replications. The fertilizer dose of N- P_2O_5-K_2O 120-60-120 kg ha^{-1} recommended for EFY to the eastern region of India [25] was followed. Water soluble N, P and K fertilizers (urea, urea phosphate and potassium sulphate) were used in drip fertigation treatments. Whereas urea, single super phosphate (SSP) and muriate of potash (MOP) were sued as source of N, P and K respectively for soil application. Farmyard manure @ 10 t/ha was incorporated in the last plough in all the treatments.

Planting and Other Intercultural Operations: The field was ploughed once and tilled twice before leveling. Ridge and furrow was formed by maintaining 90 cm distance ridge to ridge. On the top of the ridge 400 g weight whole seed corm was planted at 90 cm spacing. Thus the spacing of 90 x 90 cm was maintained. The seed corms were placed 5-7 cm below the soil. The fertigation treatments were imposed 10 days after planting because the seed corm takes 10-15 days to initiate root and shoot primordia. The crop was drip irrigated 80% CPE as recommended by Nedunchezhiyan *et al*. [25]. Weeding followed by earthing up was done at 1, 2 and 3 MAP. The irrigation was withheld 15 days before harvesting. The crop was harvested 8 MAP.

Weather: The climate of the region is characterized by hot and humid summer and cold and dry winter. The rainfall received during the crop growth period was 1762.1 mm in 67 rainy days during 2013 and 1504.8 mm in 72 rainy days during 2014. In 2013, during the crop growth period the average maximum temperature was ranged between 28.8 and 38.7°C, whereas the average minimum temperature between 14.4 and 27.0°C. In 2014, during the crop growth period the average maximum temperature was ranged between 27.7 and 39.2°C, whereas the average minimum temperature between 14.2 and 26.3°C. The average means humidity during the crop growth period was 77 and 72% in 2013 and 2014 respectively. During pre and post monsoon as well as dry spell of the crop growth period 175.4 and 209.7 mm of water was applied through drip irrigation (80% CPE) in 2013 and 2014, respectively.

Growth Observations: EFY produces a long umbrella shaped canopy (a tripartite dissected leaf on single pseudostem). It produces on average 2-3 leaves per plant or hill when whole corms are planted. Usually second pseudostem emerges at 3 MAP. The growth (plant height and canopy spread) of elephant foot yam was negligible between 5-6 months and then decline/senescence starts. Growth observations on plant height, canopy spread and pseudostem girth at collar region were recorded after the emergence of first pseudostem at 3 MAP and the second pseudostem at 5 MAP [10]. As elephant foot yam plant withered/dried at 8 MAP, further observations were not recorded. However, observations on dry matter partitioning were taken from the whole plant/hill at 3, 5 and 8 MAP.

Nutrient Estimation and Uptake: The N, P and K content in the shoot, corm and root were estimated at 3, 5 and 8 MAP. Nitrogen was determined by modified micro-Kjeldahl method [34]. Phosphorus was determined by vanado molybdo phosphoric acid yellow colour method [34]. Potassium was determined by Flame photometer [34]. Nutrient uptake was calculated by multiplying nutrient content with dry matter production.

Nutrient use Efficiency Estimation: Nutrient use efficiencies were assessed by estimating the Agronomic efficiency (AE; kg yield increase per kg N/P/K applied), Recovery efficiency (RE; kg increase in N/P/K uptake per kg N/P/K applied), Physiological or internal efficiency (PE; kg yield increase per kg increase in N/P/K uptake) and Partial factor productivity (PFP; kg yield per kg N/P/K applied) [35] as follows:

Agronomic efficiency (AE) = $(Y_t-Y_0)/F$
Recovery efficiency (RE) = $(U_t-U_0)/F$
Physiological or internal efficiency (PE) = $(Y_t-Y_0)/(U_t-U_0)$
Partial factor productivity (PFP) = Y_t/F

where, Y_t is corm yield in test plot (t ha^{-1}); Y_0 is corm yield in control plot (t ha^{-1}); U_t is total N/P/K uptake in test plot (kg ha^{-1}); U_0 is total N/P/K uptake in control plot (kg ha^{-1}); F is N/P/K applied in test plot (kg ha^{-1}).

Statistical Analysis: The data collected were subjected to analysis of variance (ANOVA) for one way using SAS statistical software (SAS Institute Inc., 2002). The homogeneity of error variance was tested using Bartlett's x^2-test. As the error variance was homogeneous, pooled analysis was done. Comparison of treatment means for significance at 0.05 level of probability was done using the least significant differences (LSD) as suggested by Gomez and Gomez [36].

RESULTS AND DISCUSSION

Growth: EFY produces crown like foliage which is borne on a fairly stout, single, upright pseudostem (petiole). On an average, each plant produced 2 to 3 leaves during a growth period of eight months and each leaf had longevity of 3-4 months. The growth was negligible between 5-7 months and then decline/senescence started. The results presented in Table 1 revealed maximum plant height, canopy spread and pseudostem girth at 3rd and 5th MAP was recorded in treatments that received higher fertigation during that particular crop period (Table 1). At 3 MAP, the treatments T_1S_2 and T_2S_1 resulted in taller plants, more canopy spread and pseudostem girth whereas the treatments check (soil application of fertilizer), T_3S_1 and T_3S_2 resulted in lower plant height, plant spread and pseudostem girth. Significantly lowest

Table 1: Growth and yield of elephant foot yam as influenced by fertigation interval and number of splits.

	Plant height (cm)		Canopy spread (cm)		Pseudo stem girth (cm)				
Treatments	3 MAP	5 MAP	3 MAP	5 MAP	3 MAP	5 MAP	Corm diameter (cm)	Corm length (cm)	Corm yield plant^{-1} (g)
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
LSD (P=0.05)		5	9	3	5	0.4	0.6	0.7	0.6 180

plant height, plant spread and pseudostem girth were recorded in control treatment at 3 MAP. The fertigation applied in 30-40 split doses at 2-3 days interval resulted in the maximum plant height, canopy spread and pseudostem girth at 3rd MAP (Table 1).

At 5 MAP, the growth attributes were recorded on 2nd leaf. Usually 2nd leaf is taller and more spread than the 1st leaf. Between 3rd and 5th month the plant height increased by 20.6% (Table 1). At 5th MAP, maximum plant height was noticed in the plants under the treatment T_2S_3 and T_1S_3 and the difference was insignificant. This indicated that the treatments received more nutrients at early stage of crop growth (between planting and 3rd MAP) produced tallest plants. Ravi *et al*. [37] reported that full development of 1st leaf occurs during 2-3 MAP. Between 3 and 5 MAP, the canopy spread increased by 31.4%. This indicated that the percent increase in canopy spread was greater than the plant height between 3rd and 5th MAP. The treatments T_2S_3 and T_3S_1 resulted in maximum canopy spread at 5 MAP. This indicated that the increase in canopy spread between 3rd and 5th MAP depend upon amount of nutrients received during that particular period. Between 3rd and 5th MAP, the pseudostem girth increased by 24.2%. This indicated that the percent increase in pseudostem girth increase was greater than the plant height between 3rd and 5th MAP. Maximum pseudostem girth was recorded in plants under the treatments T_2S_3 and T_3S_1 at 5th MAP. The fertigation applied in 50 split doses at 3 days interval and in 40 split doses at 4 days interval resulted in greater canopy spread and pseudostem girth at 5th MAP. This indicated that more nutrients are to be applied before 3rd month for taller plants and before 5th month for greater canopy spread and pseudostem girth. Sahoo *et al*. [26] and [38] also observed greater growth attributes with increase in nutrient application. However, nutrient application beyond 5th month did not influence the shoot growth. Ravi *et al*. [39] while studying on EFY growth reported a plateau between 5th and 7th months and then plant senescence. The plant height, plant spread and pseudostem girth at 5th MAP were significantly the lowest in the control plants (Table 1).

Dry Matter Production and Partitioning: Total dry matter production and dry matter partitioning into shoot, corm and root at 3rd, 5th and 8th MAP is presented in the Fig. 1. EFY produces fibrous root on the surface of developing corm. The roots spread radially and found maximum within 60 cm depth of soil [7]. The dry matter accumulation in corm was greater than that in the shoot at 3rd, 5th and 8th MAP. At 3rd MAP, the dry matter accumulation in the shoot, corm, root and total was maximum in plants under the treatment T_1S_2 and it was followed by T_2S_1. This was due to higher growth attributes. At 5th MAP, the treatment T_2S_3 resulted in maximum dry matter accumulation in the shoot, corm, root. At 8th MAP, T_3S_3 resulted in maximum dry matter accumulation in the shoot. It was followed by T_3S_2, T_2S_3 and T_3S_1. This indicated that supply of nutrients after 5th month, increased dry matter accumulation by continuing photosynthetic activities. Minimum dry matter accumulation in the shoot was observed in check plants (where fertilizers were applied to the soil) (Fig. 1). The dry matter accumulation in the corm was maximum in plants under the treatment T_3S_2 and it was followed by T_2S_3. The check treatment resulted in the minimum corm dry matter accumulation. The root dry matter accumulation was the maximum in plants under the treatment T_3S_3 followed by T_3S_2. The treatment T_3S_2 resulted in maximum total dry matter accumulation in the

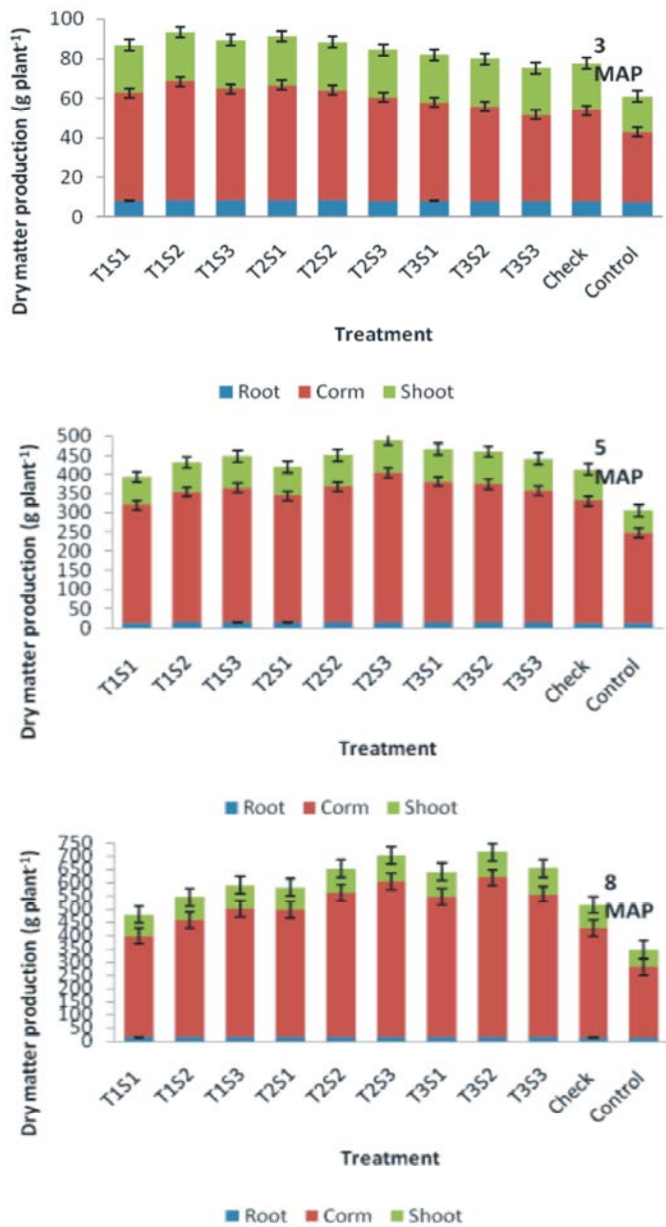

Fig. 1: Dry matter production and partitioning at 3, 5 and 8 MAP in elephant foot yam as influenced by fertigation interval and number of split doses of recommended fertilizer (means ± SE).

plants (Fig. 1). It was followed by T_2S_3. Lower total dry matter accumulation was observed in check plants. The lowest dry matter accumulation was recorded in the shoot, corm and root in control plants (Fig. 1). This indicated that in control treatment, the production and partitioning of photosynthates was lesser in control plants owing to non-availability of sufficient nutrients for crop growth and development. Furthermore, the growth attributes like plant height, canopy spread and girth of pseudostem were lower in control plants.

Corm Yield: The corm of EFY is the modified stem from which the leaf had emerged. The photosynthate produced in the source (shoot) was effectively translocated in to the bulking corm. EFY plant normally produces single depressed-globose shaped corm. If seed corm produces more number of sprouts after planting then each sprout develops as an independent plant and produces a separate corm. These corms may develop side by side in cluster but are smaller in size. Discerning difference in corm diameter, corm length and corm yield per plant was

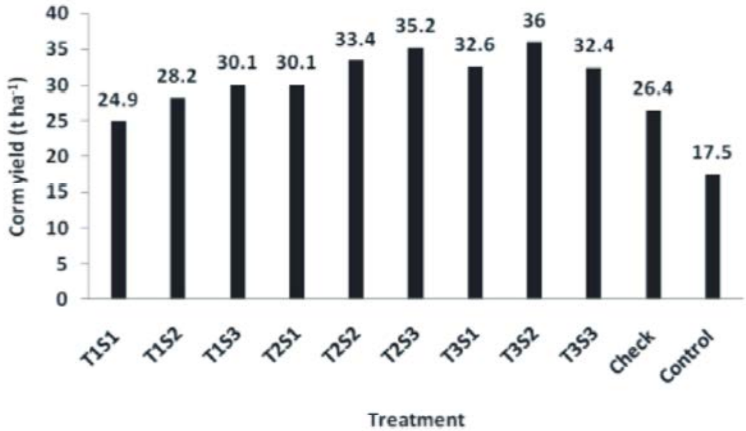

Fig. 2: Effect of fertigation interval and number of split doses of recommended fertilizer on corm yield (SEm±: 0.6; LSD (P=0.05): 1.7)

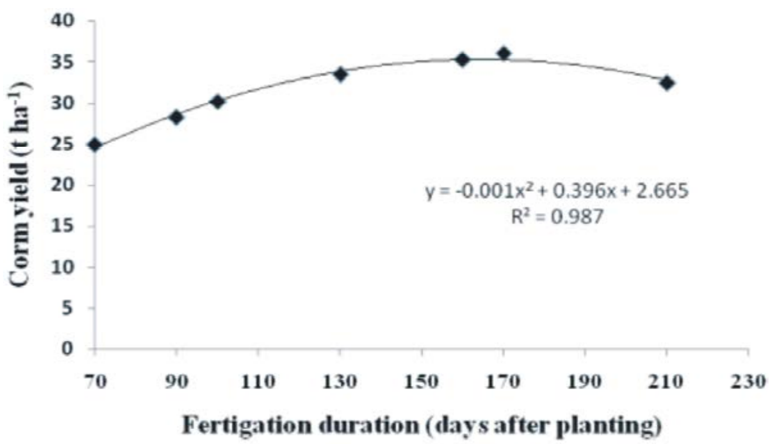

Fig. 3: Effect of fertigation duration on corm yield.

noticed with respect to fertigation interval and number of split dose of recommended fertilizer (Table 1). Maximum corm diameter, corm length and corm yield per plant were observed in plants under the treatment T_3S_2 and it was followed by T_2S_3. This may be due to greater growth attributes (plant height, canopy spread and pseudostem girth) in these treatments. The treatment check resulted in the minimum corm diameter and length and corm yield per plant. Significantly lowest corm diameter and length and corm yield per plant was recorded in control plants (Table 1).

Marked variation in the corm yield was observed with respect to drip fertigation interval and number of split dose of recommended fertilizers (Fig. 2). The treatment T_3S_2 resulted in maximum corm yield than other treatments and was statistically at par with plants under the treatment T_2S_3. The greater corm yield in these treatments was due to greater growth, dry matter production and partitioning. This indicated that if fertigation was given at 4 days interval then the number of split dose should be 40 or if fertigation was given at 3 days interval, the number of split dose should be 50. Above 40 split doses at 4 days interval or below 50 split doses in 3 days interval reduced the corm yield drastically. In the former case, the crop was unable to utilize applied fertilizers, whereas in the latter case the crop was unable to get required nutrients due to various kinds of losses. Trials with fertigation of potato demonstrated that a constant N-concentration in the final solution provided a better yield [40]. In the present study, drip fertigation at 2 days interval was not at all effective for this long duration crop (elephant foot yam). Interpolation of fertigation duration has indicated that the crop responded upto 180 DAP (Fig. 3). EFY plants were unable to utilize nutrients applied after 180 DAP. Drip fertigation could provide nutrients directly in to the root zone of plants with lesser loses compared to soil application. Jata *et al*. [41] reported greater corm yield of EFY plants under the fertigation than under the soil

Table 2: Correlation between nutrient uptake and corm yield.

	N uptake			P uptake			K uptake		
Parameter	3 MAP	5 MAP	8 MAP	3 MAP	5 MAP	8 MAP	3 MAP	5 MAP	8 MAP
Corm yield	0.4546	0.9499**	0.9945**	0.5196	0.9584**	0.9959**	0.5555*	0.9220**	0.9952**

*Significant at 5% probability and **Significant at 1% probability.

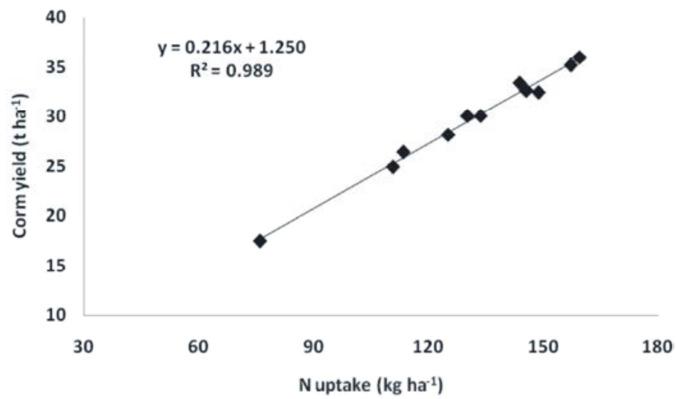

Fig. 4: Realtionship between N uptake and corm yield.

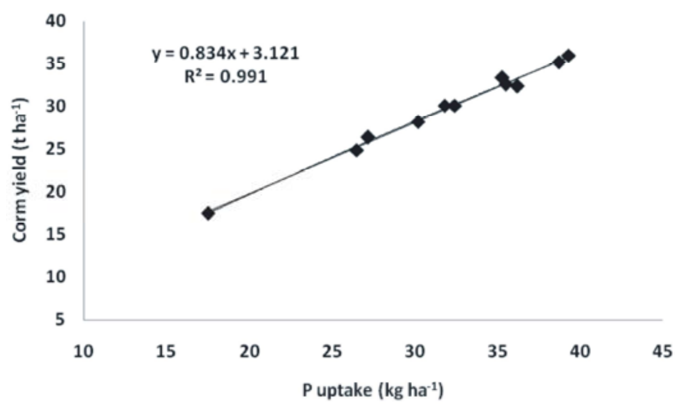

Fig. 5: Realtionship between P uptake and corm yield.

application of fertilizers. Nevertheless, fertigation nutrient losses may occur, if not applied in proper dose in proper interval. Plants need optimum dose at optimum interval for efficient utilization of applied fertilizers/nutrients. Tumbare and Bhoite [42] reported that weekly fertigation through drip irrigation in 14 equal splits starting from the first week of transplanting was beneficial for green chilli grown in a sandy clay loam soil.

Corm yield was positively correlated with N, P and K uptake (Table 2). At 5th and 8th MAP, a positive significant (P= 0.01) correlation between nutrient uptake and corm yield was observed. Corm yield was linearly related to total N (R^2= 0.9890), P (R^2= 0.9910) and K (R^2= 0.9900) uptake (Fig. 4-6). Corm yield increased with increase in total N, P and K uptake by the EFY crop. Byju *et al*. [43] reported that the NPK uptake requirements at different yield potentials (60-100 t ha^{-1}) of EFY showed linear relation between yield and NPK uptake at lower yield target. The corm yield of check plants was lower and was comparable with plants under the treatment T_1S_1 (Fig. 2). This indicated that drip fertigation at 2 days interval with the application of recommended dose of fertilizers in 30 splits was as equal as soil application of recommended dose of fertilizer. Nutrient availability in these two treatments to the plant is lesser than previous treatments owing to various kinds of losses and fixation. Significantly, the lowest corm yield was observed in control plants (Fig. 2). EFY being a high yielding crop mines large amount of nutrients from the soil. Hence, major nutrients are externally supplied to the soil through fertilizers. Venkatesan *et al*. [22] and Sahoo *et al*. [44] reported that EFY corm yield increased with increase in fertilizer levels.

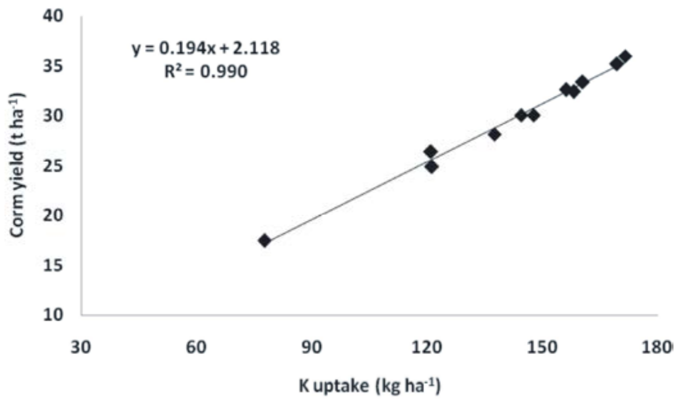

Fig. 6: Realtionship between K uptake and corm yield

Table 3: N uptake (kg ha^{-1}) of elephant foot yam as influenced by fertigation interval and number of splits.

	3 MAP				5 MAP				8 MAP			
Treatments	Shoot	Corm	Root	Total	Shoot	Corm	Root	Total	Shoot	Corm	Root	Total
T_1S_1	10.0	4.8	0.3	15.1	41.5	48.6	0.3	90.4	43.5	66.8	0.3	110.6
T_1S_2	10.3	5.2	0.3	15.8	43.9	54.0	0.3	98.2	47.7	77.0	0.3	125.0
T_1S_3	10.1	4.9	0.3	15.3	46.4	55.8	0.3	102.5	48.7	84.5	0.3	133.5
T_2S_1	10.3	5.1	0.3	15.7	42.6	52.5	0.3	95.4	45.7	84.1	0.3	130.1
T_2S_2	10.1	4.8	0.3	15.2	46.2	56.3	0.3	102.8	48.2	95.2	0.3	143.7
T_2S_3	9.8	3.9	0.2	13.9	47.8	64.0	0.4	112.2	52.0	104.8	0.3	157.1
T_3S_1	9.7	3.7	0.2	13.6	47.9	60.1	0.4	108.4	51.1	94.2	0.3	145.6
T_3S_2	9.6	3.5	0.2	13.3	48.0	59.1	0.3	107.4	52.1	107.0	0.4	159.5
T_3S_3	9.5	3.3	0.2	13.0	47.6	56.2	0.3	104.1	52.3	95.9	0.4	148.6
Check	9.5	3.4	0.2	13.1	46.5	50.3	0.3	97.1	45.8	65.4	0.3	113.4
Control	7.2	2.5	0.2	9.9	31.0	36.8	0.3	68.1	34.8	40.9	0.2	75.9
SEm±	0.27	0.07	0.006	0.37	0.95	1.16	0.007	2.58	1.05	1.80	0.006	3.47
LSD (*P*=0.05)	0.8	0.2	NS	1.1	2.8	3.4	NS	7.6	3.1	5.3	0.02	10.2

Table 4: P uptake (kg ha^{-1}) of elephant foot yam as influenced by fertigation interval and number of splits

	3 MAP				5 MAP				8 MAP			
Treatments	Shoot	Corm	Root	Total	Shoot	Corm	Root	Total	Shoot	Corm	Root	Total
T_1S_1	2.5	2.2	0.1	4.8	8.0	15.9	0.2	24.1	7.5	18.9	0.1	26.5
T_1S_2	2.6	2.4	0.1	5.1	8.4	17.7	0.2	26.3	8.3	21.8	0.1	30.2
T_1S_3	2.5	2.3	0.1	4.9	8.9	18.3	0.2	27.4	8.4	23.9	0.1	32.4
T_2S_1	2.5	2.3	0.1	4.9	8.2	17.2	0.2	25.6	7.9	23.8	0.1	31.8
T_2S_2	2.5	2.2	0.1	4.8	8.9	18.4	0.2	27.5	8.3	26.9	0.1	35.3
T_2S_3	2.4	2.1	0.1	4.6	9.2	21.1	0.2	30.5	9.1	29.5	0.1	38.7
T_3S_1	2.4	1.9	0.1	4.4	9.1	19.8	0.2	29.1	8.9	26.5	0.1	35.5
T_3S_2	2.4	1.9	0.1	4.4	9.1	19.5	0.2	28.8	9.1	30.1	0.1	39.3
T_3S_3	2.4	1.7	0.1	4.2	9.0	18.6	0.2	27.8	9.1	27.0	0.1	36.2
Check	2.4	1.8	0.1	4.3	9.0	14.7	0.2	23.9	8.3	18.8	0.1	27.2
Control	1.8	1.3	0.1	3.2	6.0	10.3	0.2	16.5	5.9	11.5	0.1	17.5
SEm±	0.07	0.07	0.006	0.10	0.17	0.41	0.005	0.71	0.20	0.75	0.004	0.78
LSD (*P*=0.05)	0.2	0.2	NS	0.3	0.5	1.2	NS	2.1	0.6	2.2	NS	2.3

Nutrient Uptake: Nutrient uptake is the function of biomass production and nutrient content. Discernable difference in N, P and K uptake was observed with respect to fertigation interval and duration (Table 3, 4 and 5). Nutrient uptake increased with the increase in age of the crop. This was mainly due to the production of more dry matter. At 3rd MAP, nutrient uptake by the shoot was more than in the corm. At 5th and 8th MAP, nutrient uptake in the corm was more than in the shoot. There was no much variation in nutrient uptake by the root across all

Table 5: K uptake (kg ha^{-1}) of elephant foot yam as influenced by fertigation interval and number of splits.

	3 MAP				5 MAP				8 MAP			
Treatments	Shoot	Corm	Root	Total	Shoot	Corm	Root	Total	Shoot	Corm	Root	Total
T_1S_1	11.5	10.6	0.3	22.4	40.5	78.8	0.7	120.0	38.6	82.0	0.6	121.2
T_1S_2	11.8	11.6	0.3	23.7	42.7	87.7	0.7	131.1	42.4	94.5	0.6	137.5
T_1S_3	11.6	10.9	0.3	22.8	45.2	90.7	0.7	136.6	43.3	103.7	0.6	147.6
T_2S_1	11.7	11.2	0.3	23.2	41.5	85.2	0.7	127.4	40.6	103.2	0.6	144.4
T_2S_2	11.5	10.7	0.3	22.5	45.0	91.4	0.8	137.2	42.8	116.9	0.7	160.4
T_2S_3	11.0	9.6	0.3	20.9	45.5	98.1	0.8	144.4	44.8	123.9	0.7	169.4
T_3S_1	11.0	9.1	0.3	20.4	44.8	92.1	0.7	137.6	44.1	111.4	0.6	156.1
T_3S_2	10.9	8.8	0.3	20.0	45.0	90.5	0.7	136.2	44.3	126.5	0.7	171.5
T_3S_3	10.8	8.0	0.3	19.1	44.6	86.2	0.7	131.5	44.0	113.4	0.7	158.1
Check	10.3	7.2	0.1	17.6	41.8	68.1	0.5	110.4	38.7	81.8	0.5	121.0
Control	7.6	5.1	0.1	12.8	27.1	45.2	0.4	72.7	26.7	50.5	0.4	77.6
SEm±	0.24	0.21	0.007	0.44	0.99	1.77	0.017	3.80	0.95	3.50	0.22	4.90
LSD (*P*=0.05)	0.7	0.6	0.02	1.3	2.9	5.2	0.05	11.2	2.8	10.3	0.06	14.4

the growth period. Nutrient uptake was linearly related to dry matter production. The difference in nutrient uptake by the shoot was negligible between 5th and 8th MAP as there was no increase of shoot dry matter. After 5th MAP, only the corm dry matter increased.

The N uptake by the shoot and corm increased up to crop senescence (8th MAP). But no definite trend was observed with regard to N uptake in the root. The total N uptake increased with the age of the crop and it was maximum at 8th MAP (harvest) in all the treatments (Table 3). The N uptake by the shoot, corm and root was greater in plants under the treatment T_1S_2 at 3rd MAP. The treatment T_1S_2 resulted in significantly greater total N uptake at 3rd MAP and it was statistically at par with plants under the treatment T_2S_1, T_1S_3, T_2S_2 and T_1S_1. The treatment check resulted in the minimum total N uptake at 3rd MAP. However, it was statistically compared with T_3S_1, T_3S_2 and T_3S_3. The N uptake by the shoot, corm and root was greater in plants under the treatment T_3S_2, T_2S_3 and T_2S_3 respectively at 5th MAP. At 5th MAP, the total N uptake was greater in plants under the treatment T_2S_3 and it was statistically at par with plants under the treatment T_3S_1 and T_3S_2. The minimum total N uptake was recorded in check plants (Table 3) and was statistically compared with plants under the treatment T_3S_3, T_2S_2, T_1S_3 and T_1S_2. At 8th MAP, N uptake by the shoot was greater in plants under the treatment T_3S_3 whereas corm and root N uptake was greater in plants under the treatment T_3S_2. At 8th MAP, the treatment T_3S_2 resulted in greater total N uptake and was statistically compared with plants under the treatment T_2S_3. These treatments had 40.7 and 38.5% greater total N uptake than the check plants (Table 3). Presumably more frequent application of N resulted in increased availability of N throughout the active crop growth period when the nutrient requirement was maximum. The fertigation enhanced the overall root activity and improved the mobility of N element and their uptake by the plants [45]. The N loss is minimal when applied in more number of splits. The fertigation events of longer duration distributed nitrate more uniformly throughout the root zone and reduced the nitrate leaching [46]. Dhuka *et al*. [47] and Ratanoo *et al*. [48] also reported that more split application of N resulted in greater N uptake in cereals.

The treatments T_3S_2 and T_2S_3 resulted in 110.1 and 107.0% greater total N uptake than control (Table 3). This was due to greater level of N available to the plants and greater dry matter production (Fig. 1). The N uptake was also linearly related (R^2= 0.9890) to corm yield (Fig. 4). The uptake of mineral nutrients, notably N, increased substantially through fertigation. This was in agreement with Papadopoulos, [49] and Phene *et al*., [21]. Sahoo *et al*. [50] reported that better utilization of N was observed at greater nutrient application. The treatment check resulted in lower total N uptake and it was statistically at par with plants under the treatment T_1S_1 at all the growth stages (3rd, 5th and 8th MAP). Significantly, lowest total N uptake and shoot and corm N uptake was reordered in control plants during the entire growth period.

In EFY, the total P uptake was lesser than N and K (Table 4). The P accumulation in the shoot increased up to 5th month and then decreased towards crop senescence (8 MAP). This may be due to the translocation of P from mature leaves to growing corms. The shoot P uptake was greater in plants under the treatments T_1S_2 and T_2S_3 at 3rd and 5th MAP, respectively. At 8th MAP, the P uptake by the shoot was same level among treatments T_2S_3, T_3S_2 and

T_3S_3. The P uptake in these treatments was higher than rest of the treatments. The P uptake by the corm increased steadily upto harvest (8 MAP) (Table 4). The P uptake in corm was greater in plants under the treatment T_1S_2 at 3rd MAP and was statistically at par with plants under the treatments T_1S_3, T_2S_1, T_2S_2 and T_1S_1. At 5th MAP, the corm P uptake was significantly greater in plants under the treatment T_2S_3 than in other treatments. At 8th MAP, the treatment T_3S_2 resulted in greater P uptake by the corm. But this was statistically at par with plants under the treatment T_2S_3. The P uptake by the root was maximum at 5th month irrespective of the treatment and it decreased towards 8 MAP. The differences in P uptake by the root were insignificant with respect to the treatments through the entire crop growth period. The total P uptake increased with the age of the crop and it was maximum at 8 MAP (harvest) in all the treatments (Table 4). The treatments T_1S_2, T_2S_3 and T_3S_2 resulted in maximum total P uptake at 3rd, 5th and 8th MAP respectively. At 8 MAP, plants under the treatment T_3S_2 and T_2S_3 had 44.5 and 42.3% greater total P uptake than the check plants (Table 4). The reason may be that more frequent application of P resulted in increased availability of P throughout the active crop growth period when it was most needed. The water soluble P moves to the deep root zone along with water. The P covers greater soil volume when applied through a drip irrigation system than as a soil amendment [51]. When P was applied as water soluble form phosphorus moved in a calcareous loam soil to a depth of 30 cm. The fixation of P in the soil is less when applied through drip irrigation in split doses compared to one time basal application in the soil. Application of water soluble P through drip irrigation significantly increased total P uptake (Table 4). Tumbare and Nikam [52] stated that application of recommended dose of P through drip irrigation at 2 days interval upto 105 days resulted in significantly greater uptake of phosphorus (12.58 kg ha^{-1}) by chilli than surface irrigation and soil application of P (8.53 kg ha^{-1}). In the present study, the treatments T_3S_2 and T_2S_3 resulted in 124.6 and 121.1% greater total P uptake than in control plants (Table 4). This was due to greater P availability to the plants and dry matter production (Fig. 1). The P uptake was linearly related (R^2= 0.9910) to the corm yield (Fig. 5). Significantly, the lowest total P uptake, in the shoot and corm was recorded in control plants during entire crop growth period (Table 4).

The total K uptake was greater than N and P accumulation in EFY whole plant (Table 5). The shoot and root K uptake increased upto 5th month and then decreased towards crop senescence (8 MAP). This may be due to translocation of K along with starch towards bulking corm. The K uptake by the corm increased continuously upto harvest (8 MAP). The shoot, corm and root K uptake were greater in plants under the treatment T_1S_2 at 3rd MAP and T_2S_3 at 5th MAP. At 8th MAP, K uptake in the shoot was greater in plants under the treatment T_2S_3 whereas K accumulation in the corm and root was greater in plants under the treatment T_3S_2. The total K uptake increased with the age of the crop and it was maximum at 8th MAP (harvest) in all the treatments (Table 5). At 3rd MAP, the total K uptake was maximum in T_1S_2 and it was statistically at par with plants under the treatment T_2S_1, T_1S_3, T_2S_2 and T_1S_1. The check treatment resulted in significantly minimum K uptake compared to all fertigation treatments. The treatment T_2S_3 resulted in higher total K uptake at 5th MAP and it was statistically comparable with T_3S_1, T_2S_2, T_1S_3 and T_3S_2. The check treatment resulted in lower K uptake and it was statistically comparable with plants under the treatment T_1S_1. At 8th MAP, greater total K uptake was noticed in plants under the treatment T_3S_2 and was statistically at par with plants under the treatment T_2S_3, T_2S_2 and T_3S_3. The K uptake in plants under the treatment T_3S_2, T_2S_3, T_2S_2 and T_3S_3 was 41.7, 40.0, 39.3 and 37.1%, respectively greater than check plants. The reason may be that more frequent application of K resulted in increased availability of K throughout the active growth period when it was most needed. The treatments T_3S_2, T_2S_3, T_2S_2 and T_3S_3 resulted in 121.0, 118.2, 106.7 and 103.7%, respectively greater total K uptake than control plants (Table 5). This was due to greater availability of K to the plants and greater dry matter production (Fig. 1). The K uptake was also linearly related (R^2= 0.9900) to the corm yield (Fig. 6). The check treatment resulted in lower K uptake during the entire growth period and was statistically at par with plants under the treatment T_1S_1. In check plants at 8th MAP, the K uptake by the shoot was maximum in plants under the treatment T_2S_3, whereas K accumulation in the corm and the root was maximum in plants under the treatment T_3S_2. Hochmuth and Smajstrla [53] reported that fertigation at weekly or bi-weekly or monthly was the best to maximize the nutrient uptake by the crop depending on the soil type. But greater irrigation frequency might provide desirable condition for water and nutrient movement in the soil and for uptake by the roots [54]. Tumbare and Nikam [52] reported that application of recommended dose of K through drip irrigation at 2 days interval upto 105 days resulted in significantly greater uptake of potassium (99.1 kg ha^{-1}) by chilli than surface irrigation and soil application of K (44.6 kg ha^{-1}).

Table 6: N, P and K use efficiency of elephant foot yam as influenced by fertigation interval and number of splits.

Treatments	(AE_N)	(PE_N)	(RE_N%)	(PFP_N)	(AE_P)	(PE_P)	(RE_P%)	(PFP_P)	(AE_K)	(PE_K)	(RE_K%)	(PFP_K)
T_1S_1	62.5	216.1	28.9	207.5	125.0	833.3	15.0	415.0	62.5	172.0	36.3	207.5
T_1S_2	89.2	217.9	40.9	235.0	178.3	842.5	21.2	470.0	89.2	178.6	49.9	235.0
T_1S_3	105.8	220.5	48.0	250.8	211.7	852.3	24.8	501.7	105.8	181.4	58.3	250.8
T_2S_1	105.8	234.3	45.2	250.8	211.7	888.1	23.8	501.7	105.8	190.1	55.7	250.8
T_2S_2	133.3	236.0	56.5	278.3	266.7	898.9	29.7	556.7	133.3	193.2	69.0	278.3
T_2S_3	147.5	218.0	67.7	293.3	295.0	834.9	35.3	586.7	147.5	192.8	76.5	293.3
T_3S_1	125.8	216.6	58.1	271.7	251.7	838.9	30.0	543.3	125.8	192.4	65.4	271.7
T_3S_2	154.2	221.3	69.7	300.0	308.3	848.6	36.3	600.0	154.2	197.0	78.3	300.0
T_3S_3	125.0	206.3	60.6	270.0	250.0	802.1	31.2	540.0	125.0	186.3	67.1	270.0
Check	74.2	237.3	31.3	220.0	148.3	917.5	16.2	440.0	74.2	205.1	36.2	220.0
SEm±	2.80	6.62	0.81	7.03	4.86	23.8	0.61	14.32	2.80	6.69	1.55	7.03
LSD (*P*=0.05)	8.3	19.6	2.4	20.8	14.4	70.3	1.8	42.4	8.3	19.8	4.6	20.8

Furthermore greater concentration of K was found in the upper layers of the soil i.e. at 0 to 20 cm soil depth and lower concentration of K was found in the lower layers of the soil i.e. 20 to 40 cm soil depth under fertigation. Significantly the minimum total K uptake, accumulating in the whole plant, shoot, corm and root was recorded in control plants during the entire growth period (Table 5).

Nutrient use Efficiency: The partial factor productivity (PFP) for applied nutrient is a useful measure of nutrient use efficiency because it provides an integrative index that quantifies total economic output relative to utilization of nutrient in the system, including the indigenous soil nutrient supply and applied nutrient [55]. The PFP reflects both AE as well as the balance between the indigenous soil nutrient supply and applied nutrient. The AE represents the product of PE with which the crop utilizes the acquired nutrient to produce more yield and the RE of applied nutrient. The AE is a useful measure of nutrient use efficiency, as it provides an integrative index that quantifies total economic output relative to the utilization of all nutrient resources in the system. The PE is the fraction of applied nutrient utilized for yield production and RE is the fraction of applied nutrient that is absorbed by a crop.

Marked variation in AE, PE, RE and PFP of N/P/K was observed with respect to fertigation treatments (Table 6). The treatment T_3S_2 resulted in greater $AE_{N/P/K}$, $RE_{N/P/K}$ and $PFP_{N/P/K}$. However, it was statistically at par with the treatment T_2S_3. The treatments T_3S_2 and T_2S_3 resulted in 107.8 and 98.8% greater $AE_{N/P/K}$ and 36.4 and 33.3% greater $PFP_{N/P/K}$ over the check. The above treatments also resulted in 122.7 and 116.3% greater RE_N, 124.1 and 117.9%, greater RE_P and 116.3 and 111.3% greater RE_K over the check (Table 6). In the present study, the AE_N, RE_N and PFP_N increased with fertigation duration and attained maximum when fertigation was given up to 170 days after planting. This implies that more number of split applications of fertigation is essential for maintaining crop growth and greater AE. This also indicated that synchronizing split NPK application with crop demand enhanced AE, RE and PFP of NPK. Cassman *et al*. [56] reported that the maximum fertilizer nutrient recovery was obtained when more nutrients were available to the plant. Application of recommended dose of N in 3-split doses resulted in the greater AE_N and RE_N than 2-split doses in wheat [48]. Alcoz *et al*. [57] reported an increase in the RE_N and AE_N due to split application of nutrients. The P covers greater soil volume when applied as orthophosphoric acid through a drip irrigation system than triple super phosphate (TSP) applied through the soil [51]. When P was applied as water soluble urea phosphate it moved in a calcareous loam soil to a depth of 30 cm thereby increasing the availability to plants. The K application had more effect on yield when applied through drip irrigation [58]. The check treatment resulted in the minimum $AE_{N/P/K}$, $RE_{N/P/K}$ and $PFP_{N/P/K}$ (Table 6). Adoption of inefficient nutrient management practices (application of fertilizer in the soil in 3 splits doses of N and K) is responsible for the minimum AE, RE and PFP. The minimum AE, RE and PFP of NPK in check plants may be attributed to the non-matching of NPK applied with the demand for a long duration. Similar results were reported by Sen *et al*. [59] in rice and Singh *et al*. [60] in maize. In cassava, minimum $AE_{N/P/K}$ and $RE_{N/P/K}$ were reported by Howeler [61] and Byju *et al*. [62] when nutrients were applied directly in the soil. Since the plant growth and nutrient uptake are closely interrelated, it is difficult to determine whether the poor $AE_{N/P/K}$, $RE_{N/P/K}$ and $PFP_{N/P/K}$ in check treatment is due to the inability of the plant to recover nutrient or the inability of the plant to utilize that nutrient for growth and yield production [63]. But more than 50% of applied nutrients are lost in soil application compared to 10% loss in fertigation [64]. Fertigation minimises loss of N due to leaching, supply precisely required quantity of nutrients directly to the root zone in available forms at the right time [65].

The $PE_{N/P/K}$ was noticed greater in check plants (Table 6) and was statistically at par with plants under the treatment T_2S_2, T_2S_1, T_3S_2, T_1S_3 and T_1S_2. The applied N/P/K available to the crop in these treatments was low but was utilized by the crop more efficiently for yield production. Paramasivan *et al*. [66] also observed greater PE in medium fertilized plot than heavily fertilized plot. The treatments T_3S_2 and T_2S_3 resulted in 6.7 and 8.1% lesser $PE_{N,}$ 7.5 and 9.0% lesser PE_P and 3.9 and 6.0% lesser PE_K respectively than the check plants. At greater yield level, there was reduction in PE values. This was due to more absorption of applied N/P/K by the crop which was not utilized efficiently like check treatment. Similar observations were made earlier by Byju *et al*. [67] for cassava and Byju *et al*. [43] for EFY. Kaur *et al*. [68] also reported a 6% decrease in PE when they applied N in 3-split doses compared to 2-splits in wheat. Similar results were also reported by Ratanoo *et al*. [47].

CONCLUSIONS

Elephant foot yam (EFY) growth i.e. plant height, canopy spread and pseudostem girth at different growth period (between 3rd and 5th month) was dependent on amount of fertigation received during that period. The increase of growth attributes was negligible between 5th and 7th month and then declined as crop senescence started. The corm yield increased with increasing fertigation interval from 3 to 4 days with 40 to 50 split applications. However, the crop did not responded to fertigation beyond 180 DAP. The corm yield was positively and strongly correlated with N, P and K uptake. The fertigation at 4 days interval with 40 numbers of split doses of recommended fertilizer and fertigation at 3 days interval with 50 numbers of split dose of recommended fertilizer resulted in maximum corm yield, nutrient (N, P and K) uptake and use efficiency (AE, RE and PFP). Thus synchronizing split NPK application with the crop demand enhanced AE, RE and PFP of NPK. The PE of absorbed nutrients (N, P and K) utilized for sink (corm) development was lesser in the above treatments compared to check. Thus, for EFY, fertigation of water soluble fertilizer N- P_2O_5-K_2O 120-60-120 kg/ha at 4 days interval in 40 split doses (N-P_2O_5-K_2O 3-1.5-3 kg $ha^{-1}dose^{-1}$) or at 3 days interval in 50 split doses (N-P_2O_5-K_2O 2.4-1.2-2.4 kg $ha^{-1}dose^{-1}$) can be recommended for greater crop growth, corm yield and N, P and K use efficiency.

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