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Customized Fertilizer Formulations for Elephant Foot Yam (*Amorphophallus paeoniifolius* (Dennst.) Nicolson) under Intercropping in Coconut Gardens for Kerala, India

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Among tropical tuber crops, elephant foot yam (*Amorphophallus paeoniifolius* (Dennst.) Nicolson) is a highly potential and ideal intercrop in the coconut gardens of Kerala, especially in agro-ecological unit (AEU) 3 and AEU 9 with laterite and sandy soil types, respectively. This paper narrates the protocols developed for evolving customized fertilizer (CF) formulations for elephant foot yam (EFY) under intercropping in coconut gardens of Kerala including their testing and validation in different parts of the State to arrive at the best grade and rate of application. The methodology included, arriving at the weighted average data of each chemical parameter of the two AEUs and the theoretical optimum of the nutrient recommendation evolved for N, P, K, Mg, Zn, B, dolomite based on the weighted average data was 71: 12.5: 106.5: 12.8: 4.2: 1.31: 1000 kg ha^{-1} for AEU 3 and 78: 12.5: 90: 12.8: 4.2: 1.31: 1000 kg ha^{-1} for AEU 9, respectively. The actual optimum nutrient doses evolved based on nutrient omission plot (NOP) and nutrient level (NL) experiments for N, P, K, Mg, Zn, B and dolomite was 140: 20: 225: 19.2: 4.2: 1.575: 1500 kg ha^{-1} for AEU 3 and 160: 12.5: 180: 19.2: 6.3: 1.975: 1500 kg ha^{-1} for AEU 9, respectively. Based on the nutrient use parameters computed for an yield target of 45 t ha^{-1}, as per soil test crop response (STCR), quantity of nutrients to be supplied through CF formulation was arrived as 203 and 185, 58 and 63, 145 and 175 kg N, P_2O_5 and K_2O, respectively for AEU 3 and AEU 9. In the case of secondary and micronutrients, the level at which the highest tuber yield obtained as 19.2, 4.2 and 1.575 kg ha^{-1} Mg, Zn, B, respectively for AEU 3 and 19.2, 6.3 and 1.975 kg ha^{-1} for AEU 9 was taken. Considering the nutrient content in the CF as 20% N and 70% K, for an application rate of 500 kg ha^{-1}, the grades of the CF based on STCR approach was arrived as N: P_2O_5: K_2O: Mg: Zn: B is 8: 11: 21: 3.5: 1: 0.3 for AEU 3 (CF1) and 7: 12: 24: 3.5: 1.25: 0.4 for AEU 9 (CF2). In the response curve (RC), the nutrient levels at the highest tuber yield obtained under NOP and NL was taken and the grades of N: P_2O_5: K_2O: Mg: Zn: B arrived was 7: 3: 25: 4: 1.25: 0.4 for AEU 9 (CF3) and 6: 3: 30: 3.5: 1: 0.3 for AEU 3 (CF4). Among these four grades, the first three grades tested at two doses *viz.* 500 and 625 kg ha^{-1} in three farmers' fields of the two AEUs indicated better performance of all the three grades @ 625 kg ha^{-1}. The three grades @ 625 kg ha^{-1} tried in large plots of the five major EFY growing districts of Kerala *viz.* Thiruvananthapuram, Kollam, Pathanamthitta, Kottayam and Ernakulam for profitability, soil health and tuber quality revealed CF2 with grade as N: P_2O_5: K_2O: Mg: Zn: B @ 7: 12: 24: 3.5: 1.25: 0.4 as the best in terms of tuber yield, BC ratio, soil quality indices and biochemical attributes of the tuber.

Key words: *Amorphophallus paeoniifolius,* agro-ecological units, tuber yield, nutrient requirement, fertilizer use efficiency, customized fertilizer, soil test crop response, response curve, BC ratio, soil quality

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Root and tuber crops are the third most important group of food crops, after cereals and grain legumes which in turn constitute either staple or subsidiary food for about one-fifth of the world population in tropics and sub-tropics (Edison 2006). *Amorphophallus paeoniifolius* (Dennst.) Nicolson commonly known as 'elephant foot yam' (EFY) is a

highly potential tropical tuber crop of Araceae family and is regarded as the 'King of tuber crops'. It is widely grown and consumed in South Eastern countries like India, Philippines Malayasia, Indonesia and some other Southern countries. In India, it is widely cultivated in Andhra Pradesh, Bihar, Chhattisgarh, Jharkhand, Gujarat, Kerala, Maharashtra, Tamil Nadu, Uttar Pradesh, West Bengal and North Eastern States (Nedunchezhiyan and Byju 2005). It is classified under the group of vegetables in India having a production of 659 million tonnes from an area of 26,000 ha land with a productivity of 25.35 t ha^{-1} (GOI 2017). It is a nutritional crop containing carbohydrates, minerals and vitamins having medicinal properties too and is commonly used in ayurvedic preparations and tribal medicines in India. Nair and Mohankumar (1991) reported that, under Kerala condition, a ten month duration crop of EFY requires a fertilizer dose of 100:50:150 kg N, P_2O_5 and K_2O ha^{-1} for optimum yield. In Kerala, tropical tuber crops like EFY, yams, taro, tannia, arrowroot are grown as intercrop in coconut gardens. The EFY is a major intercrop in the Onattukara sandy plain (AEU 3) and South Central laterites (AEU 9) of Kerala. The nutrient management studies under both sole cropping and intercropping situations (Biswanath et al. 2014) indicated that EFY is highly responsive to fertilizers and manures and provides reasonably good profit as an intercrop in coconut, arecanut, banana and rubber plantations and hence provision of adequate nutrition is essential for better growth and tuber yield.

According to Hegde et al. (2007) multi-macro nutrient and micronutrient mixtures are found to facilitate the application of a wide range of plant nutrients in proportion to suit the specific requirements of the crops. 'Custom-made fertilizers' emerged as a new idea of scientific research in the field of nutrient management specific to soils and crops. These fertilizers are generally assumed to maximize crop yields while minimizing the unwanted impacts on the environment and hence human health. Customized fertilizers (CF) can be defined as multi-nutrient carriers which contain macro and micronutrients, whose sources are from inorganic and organic origin and are formulated through specific systematic process of granulation with correct quality checks and satisfy crops' nutritional demands, specific to area, soil and plant growth. CF usually contain constraint nutrients specific to the soils like Ca, Mg, S, Zn, B in addition to N, P, K in proportion that suits to crop and soil requirements. These are formulated

based on a series of experiments to arrive at the optimum nutrient specific to soils and crops other than taking into account the consumer preference especially with respect to the application rates. Rakshit et al. (2012) indicated that CF manufacture basically involves mixing and crushing of fertilizers followed by steam injection, granulation, drying, sieving and cooling, so as to get a uniform product with every grain having the same nutrient composition.

Though we have the blanket recommendation, there is widespread occurrence of nutrient deficiencies especially those of secondary and micronutrients. Since designed fertilizers specific to crops and regions are becoming popular and EFY is a highly nutrient demanding and nutrient responsive crop, an attempt was made to develop CF formulations for EFY intercropped in coconut gardens of the two agro-ecological units (AEU) of Kerala viz. AEU 3 and AEU 9.

Materials and Methods

The study sites viz. Onattukkara sandy plain (AEU 3) extend mainly in two districts such as Alappuzha and Kollam, and South Central laterites (AEU 9) covers the six districts such as Thiruvananthapuram, Kollam, Alappuzha, Pathanamthitta, Kottayam and Ernakulam. The methodology for the development of CF involved the following steps:

Evolution of the weighted average data of soil chemical parameters and soil test based fertilizer (STBF) rate for two AEUs

The methodology for the evolution of CF would start with building-up of crop and soil database of EFY growing regions. The secondary data on soil nutrient availability of the selected AEUs was from the soil database of the independent panchayats of the whole State of Kerala under the Kerala State Planning Board coordinated project on 'Soil based plant nutrient management plans for agro ecosystems of Kerala'. The AEU 3 comprised of 43 panchayats of the two districts and AEU 9 had 161 panchyats covering the above six districts. The weighted average of the soil test data of the comprising panchayats of the two AEUs was computed taking into account the average chemical parameters of each panchayat with respect to its area. The weighted average data of each soil chemical property was used to arrive at the soil test based fertilizer (STBF) rate for the two AEUs as per Aiyer and Nair (1985) for major nutrients and soil

critical level for secondary and micronutrients as per KAU (2012).

Nutrient omission plot experiments and nutrient level experiments to arrive at the optimum rate of application of nutrients for the two AEUs

In order to arrive at the optimum nutrient rate of major (N, P and K), secondary nutrients (Mg) and micronutrients (Zn and B), two separate experiments *viz*. nutrient omission plot (NOP) experiment and nutrient level (NL) experiments with different levels of the nutrient in question were conducted in three locations *viz*. two in AEU 9 (farmer plot at Kozhencherry in Pathanamthitta district and one in on station at ICAR-CTCRI) and one in AEU 3 (farmer plot in Chettikulangara in Alapuzha district) during 2015-16. These trials were conducted with EFY variety Gajendra and were laid out in randomized complete block design (RCBD) with 15 treatments replicated twice. Each plot consisted of 25 plants and the plot size was 4.5 m × 4.5 m.

Nutrient omission plot experiment for major nutrients

In the NOP experiment, different levels of the optimum fixed based on mean weighted average data of N, P and K of the two AEUs was taken in addition to an omission treatment (minus) for each of these nutrients. For N, the levels tested were 0.5N, 1.5N, 2N, for P, based on the soil test, as the recommended rate was zero, a maintenance dose of 25% of PoP (Package of Practices) was taken as the optimum and the levels were 1.25P, 1.5P and K levels were 0.75K, 1.5K and 2K. The soil test based levels of nutrients *viz*. Mg, Zn and B and dolomite arrived as per KAU (2012) was kept as optimum in both AEUs.

Nutrient level experiment for secondary and micronutrients

The secondary and micronutrients taken care were Ca, Mg, Zn and B as they were found limiting for these two soil types as evidenced from the project report of the Kerala State Planning Board (KSPB 2013). Dolomite was found as the best liming material for these two AEUs (Susan John *et al*. 2013) due to deficiency of both Ca and Mg in these soils as well as the prevalence of subsoil acidity (low pH with high saturation of Al^{3+} ions). In the case of these nutrients and dolomite, in addition to the optimum, the levels of dolomite were 0.5 D, 1.5 D and 2 D, Zn levels were 0.5 Zn, 1.5 Zn and 2 Zn, B levels were 0.5, 1.25 and 1.5B, Mg levels were 0.25M, 0.5M and 1.5M were tested.

After proper ploughing and land preparation, pits were taken at a spacing of 0.9 m × 0.9 m accommodating 25 plants in each plot. The seeds were treated with cow dung and ash slurry containing *Trichoderma* formulation to manage the fungal disease *viz*. collar rot prevalent in EFY. After planting the crop, the treatments were given through fertilizers as basal and top dressing at the recommended dose during specific time periods. All the intercultural operations were done on time and destructive sampling was done at peak vegetative growth stage of the crop around 6 months after planting (MAP) from inner plants. The fresh weight of the entire lamina and pseudostem of two plants per plot was recorded and 100 g fresh weight of these samples was oven dried for dry matter, plant nutrient analyses (Singh *et al*. 2005) and hence nutrient uptake. Harvesting was done at 10 MAP and tuber yield was recorded. The pre-and post-harvest soil samples also were analyzed for all the nutrients (Singh *et al*. 2005) in question.

Arriving at the optimum nutrient rate of each nutrients for the two AEUs

Based on the tuber yield data of the two AEUs, the optimum nutrient rate of primary (N, P and K), secondary (Mg), micronutrients (Zn and B) and dolomite were standardized after statistical analysis of the data.

Understanding the nutrient application rate by EFY farmers of the two AEUs

A survey was conducted among 72 farmers belonging to the different places of AEU 3 and 9 to assess the general nutrient management strategy of EFY under coconut intercropping with respect to the type of organic manures, chemical fertilizers, their rate and mode of application which in turn will help to decide on the rate of application of the CF developed in parity with farmers' application rate. The general consensus based on the survey was followed in the project wherever farmers' practice was mentioned.

Arriving at the grades of the CF for the two AEUs

Parameters like nutrient requirement (NR) (kg nutrient taken up per tonne of tuber), total initial soil available nutrient supply, percentage nutrient contribution from soil (CS%), soil nutrient supply (kg ha^{-1}), total plant nutrient uptake (kg ha^{-1}), fertilizer use/agronomic efficiency (%) were computed from the data collected from NOP and NL experiments to arrive at the nutrient to be taken up from the fertilizer (kg

Table 1. Treatments for the field experiment

Treatments	Details	Description
1	CF 1 @ 500 kg ha^{-1}	STCR AEU 3
2	CF 2 @ 500 kg ha^{-1}	STCR AEU 9
3	CF 3 @ 500 kg ha^{-1}	RC AEU 9
4	CF 1 @ 625 kg ha^{-1}	STCR AEU 3
5	CF 2 @ 625 kg ha^{-1}	STCR AEU 9
6	CF 3 @ 625 kg ha^{-1}	RC AEU 9
7	POP	
8	FP	

Table 2. Initial soil chemical parameters of AEU 3 and AEU 9

Parameters	AEU 3	AEU 9
pH	5.70	5.50
Electrical conductivity (dS m^{-1})	0.29	0.28
Organic carbon (%)	0.94	1.39
Available P (kg ha^{-1})	60.5	64.6
Exchangeable K (kg ha$^{-1)}$	209.0	271.0
Exchangeable Ca (meq 100g^{-1})	0.36	1.85
Exchangeable Mg (meq 100g^{-1})	0.31	0.88
Available S (ppm)	4.68	20.2
Available Zn (ppm)	3.74	5.3
Available Cu (ppm)	1.76	3.43
Available Fe (ppm)	99.0	60.8
Available Mn (ppm)	18.7	35.0
Available B (ppm)	0.68	0.78

ha^{-1}) and finally the fertilizer nutrient application requirement. These parameters along with the survey results were used to design the fertilizer mixture grade which in turn contains nutrients *viz.* N and K @ 20 and 70%, respectively and other nutrients in full. Among the four grades designed for two AEUs based on STCR (for an yield target of 45 t ha^{-1}) and RC approach, three were tested in farmers' field during the consecutive year with two rates as 500 and 625 kg ha^{-1}.

Experiments to screen the best dose and the best CF formulation

Field experiments were conducted in 3 locations in AEU 9 including on station at ICAR-CTCRI and one location at AEU 3 with 8 treatments replicated thrice in RCBD during 2016-17 with treatments as indicated below (Table 1). The parameters primarily evaluated to arrive at the best CF included tuber yield, tuber quality, soil quality index and BC ratio.

As the result of this experiment indicated all the three CFs @ 625 kg ha^{-1} was equally good with respect to the above parameters, the next year experiment was conducted as a multi-locational trial in RCBD to identify the best CF (out of the three CFs tried). This experiment consisted of five treatments (three CFs at 625 kg ha^{-1} along with PoP and Farmers' practice) each having 80 plants per treatments in each site in farmers' fields in the major five EFY growing districts of Kerala *viz.* Thiruvananthapuram, Kollam, Pathanamthitta, Kottayam and Ernakulam.

Results and Discussion

Evolution of the weighted average data of the soil chemical parameters of the two AEUs

The weighted average data of the soil chemical parameters of the two AEUs is presented in table 2.

The STBF optimum rate (theoretical optimum) evolved based on the above data of the two AEUs were as N, P, K, Mg, Zn, B, dolomite @ 71: 12.5: 106.5: 12.8:4.2: 1.31: 1000 kg ha^{-1} and 78: 12.5: 90: 12.8: 4.2: 1.31: 1000 kg ha^{-1} for AEU 3 and AEU 9, respectively (Anju *et al.* 2016).

Nutrient omission plot experiment and nutrient level experiment to arrive at the actual optimum rate of application of nutrients for the two AEUs

Tuber yield was taken as the first criteria to arrive at the actual optimum nutrient rate. For working out the other parameters to design the grade of the designed fertilizer *i.e.* CF, the data generated from NOP and NL experiments were taken.

Standardization of NPK (NOP experiment)

In this experiment, the tuber yield data indicated 2 N as significantly highest giving a tuber yield of 45.9 t ha^{-1} in AEU 3. In AEU 9, in location 1, optimum N (33.6 t ha^{-1}) was on par with 1.5 N (38.7 t ha^{-1}) and 2N (45.2 t ha^{-1}). But in AEU 9, location 2, 2N (43.8 t ha^{-1}) was on par with 1.5 N (36.0 t ha^{-1}). However, the average data of the two locations of AEU 9 indicated 2 N (45.0 t ha^{-1}) as significantly higher than other treatments. Hence, 2N (142 and 156 kg ha^{-1} for AEU3 and AEU 9, respectively) was taken as the optimum for the two AEUs (Table 3). The high yield response with highest dose of N can be attributed to the high N deficiency (30%) of the coconut growing areas which might have resulted in better response to the applied higher levels of N (Kavitha and Sujatha 2015). Moreover, as N being one of the most important single factors limiting the production of the yam tuber (Aduayi and Okpon 1980), application of this nutrient at higher level might have resulted in higher tuber yield.

In AEU 3, 1.5 P recorded significantly the highest tuber yield (36.5 t ha^{-1}). In AEU 9, in both

Table 3. Tuber yield (t ha^{-1}) under nutrient omission plot and nutrient level experiments in AEU 3 and AEU 9

Treat. No	Description	AEU 3	AEU 9	Description	AEU 3	AEU 9
T1	Opt	32.4	30.3	OPT	32.2	33.5
T2	-N	19.0	24.3	0.5 D*	24.5	28.5
T3	0.5N	29.0	26.6	1.5D	35.4	38.0
T4	1.5N	38.4	37.4	2D	42.0	42.7
T5	2N	45.9	45.0	0.5B	26.7	30.6
T6	-P	25.5	26.1	1.25B	39.4	33.5
T7	1.25P	29.2	29.8	1.5B	40.3	41.1
T8	1.5P	36.6	32.4	M	26.7	27.6
T9	-K	20.7	26.0	0.25M	17.5	19.2
T10	0.75K	27.4	28.6	0.5M	23.7	29.0
T11	1.5K	37.1	34.1	1.5M	33.9	40.4
T12	2K	46.4	45.4	Zn	29.2	28.2
T13	FP	34.7	32.3	0.5Zn	23.3	28.2
T14	PoP	33.1	29.9	1.5Zn	28.2	34.1
T15	AC	17.3	24.4	2ZN	31.1	34.7
SEm±		1.11	2.5		2.2	2.5
CD (p=0.05)	-	*3.38*	*11.5*		*6.7*	*5.8*

* Dolomite

locations, minus P recorded yield on par with the other higher levels. But the mean data over these two locations revealed optimum P (P @ 12.5 kg ha^{-1}) on par with other higher levels and hence in AEU 3, P @ 18.75 kg ha^{-1} and in AEU 9, optimum P @ 12.5 kg ha^{-1} was taken (Table 3). According to Fernandes *et al.* (2015) P application can increase the yield of marketable tubers in yams.

Among the five levels of K tried, in AEU 3, 2K as K @ 212 kg ha^{-1} gave significantly the highest tuber yield (46.4 t ha^{-1}). In AEU 9, in location 1, 2K (47.0 t ha^{-1}) was on par with 1.5 K (40.2 t ha^{-1}). In location 2, 2K was significantly the highest with a tuber yield of 43.7 t ha^{-1}. The mean over the two locations of AEU 9 showed 2 K (45.7 t ha^{-1}) as significantly the highest in tuber yield. Hence, in both locations, 2K (@ 212 kg ha^{-1} in AEU 3 and 180 kg ha^{-1} in AEU 9) was taken as the optimum (Table 3). The significance of K in enhancing the productivity of tuber crops was reported by many researchers. According to Susan John *et al.* (2010), K is the most significant nutrient for tropical tuber crops for enhancing tuber yield, tuber quality and maintaining soil available K status.

Standardization of Ca, Mg, B and Zn (NL experiment)

As regards to the tuber yield under dolomite, in AEU 3 and 9, 2D was on par with 1.5D (Table 3) and hence in both AEUs, dolomite @ 1.5 t ha^{-1} was recommended as the optimum. The good response with dolomite can be justified as per the studies of

Wissen *et al.* (2015) that, Ca was effective in enhancing tuber weight and hence tuber yield. In the case of Mg, in both AEUs, 1.5 Mg was on par with optimum Mg and hence, 1.5 Mg (Mg @ 19.2 kg ha^{-1}) was taken as the optimum. The result is in conformity with the reports of Talukder *et al.* (2009) that, the tuber yield in potato increased significantly with increasing rate of Mg up to 10 kg ha^{-1}. In AEU 3, though 1.5B recorded highest tuber yield, it was on par with 1.25 B (1.63 kg B), hence it was taken as the optimum. Similarly in AEU 9, the two locations as well as the mean of AEU 9 showed 1.5 B (1.96 kg B) as the optimum as it gave a significantly higher yield over all the other levels. In AEU 3, the highest tuber yield was recorded by 2Zn which in turn was on par with all levels except 0.5 Zn and hence optimum Zn (4.2 kg) was taken as the best optimum. In AEU 9, the mean of the two locations indicated 2Zn is on par with 1.5Zn and hence 1.5 Zn (6.3 kg) was taken as the best optimum (Table 3). Sahota *et al.* (1982) found that, trace elements like Zn and B can increase the tuber yield by increasing the tuber size and tuber number and Zn has a significant role in enzyme systems and is a team player with NPK in many plant development processes.

Arriving at the optimum rate of application of nutrients for the two AEUs

The best optimum nutrient doses for N, P, K, Mg, Zn, B and dolomite arrived for the two AEUs through NOP and NL experiments based on the tuber yield were N: P: K: Mg: Zn: B: dolomite @ 140: 20:

225: 19.2: 4.2: 1.634: 1500 kg ha^{-1} for AEU 3 and 160:12.5: 180: 19.2: 6.3: 1.965: 1500 kg ha^{-1} for AEU 9, respectively.

Understanding the nutrient application rate by EFY farmers of the two AEU's

The farmers' survey indicated the general application rate as factomphos containing N:P:K:S (20:20:0:15) @200 kg ha^{-1} (4 bags), MOP @250 kg ha^{-1} (5 bags) and urea @ 250 kg ha^{-1} (5 bags) along with FYM @25 t ha^{-1}. It is also known that, progressive farmers are applying 14 (700 kg) bags of chemical fertilizers and normal farmers are applying 8 (400 kg) bags of chemical fertilizers. Hence, the rate of application of the designed custom made fertilizer was fixed as 10-15 bags ha^{-1} (500-750 kg ha^{-1}).

Arriving at the grades of the CF for the two AEUs

The grades of the fertilizer mixture for the two AEUs were arrived using STCR and RC approaches.

STCR approach

The nutrient requirement (NR) with respect to N, P and K computed for the different field experiments in different locations of AEU 3 and AEU 9 during the first year under the NOP experiment is presented in table 4.

As regards to the NR for N, P and K, the N, P and K uptake under different levels of these nutrients was considered and the mean uptake of N, P and K at different levels of N, P and K in AEU 3, AEU 9 and mean of AEU 3 and 9 were presented in table 4. In this study, the nutrient uptake calculated for an yield target of 45 t ha^{-1} was 166 kg N, 32 kg P and 201 kg K ha^{-1}. Byju *et al.* (2016) reported an N, P and K uptake of 179, 31, 318 kg ha^{-1} respectively for an yield target of 45 t ha^{-1}. For subsequent computation of grades, the NR for N, P and K was taken as 3.68, 0.7 and 4.47 kg t^{-1} of tuber which is the average value of AEU 3 and AEU 9. Byju *et al.* (2016) reported values as 4-4.29, 0.7-0.76, 7-7.63 kg N, P and K respectively for yield target ranging from 10-70 t ha^{-1}.

Total initial soil available nutrient supply

The initial soil available nutrient supply for crop growth and yield for the particular season is taken as

Table 4. Nutrient requirement (NR) for N, P and K in the two AEUs under nutrient omission plot experiment

Description	AEU 3	AEU 9(1)	AEU 9(2)	AEU 9	AEU 3&9
					Mean
NR for N					
Opt	3.26	3.86	4.05	3.96	3.61
-N	5.21	3.45	3.35	3.4	4.31
0.5N	3.84	4.03	3.96	4.00	3.92
1.5N	4.18	3.42	2.94	3.18	3.68
2N	2.29	3.93	3.11	3.52	2.91
Mean	4.02	4.04	3.47	3.75	3.89
SEm±	0.66	1.03	0.89	0.62	0.53
CD (p=0.05)	2.01	NS	NS	NS	NS
Mean N (N plots alone)	3.76	3.74	3.48	3.61	3.68
NR for P					
-P	0.80	0.52	1.11	0.82	0.81
1.25P	0.65	0.64	0.95	0.80	0.72
1.5P	0.46	0.59	0.80	0.70	0.58
Mean	0.61	0.56	0.87	0.71	0.66
SEm±	0.10	0.14	0.25	0.14	0.11
CD(p=0.05)	0.30	NS	NS	NS	0.30
Mean P (P plots alone)	0.64	0.59	0.94	0.76	0.70
NR for K					
-K	3.96	7.59	6.3	6.95	5.45
0.75K	2.76	7.81	4.91	6.36	4.56
1.5K	2.52	4.54	4.7	4.62	3.57
2K	4.47	5.61	4.1	4.86	4.66
Mean K	3.29	6.62	4.12	5.37	4.33
SEm±	0.73	1.49	1.21	0.91	0.62
CD(p=0.05)	NS	NS	NS	NS	NS
Mean K (K plots alone)	3.37	6.22	4.92	5.57	4.47

the sum of initial soil nutrient status and the nutrient added through FYM. The FYM applied @ 25 t ha^{-1} had 33% moisture and the N, P and K content were 0.562, 0.0963, 0.58% respectively. In the case of soil available initial N, the status in AEU3 and mean of AEU 9 was 107.2 kg ha^{-1}. Taking into account both these, the total soil available N supply before the start of the experiment was 200 kg ha^{-1} in both AEUs. In the case of soil available P, the initial soil available P in AEU 3 and mean of AEU 9 were 45.1 and 49.1 kg ha^{-1}, and the values were calculated as 61.0 and 65.00 kg ha^{-1} respectively, for AEU 3 and AEU 9. The corresponding values for AEU 3 and AEU 9 in the case of soil available K was 209 and 271 kg ha^{-1}, respectively. In the computation of grades of the CF mixture, the initial soil available N, P and K of AEU 3 was taken as 200, 61 and 209 and AEU 9 as 200, 65, 271 kg ha^{-1}, respectively (Table 5). These values in turn were used to arrive at the percentage contribution (innate soil nutrient supply) from the soil after considering the nutrient uptake of these nutrients from plots omitted with these nutrients.

NPK uptake of the NPK omitted plots

For computing the grades, to arrive at the inherent nutrient supplying capacity of the soil, the N, P and K uptake under -N, -P and -K plots were taken from the NOP experiment. Hence, the N uptake in -N plots under AEU 3, AEU 9 were 111.1 and 65.6 kg ha^{-1}, respectively. In the case of P, these values were 20.29 and 21.64 kg ha^{-1}, respectively for AEU 3 and AEU 9 and the K uptake in K omitted plots were 92.6 and 131.4 kg ha^{-1}, respectively under AEU 3 and AEU 9.

Percent contribution of NPK from indigenous supply

The innate N, P and K supplying capacity (% contribution from soil) was computed by dividing the N, P and K uptake in the respective N, P and K omitted plots with total initial soil available N, P and K supply.

The data computed is given in table 5 as 55.6, 33.3 and 44.3% for AEU 3, and 32.8, 33 and 48.5% for AEU 9, respectively. This was worked out as 111, 20 and 93 kg ha^{-1} N, P, K for AEU 3 and 66, 21 and 131 kg ha^{-1} for AEU 9, respectively. Byju *et al.* (2016) reported values as 94.16, 17.52 and 154.66 kg ha^{-1} as indigenous NPK supply from the soil.

Agronomic/fertilizer use efficiency

It is the quantity of tuber produced (kg) for each kg of nutrient applied. For the computation of grades of the CF mixtures, the fertilizer use efficiency was very important. For the purpose of arriving at the grades, the fertilizer use efficiency of N, P and K for AEU 3 was taken as 27.1, 48.5 and 90.0, respectively and for AEU 9 as 54, 40 and 48, respectively (Table 5). This was based on the level of N, P and K at which there is highest/maximum tuber yield and this being 2N, 1.5P and 2K for AEU 3 and 1.5N, P and 2K for both locations of AEU 9. The N, P and K use efficiency as reported by Byju *et al.* (2016) was 32.35, 15.20 and 34.42%, respectively.

Nutrient to be taken up from fertilizer

This was calculated as the difference of nutrient uptake for the targeted yield of 45 t ha^{-1} and the inherent nutrient supplying/nutrient contribution from the soil. In AEU 3, it is calculated as N, P and K @

Table 5. Parameters computed for AEU 3 and AEU 9 for arriving at customized fertilizer grades

Parameters	AEU 3						AEU 9					
	N	P$_2$O$_5$	K$_2$O	Mg	Zn	B	N	P$_2$O$_5$	K$_2$O	Mg	Zn	B
Nutrient requirement (kg t^{-1})	3.68	0.70*	4.47*	19.2	4.2	1.58	3.68	0.70*	4.47*	19.2	6.3	1.97
Total initial soil available nutrient supply (kg ha^{-1})	200	61*	209*				200	65*	271*			
Innate nutrient supply (%)	55.6	33.3	44.3				32.8	33.3	48.5			
Nutrient supplied through soil (kg ha^{-1})	111	20*	93*				66	21*	131*			
Nutrient uptake (45 t ha^{-1})	166	32*	201*				166	32*	201*			
Fertilizer use efficiency (%)	27.1	48.5	90				54	40	48			
Nutrient to be applied through fertilizer (kg ha^{-1})	203	58	145				185	63	175			
Customized fertilizer grade (%)	8	12	20	3.84	0.84	0.32	7	13	25	3.84	1.26	0.4

*as P and K

55, 12 and 108 kg ha^{-1}, respectively and the respective values for AEU 9 was 100, 11 and 70 kg ha^{-1}. After accounting the fertilizer use efficiency, the N, P and K application requirement was calculated as 203, 58 and 145 for AEU 3 and 185, 63, and 175 kg N, P$_2$O$_5$ and K$_2$O, respectively for AEU 9 (Table 5).

Secondary and micronutrient requirement

In the case of secondary nutrients *viz.,* Mg and micronutrients *viz.,* Zn and B, from NL experiment, the level at which the highest tuber yield obtained was 19.2 kg Mg, 4.2 kg Zn and 1.634 kg B for AEU 3 and for AEU 9, it was 19.2 kg Mg, 6.3 kg Zn and 1.965 kg B (Table 5).

Formulation of grade of the CF's

In AEU 3, since the CF formulation has 20% N, full P and 70% K, the grade formulated as per the N, P and K requirement computed should have N, P$_2$O$_5$ and K$_2$O @ 40.2, 57 and 101.5 kg ha^{-1}, respectively. If the CF formulation is applied @ 500 kg ha^{-1}, the N: P$_2$O$_5$: K$_2$O content (%) is @ 8: 11: 20. Considering the above optimum nutrient rate of Mg, Zn and B, the grades were 3.84, 0.84 and 0.315, respectively. Hence, the final grade of the CF mixture for AEU 3 as per STCR approach was N: P$_2$O$_5$: K$_2$O: Mg: Zn: B @ 8: 11: 21: 3.84: 0.84: 0.315 for an application rate of 500 kg ha^{-1} considering the CF contains 20% N, full P and 70% K (Anju *et al.* 2018).

Under AEU 9, the grade formulated as in the case of AEU 3, have the content of N: P$_2$O$_5$: K$_2$O as @ 7: 12: 24 (%). In the case of Mg, Zn and B, based on their optimum level, the grades were 3.84, 1.26 and 0.394, respectively. The grade of the CF mixture for AEU 9 was N: P$_2$O$_5$: K$_2$O: Mg: Zn: B @ 7: 12: 24: 3.84: 1.26: 0.4. According to Singh *et al.* (2014), STCR approach for target yield is unique in indicating both soil test based fertilizer dose and the level of yield that can be achieved with good agronomic practices.

Response curve (RC) approach

In this approach, the level of the above nutrients

at which the highest/maximum tuber yield obtained was taken as the optimum level for arriving at the grades. In AEU 3, the levels of N, P$_2$O$_5$, K$_2$O, Mg, Zn and B where the highest yield recorded was 142, 12.5, 213, 19.2, 4.2 and 1.6, respectively and the respective values for AEU 9 was156, 12.5, 180, 19.2, 6.3 and 1.965 kg ha^{-1}, respectively. Keeping these levels with the basic concept that CF has 20% N, full P and 70% K, and full of Mg, Zn and B, the above nutrient contents on per hectare basis were 28.4, 12.5, 149.1, 19.2, 4.2 and 1.634 kg ha^{-1} for AEU 3 and 31.2, 12.5, 126, 19.2, 6.3, 1.965 kg ha^{-1} N, P$_2$O$_5$, K$_2$O, Mg, Zn and B, for AEU 9 respectively. For an application rate of 500 kg ha^{-1} of the CF mixture, the grade (% nutrient content) of N, P$_2$O$_5$, K$_2$O, Mg, Zn and B was 5.68, 2.5, 29.82, 3.84, 0.84, 0.32, for AEU 3 and 6.24, 2.5, 25.2, 3.84, 1.26, 0.395, for AEU 9 respectively. The final grade as per the response curve approach for AEU 3 was N: P$_2$O$_5$: K$_2$O: Mg: Zn: B was 6: 3: 30: 3.5: 0.8: 0.3 and 6.24, 2.5, 25.2, 3.84, 1.26, 0.395 for AEU 9. The response curves fitted for Mg, Zn and B for AEU 3 and AEU 9 are presented in fig. 1.

Byju *et al.* (2016) based on QUEFTS model developed CF for EFY with grade as N: P: K: Mg: Zn: B 12: 4: 18: 3: 0.4: 0.2 for the three districts of Kerala *viz.,* Malappuram, Wyanad and Ernakulam at an application rate of 650 kg ha^{-1}. The final grades of CF developed for the two AEU's based on the two approaches are given in table 6.

The technical and scientific expertise of Tata Chemicals (Centre for Agri solutions), Aligarh, Uttar Pradesh who are the pioneers in the development of CF was utilized for arriving at the grades of the CF for the present study.

Quantity of N and K for top dressing

Since the CF mixture contains 20% N and 70% K and full P, the rest of N and K need to be applied via top dressing. In AEU 3, the total N and K$_2$O application requirement is 203 and 145 kg ha^{-1} for an application rate of 500 kg ha^{-1}. As 20% N and 70% K requirement is met by the CF, the rest of 80% N and

Table 6. Grades/composition of the customized fertilizer mixtures developed for the two AEU's

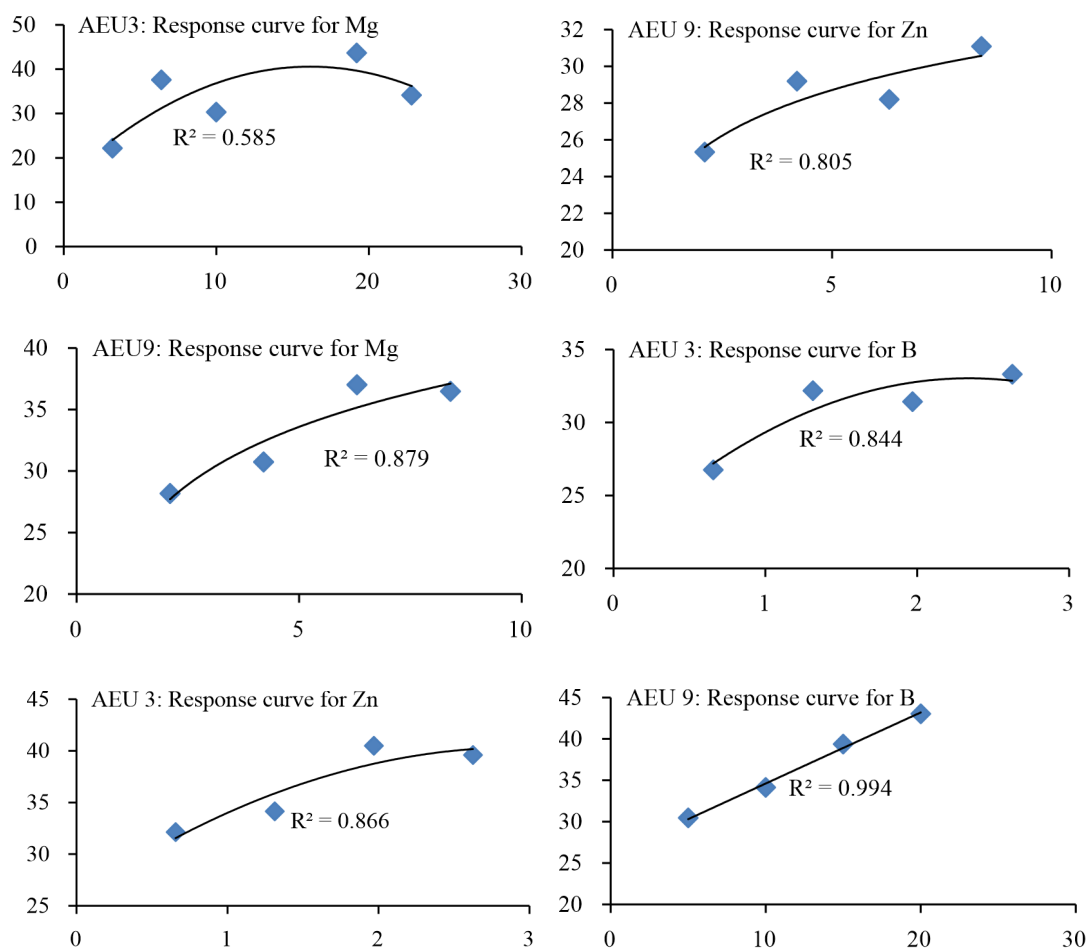| AEU's	Approach		CF GradeNutrient contents (%)					
			N	P$_2$O$_5$	K$_2$O	Mg	Zn	B
AEU3	STCR	CF1	8	11	21	3.5	1	0.3
AEU3	RC	Not selected for field trial	6	3	30	3.5	1	0.3
AEU9	STCR	CF2	7	12	24	3.5	1.25	0.4
AEU9	RC	CF3	7	3	25	4.0	1.25	0.4

Fig. 1. Response curve of nutrients under AEU 3 and AEU 9

30% K are top dressed which in turn is calculated as 350 kg urea and 73 kg MOP. In the case of AEU 9, the total N and K_2O application requirements were calculated as 185 and 175 kg ha^{-1} and converting to urea and MOP to the tune of 80% and 30% for top dressing and it was arrived as 323 and 87 kg ha^{-1}, respectively.

Testing of CFs in farmers' fields

In order to arrive at the best grade as well as the optimum rate of application, the results of the field experiments conducted in farmers' fields during 2017-18 and 2018-19 were presented with respect to tuber yield, tuber quality attributes, soil quality indices and BC ratio.

Tuber yield

The tuber yield data of the three locations where field experiments were conducted during 2016-17 (Fig. 2) showed that AEU 3 was significantly lower

over the other two sites in AEU 9. In AEU 3, the three CFs @ 500 kg ha^{-1} were on par. All the three CFs @ 625 kg ha^{-1} was significantly higher in tuber yield over 500 kg ha^{-1}. The tuber yield at site 1 under AEU 9 was significantly higher over site 2. At site 1, among the three CFs @ 500 kg ha^{-1}, CF2 and CF3 were significantly higher than CF1 and were on par. At 625 kg ha^{-1}, CF2 and CF3 were significantly higher over CF1. The same trend was seen for the mean of AEU 9 with CF2 on par with CF1. As regards to the interaction effect of treatments and locations, CF2 @ 625 kg ha^{-1} at site 1 under AEU 9 resulted in significantly higher yield which was on par with CF3 @ 625 kg ha^{-1}. Hence, for EFY under intercropping in coconut, CF2/CF3 @ 625kg ha^{-1} is found as the best. In all locations under AEU 3 and 9, both PoP and FP were on par and were significantly lower to the CF grades at the two different rates (Fig. 2).

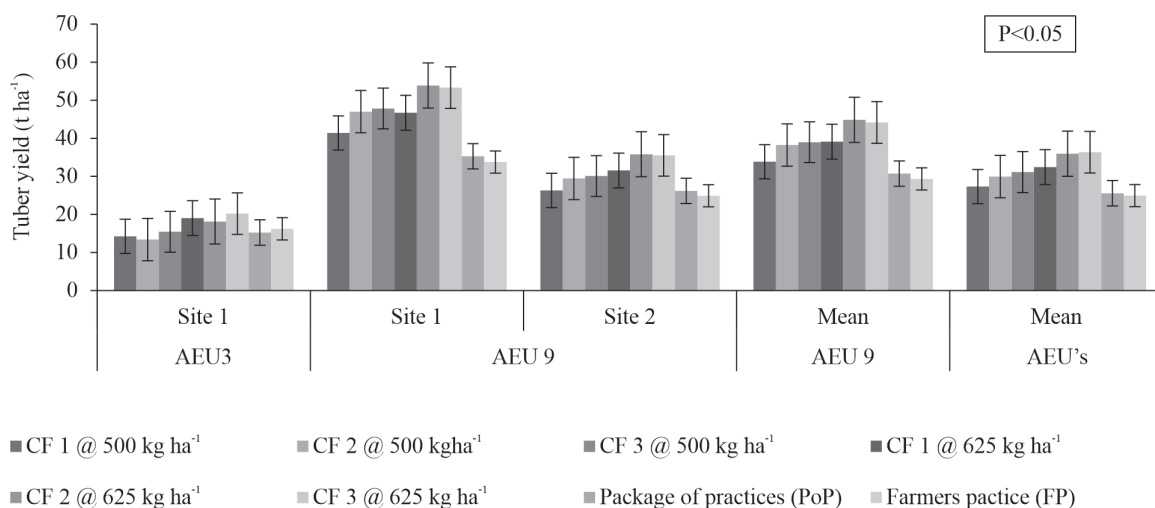Since all the CFs @ 625 kg ha^{-1} were on par at AEU 3 and almost a similar trend was observed with

Fig. 2. Effect of treatments on corm yield of elephant foot yam (2016-17)

CF2 and CF3 on par and CF2 on par with CF1, all the three CFs @ 625 kg ha^{-1} was tested for screening the best CF in the next year experiment.

Statistical analysis of the data revealed significant effect of treatments with CF2 (67.5 t ha^{-1}) on par with CF3 (62.6 t ha^{-1}) and CF1 (58.7 t ha^{-1}). However, farmers' practice (51.6 t ha^{-1}) and PoP (47.3 t ha^{-1}) recorded significantly lower tuber yield (Fig. 3). Rakshit *et al.* (2012) obtained better yield with customized fertilizer having grade as N, P, K, S, Zn and B @ 8: 16: 24: 6:0.5: 0.15 for potato manufactured by Tata Chemicals Limited, U.P.

Shekhon *et al.* (2012) also reported additional grain and straw yields in wheat with the application of higher dose of CFs. Bhaskaran and Subramanyam (2011) reported increased rice yield (11 t ha^{-1}) with

CF application over farmers' practice. There are similar reports in potato (Irfan *et al.* 2015) and grapes (Singh and Adhikari 2004) too.

Soil quality indices

Soil quality indices (SQI) were worked out for pre-planting and post-harvest soils of second year farmer field experiments and post-harvest soil samples of third year farmer field trials. The second year data presented in fig. 4 indicated substantial increase in SQI of final soil samples over initial. In AEU 3, the standardized PCA analysis extracted three principal components with a contribution of 0.544, 0.282 and 0.175% for PC1, PC2 and PC3, respectively with variables included as soil pH, available K and exchangeable Mg from PC1, SOC and available N
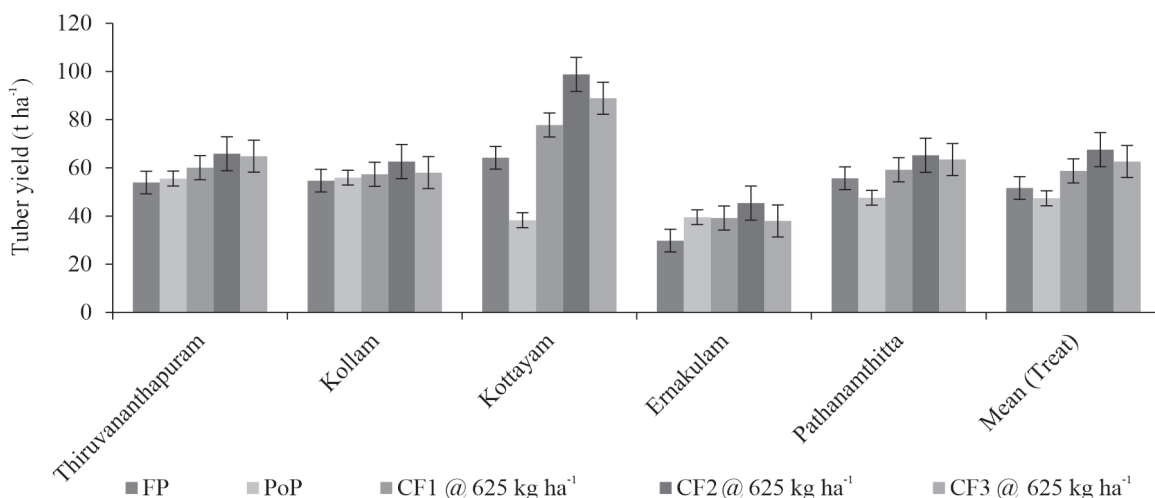

Fig. 3. Effect of treatments on corm yield (t ha^{-1}) under screening of the best customized fertilizer (2018-19)
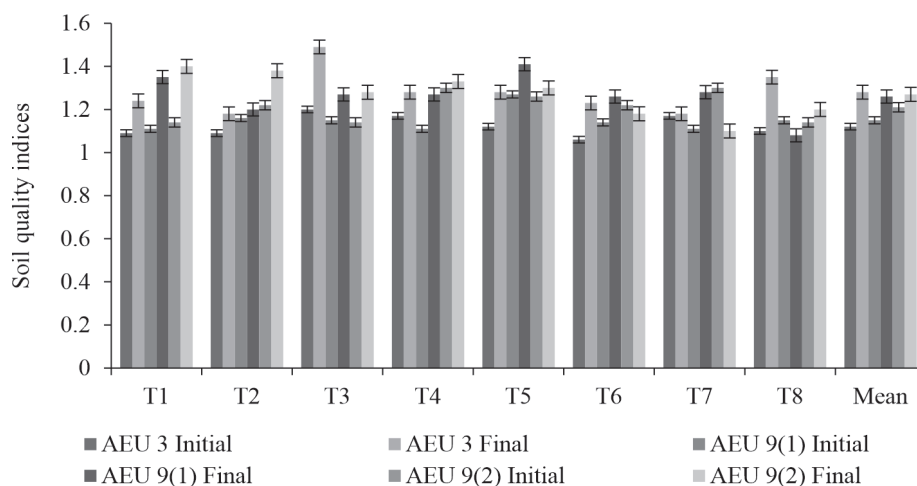
Fig. 4. Change in SQI under different treatments during the experiment (2017-18)

under PC2 and soil available Zn and B under PC3. It was seen that the initial SQI was not significantly affected by treatments whereas the final SQI showed significant effect of treatments with the mean value increased from 1.12 to 1.28. The treatment, T3 (CF3 @ 500 kg ha^{-1}) has significantly higher SQI (1.49) and was on par with T8 (FP) (1.35). T2 and T7 registered significantly low values (1.18) and was on par with T1, T4, T5 and T6. Hence, in AEU 3 which was a typical sandy soil, application of CF fertilizer could produce a better response in soil chemical characteristics thereby improved soil quality and incidentally the environmental sustainability.

In AEU 9(1), the standardized PCA analysis extracted three principal components with a contribution of 0.517, 0.266 and 0.216% for PC1, PC2 and PC3, respectively. The retained variables included soil pH, exchangeable Mg and available Zn from PC1, available P and organic carbon under PC2 and exchangeable Ca and available N under PC3. Here also, the final SQI (1.26) was higher compared to initial SQI (1.15) indicating the effect of treatments on final SQI. From these results, it is concluded that, application of CF fertilizer had resulted in the improvement of soil quality as FP resulted in a steady decline of SQI (T8) when compared to CF treatments. The AEU 9 (2) also showed the same trend where the initial SQI values were lower than final and there was no significant effect of treatments. The location wise data on the effect of treatments on SQI indicated CF treatments can definitely improve the soil quality when compared to PoP and FP.

The SQI values of the post-harvest soil of the third year experiment indicated no significant effect

of treatments. The standardized PCA extracted three principal components with a contribution of 0.428, 0.299 and 0.273% for PC1, PC2 and PC3, respectively and the retained variables included exchangeable Ca, SOC and DHA from PC1, available P and exchangeable Mg under PC2 and acid phosphatase and Zn under PC3. The SQI values of all the treatments are almost in the same range (1.39-1.31) but T2 (PoP) recorded the lowest. As all the CFs gave better SQI compared to PoP, it can be very well stated that, CF application can definitely improve the soil quality which in turn comprised of biological properties like DHA and SOC in addition to soil chemical properties. The DHA activity was higher in all the treatments which in turn revealed that, the microbial activity had been considered as an important biological property for the functional capacity of soil. The increased organic carbon in post-harvest soil and hence high SQI noted was in conformity with the reports of Zhang *et al*. (2007) that SOC is an important factor affecting soil quality and long-term sustainability of agriculture while the decrease in SOC leads to a decline in cation exchange capacity of soils, soil aggregate stability and crop yield (Freixo *et al*. 2002). Bellaki and Badanur (1994), Venkateswarlu (1984) and Ramamoorthy *et al*. (2002) reported increased DHA due to the faster rate of mineralization and decomposition of organic matter with increased nutrient availability.

Tuber quality parameters

Among the different tuber quality attributes studied *viz*. starch, sugar, crude protein, total phenols, oxalate, crude fat, crude fiber and ash during the two

years, significant effect of treatments was seen in the case of starch, crude protein, calcium oxalate, crude fibre and ash during the second year field experiment. Among these, the starch and crude protein indicated significant effect of treatments in both AEUs. The data in table 7 explains the details as below:

It is seen that the starch content was high in AEU 3 (14.49%) compared to AEU 9. In AEU 3, T1 (CF1 @ 500 kg ha^{-1}) recorded significantly higher starch content (16.22%) but on par with T2 (CF2 @ 500 kg ha^{-1}) (15.55%). T6 had the lowest starch content in both locations. In general, except T1 and T2 in AEU 3, the treatments including FP and PoP were behaving similarly in the starch content of tubers. The CF treated plots gave high crude protein content compared to PoP and FP. Though Paul *et al.* (2013) reported that EFY corms are poor in proteins, here the application of CF treatments resulted in higher per cent of crude protein. Leszczynski and Lisinska (1988) reported that crude protein content usually increases with N fertilization. Calcium oxalate is an important anti-nutritional factor prevalent in Araceae family especially in EFY. The data showed the effect of traditional farmers' practice and conventional PoP in reducing the calcium oxalate in tubers in comparison to the CF treatments. As in the case of crude fibre also, though CF's @ 625 kg ha^{-1} caused significantly higher crude fibre in AEU 3, the data at AEU 9 in both location revealed FP as best in terms of improving the crude fiber per cent when compared to CF treatments. As regards to the ash content, the effect of CFs especially CF2 @625 kg ha^{-1} resulted in significantly higher ash content over PoP and is in conformity with the findings of Kareem

(2013) that higher ash content under inorganic fertilizer plots while the least was in organo-mineral plots in the case of sweet potato tuber.

During the third year, among all the tuber quality attributes studied, significant effect of treatments was seen only in the case of sugar where T1 (FP) indicated significantly higher sugar content (1.86%) on par with T3 (CF1 @625 kg ha^{-1}) (1.72%) and T4 (CF2 @625 kg ha^{-1}) (1.85%).

BC ratio

In the case of the second year experiment (2016-17), it was seen that, the total cost of cultivation including labour cost (Rs. 3,28,250 ha^{-1}) and cost of inputs was almost same for all treatments to the tune of 3.67-3.81 lakhs ha^{-1} except PoP which was 3.54 lakhs ha^{-1}. In the case of tuber yield, under AEU 9, the yield was high compared to AEU 3 and all the CFs @ 625 kg ha^{-1} resulted in higher yield over CFs @ 500 kg ha^{-1}. However, PoP and FP resulted in comparatively low yield over CF's. Total income was computed by multiplying the tuber yield with price of one kg tuber (Rs. 30 kg^{-1}). The total/gross income followed the same trend as tuber yield in both the AEUs. Net income was highest under CFs @ 625 kg ha^{-1} as CF3 followed by CF1 and CF2 in AEU 3 and CF2 followed by CF3 and CF1 in AEU 9. The B: C ratio indicated higher under AEU 9 compared to AEU 3. CF3 @ 625 kg ha^{-1} resulted in the highest BC ratio of 1.64 and 3.60 respectively in AEU 3 and AEU 9. In AEU 3, the three CFs @ 625 kg ha^{-1} gave the higher BC ratios as CF3, CF1, CF2 to the tune of 1.64, 1.53 and 1.43, respectively. Similarly in AEU 9, CF3, CF2 and CF1 @ 625 kg ha^{-1} resulted in BC ratio

Table 7. Effect of treatments on tuber quality attributes of elephant foot yam corms

Treatment	Starch (%) (FW basis)		Crude Protein (%) DW basis		Ca Oxalate (mg 100g^{-1}) FW basis		Crude Fibre (%) DW basis		Ash (%) DW basis	
	AEU 3	AEU 9	AEU 3	AEU 9	AEU 3	AEU 9	AEU 3	AEU 9	AEU 3	AEU 9
T1	16.22[a]	12.33[bc]	14.93[b]	16.59[a]	24.53	21.86[a]	1.19[bcd]	1.08	5.04	6.22[abc]
T2	15.55[ab]	11.51[cd]	16.67[a]	15.96[ab]	24.02	15.10[bc]	1.30[bc]	0.95	5.00	4.85[e]
T3	14.44[c]	12.79[b]	14.25[b]	15.17[c]	21.00	16.96[ab]	0.86[d]	0.97	4.80	4.97[de]
T4	14.22[cd]	14.71[a]	16.33[a]	15.34[bc]	21.25	18.80[ab]	1.77[a]	1.05	4.80	6.42[ab]
T5	13.31[d]	12.06[bc]	14.38[b]	15.72[bc]	19.74	15.27[bc]	1.45[ab]	1.26	5.13	6.73[a]
T6	13.22[d]	10.74[d]	15.50[ab]	14.25[d]	21.17	14.60[bc]	1.52[ab]	1.02	4.00	5.87[bc]
T7	14.67[bc]	12.40[bc]	14.58[b]	14.41[d]	19.40	11.52[c]	0.98[cd]	1.36	5.07	5.58[cd]
T8	14.40[c]	12.61[b]	12.42[c]	12.89[e]	21.13	16.57[bc]	1.34[b]	1.84	4.67	6.55[a]
Mean	14.49	12.39	14.88	15.04	21.53	16.33	1.30	1.18	4.84	5.89
SEm±	0.355	0.293	0.431	0.219	1.36	1.725	0.114	0.249	0.664	0.217
p-Value	0.0004	<.0001	0.0002	<.0001	0.1595	0.0315	0.0016	0.2832	0.9391	0.0001
CV (%)	4.12	4.13	5.09	2.53	10.92	18.29	15.35	36.85	23.55	6.36

Table 8. Economic parameters under the field experiment (2017-18)

Treatments	Total cost of fertilizers and manures (Rs ha⁻¹)	Total cost of cultivation (Rs ha⁻¹)	Tuber yield (t ha⁻¹)		Gross income (Rs ha⁻¹)		Net income (Rs ha⁻¹)		B:C ratio	
			AEU 3	AEU 9	AEU 3	AEU 9	AEU 3	AEU 9	AEU 3	AEU 9
T1: CF1 @ 500 kg ha⁻¹	40803	369053	14.250	33.844	427511	1015320	58457	1015319	1.16	2.75
T2: CF2 @ 500 kg ha⁻¹	41745	369995	13.391	38.222	401718	1146669	31723	1146668	1.09	3.10
T3: CF3 @ 500 kg ha⁻¹	39212	367462	15.447	38.957	463395	1168695	95933	1168694	1.26	3.18
T4: CF1 @ 625 kg ha⁻¹	44138	372388	19.026	39.119	570777	1173568	198389	1173566	1.53	3.15
T5: CF2 @ 625 kg ha⁻¹	44158	381218	18.127	44.839	543810	1345160	162591	1345158	1.43	3.53
T6: CF3 @ 625 kg ha⁻¹	42885	370364	20.217	44.405	606497	1332151	236133	1332150	1.64	3.60
T7: PoP	26451	354701	15.237	30.726	457099	921766	102398	921765	1.29	2.60
T8: Farmers Practice	41215	369465	16.209	29.316	486270	879466.5	116805	879465	1.32	2.38

Table 9. Economic parameters under the field experiment (2018-19)

Treatment	Total cost of manures and fertilizers (Rs ha⁻¹)	Total cost of cultivation (Rs ha⁻¹)	Tuber yield (t ha⁻¹)	Gross Income (Rs ha⁻¹)	Net Income (Rs ha⁻¹)	B:C ratio
T1: FP	41215	369465	51.6	1549350	1221100	4.19
T2: PoP	26451	354701	47.4	1420800	1092550	4.01
T3: CF1 @ 625 kg ha⁻¹	44138	372388	58.7	1761240	1432990	4.73
T4: CF2 @ 625 kg ha⁻¹	44158	372408	67.5	2026830	1698580	5.44
T5: CF3 @ 625 kg ha⁻¹	42885	371135	62.6	1878690	1550440	5.06

of 3.60, 3.53 and 3.15, respectively. The CFs @ 500 kg ha⁻¹ resulted in BC ratios lesser than PoP and FP in AEU 3. In AEU 9, CFs @ 500 kg ha⁻¹ resulted in lower BC ratios compared to CFs @ 625 kg ha⁻¹ and PoP and FP gave still lower BC ratios than both rates of all CFs (Table 8).

During the next year, the mean tuber yield of the five locations under the two AEU's spread over the five districts of Kerala were taken for computation of economic parameters including BC ratio. Here, the BC ratio was very high ranging from 4.01-5.44. Among the three CFs, CF2 @ 625 kg ha⁻¹ resulted in the highest BC ratio of 5.44 followed by CF3 (5.06) and CF1 (4.73). The trend observed in tuber yield was followed in the case of BC ratio also. Taking into account all the parameters, though all the CFs were equally good, CF2 was found as the best in terms of the economic profitability (Table 9). Shekhon *et al*. (2012) reported minimum net return and low B:C ratio under control due to low yield. Irfan *et al*. (2017) found highest net return and BC ratio in wheat with CF grade of N: P: K: Zn: B: S @ 8:18:26:1:0.1:6.

Conclusions

Though the concept of designer fertilizers/ customized fertilizers specific to crops and soils is a new concept, the experience with many crops like potato, sugar cane, wheat, maize, onion in different agro ecological zones of the country indicated it as a holistic solution for the present imbalanced and improper nutrient management strategies. As the basic philosophy in the development of custom made fertilizers involve pro active soil and plant tissue testing, inclusion of all the required nutrients specific to soil and crop in the required proportion and involvement of advanced scientific principle in the development of the fertilizer, it will definitely improve crop and soil productivity, produce quality, increase profit with better nutrient use efficiency.

In this regard, considering CF fertilizers as a holistic nutrient management solution, an attempt was made for EFY under intercropping in coconut gardens taking into account the high nutrient demand of EFY as well as the popular cropping system in Kerala. In addition to bringing out the protocol for the development of CF formulations, the study could evolve very valuable information on the average nutrient status of the major tuber crops growing AEUs of Kerala, nutrient recommendation based on the nutrient status, the practical optimum of all nutrients, different nutrient use efficiency parameters and finally different CF grades specific to the two AEU's. As the study undertaken was a continuous one from development of the CF to its evaluation for the best

grade as well as its rate of application, not only for the specific AEUs but also for the entire state, the screening of the best formulation and its rate could be a great resource for the farmers in better management of the crop to achieve high profitability. Apart from higher economic returns, the CF formulations could contribute to better tuber and soil quality too. Hence, the information generated from this research could establish the significance of soil and plant based site specific nutrient management as a very efficient scientific tool in the nutrient management of a highly biologically efficient crop like EFY where the high nutrient demand could be replenished. The transition of nutrient management from blanket recommendation to soil based and further soil and plant requirement based as in the case of the present study through the formulation of designed/customized fertilizers can be regarded as the most appropriate considering profitability, tuber quality and soil quality.

Acknowledgement

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