Development and Evaluation of Customized Fertilizer Formulations for Tuber Crops Grown as Intercrops in Coconut Gardens

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Abstract

Tropical tuber crops like cassava, sweet potato, yams and aroids are some of the most important food crops of man since time immemorial. Soil fertility and plant nutrition studies over half-a-century at ICAR-Central Tuber Crops Research Institute (CTCRI) have shown these crops to be highly responsive to the application of fertilizers and manures. With paradigm shift in focus to issues of soil, plant, animal and human health, site-specific/custom-made fertilizer formulations based on soil nutrient status and plant nutrient requirement are gaining importance. An attempt was made to formulate customized fertilizer (CF) formulations for elephant foot yam (EFY) grown as intercrop in coconut gardens of the two agro-ecological units (AEU) of Kerala *viz*., AEU 3 and AEU 9. Elephant foot yam is a popular tuberous vegetable grown in Kerala, mostly as intercrop in coconut gardens owing to its long shelf-life; nuetraceutical, medicinal and economic benefits; tolerance to marginal environments; high yield potential; and a possibility to grow throughout the season. This paper gives the protocol followed for developing the formulations. These formulations were tested at different locations across AEUs 3 and 9 for two seasons to arrive at the best formulation along with optimum rate of application. Product CF2 with 7:12:24:2.5:1.25:0.4 grade of $N:P_2O_5:K_2O:Mg:Zn:B$ at 625 kg ha^{-1} was found to be the best. These at the 625 and 500 kg ha^{-1} rates were again tested for different genotypes of cassava and sweet potato (*var*. Sree Arun) on station and for greater yam at ICAR-CPCRI under intercropping in coconut.

Key words : Tuber yield, nutrient requirement, fertilizer use efficiency, soil test crop response, response curve, tuber quality, B:C ratio, cassava, sweet potato, intercropping of elephant foot yam

Introduction

Tropical tuber crops like cassava, sweet potato, yams, aroids and minor tuber crops are not only important as edible food crops but also find industrial, medicinal and nutraceutical uses. These crops have high biological efficiency, tolerance to marginal environments and pests, high yield potential and high starch content, and have excellent physico-chemical and biochemical properties in making many value-added products. Elephant foot yam [*Amorphophallus paeoniifolius* (Dennst.) Nicolson], abbreviated as EFY, a high potential tropical tuber crop, is widely grown and consumed in India, Philippines, Malaysia, 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. Biswanath et al. (2014) reported 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 requires adequate nutrition for sustenance of better growth and tuber yield. Nair and Mohan-kumar (1991) reported that under Kerala conditions, a ten-month duration crop of elephant foot yam requires a fertilizer dose of 100 kg N, 50 kg P_2O_5 and 150 kg K_2O ha^{-1} for getting optimum yields.

Multi macro and micronutrient mixtures have wider application to suit the specific requirements of the crop, soil and growth stages (Hegde et al., 2007). Taking into account the importance of elephant foot yam as intercrop in coconut gardens of the two major agro-ecological units (AEUs) of Kerala *viz*., AEU 3 (Onattukara sandy plain) and AEU 9 (South Central laterites), studies were initiated in 2015 to develop customized fertilizer formulations for elephant foot yam grown as an intercrop in coconut gardens of the above mentioned AEUs (Anju et al., 2016, 2018). Formulations developed for EFY were also tested for cassava.

Materials and Methods

The study sites *viz*. Onattukara sandy plains (AEU 3) cover Alappuzha and Kollam districts comprising of 43 panchayats; and south central laterites (AEU 9) cover the districts of Thiruvananthapuram, Kollam, Alappuzha, Pathanamthitta, Kottayam and Ernakulam comprising of 161 panchayats. The methodology for the development of 'customized fertilizers' (CF) involved the following steps.

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

The weighted average data of each soil chemical property evolved with respect to the area of the panchayats of each AEU was used to arrive at the soil test based fertilizer (STBF) rates for both the agro-ecological units following methodologies outlined by Aiyer and Nair (1985) for major nutrients and soil critical levels 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, K), secondary (Mg) and micro-nutrients (Zn, B), two separate experiments as nutrient omission plot experiments and nutrient level experiments with different levels of the nutrients in question were conducted at three locations namely, two in AEU 9 and one in AEU 3 during 2015-16. These trials, conducted with EFY variety Gajendra, were laid out in a randomized block design (RBD) with 15 treatments replicated twice. Each plot consisted of 25 plants and the plot size was 4.5 m × 4.5 m. In the nutrient level experiments, Ca, Mg, Zn and B were taken as there were found to be limiting in these two soil types (KSPB, 2013).

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

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

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

A total of 72 farmers belonging to the different places of AEU 3 and 9 were interviewed for finalizing the rate of application of the designed custom-made fertilizer formulations on matching with the present application rates of farmers.

Arriving at the grades of the CF for the two AEUs

Parameters like nutrient requirement (NR), soil available nutrient supply, percentage nutrient contribution from soil (CS %), soil nutrient supply (kg ha^{-1}), total plant nutrient uptake (kg ha^{-1}), nutrient to be taken up from the fertilizer (kg ha^{-1}), fertilizer use efficiency (%), and fertilizer nutrient application requirement were computed. These parameters along with the survey results were used to design the fertilizer mixture grade which in turn contained nutrients *viz.*, N and K @ 20 and 70%, respectively and other nutrients in full. The grades were designed based on soil test crop response (STCR) (for a yield target of 45 t ha^{-1}) and response curve (RC) approach for an application rate of 500 kg ha^{-1} which was arrived at based on the farmers' survey details.

Conduct of experiments in farmers' field with CF grades

During the second season, field experiments were conducted at 3 locations in AEU 9 including on-station at ICAR-CTCRI and one location at AEU 3 with 8 treatments replicated thrice in RBD. The treatment details are presented in **Table 1**.

Confirmation of the best CF grade through on-farm experimentation

Based on the result of the second season, all the three CFs @ 625 kg ha^{-1}, were again tested and compared in the five major EFY-growing districts of Kerala *viz.*, Thiruvananthapuram, Kollam, Pathanamthitta, Kottayam and Ernakulam against package of practices (PoP) developed by Kerala Agricultural University and farmers' practice (FP) of the area and the data generated was analysed in randomized block design (RBD).

Analysis of quality parameters of the EFY tubers

The tuber samples of the second and third seasons were analysed for quality attributes *viz.*, dry matter, starch, sugar, total phenol, oxalate, crude protein, fat, fibre and ash following standard analytical procedures (Padmaja et al., 2005).

Economic analysis on the use of CFs

The benefit cost analysis on the use of CFs in comparison to farmers' practice and existing package of practices recommendation also was computed.

Testing of the CFs developed in other tuber crops

The other tuber crops like cassava (three genotypes *viz.*, Sree Pavithra, CI-905 and 906) and sweet potato (*var*. Sree Arun) at ICAR-CTCRI and greater yam (*Dioscorea alata var*. Sree Keerthi) at ICAR-CPCRI under intercropping in coconut were tested for their response to the three CF grades at two levels *viz.*, 500 and 625 kg ha^{-1}.

Results and Discussion

The soil-test-based fertilizer rates evolved based on the above data were: N, P, K, Mg, Zn, B, dolomite @ 71:12.5:106.5: 16: 5.25: 1.31:1000 and 78:12.5:90:16:5.25:1.31:1000 kg ha^{-1} for AEU 3 and AEU 9, respectively. Among the different levels of N, P, K tried *viz.*, super-optimal, optimal, suboptimal in the both AEUs, 2N (@142 and 156 kg ha^{-1} for AEU 3 and

Table 1. Treatments for the field experiment

Treatment	Product code or treatment detail	Rate of application (kg ha^{-1})	Description
T_1	CF 1	500	STCR AEU 3
T_2	CF2	500	STCR AEU 3
T_3	CF3	500	RC AEU 9
T_4	CF 1	625	STCR AEU 3
T_5	CF2	625	STCR AEU 3
T_6	CF3	625	RC AEU 9
T_7	PoP		
T_8	FP		

Abbreviations : CF - Customized fertilizer; PoP - Package of practice; FP - Farmers' practice; STCR - Soil test crop response; RC = Response curve; AEU - Agro-ecological unit

AEU 9 respectively), 2K (@ 212 kg ha^{-1} in AEU 3 and 180 kg ha^{-1} in AEU 9), and P @ 18.75 kg ha^{-1} in AEU 3 and P @ 12.5 kg ha^{-1} in AEU 9 were taken as optimum based on the tuber yield data. In both the AEUs, dolomite @ 1.5 t ha^{-1}, 1.5 Mg (Mg @ 24 kg ha^{-1}) and optimum B (B @ 1.31 kg ha^{-1}) were taken as the optimum rates and in AEU 3, 1.5 Zn as Zn @ 7.88 kg ha^{-1} and in AEU 9, Zn @ 2.63 kg ha^{-1} were taken as the optimum. Based on the tuber yield data of the two AEUs, the optimum rates of N, P, K, dolomite, Mg, Zn and B were 150:20:225:1500:120:12.5:10 kg ha^{-1} for AEU 3 and 120:12.5: 200:1500:120:12.5:20 kg ha^{-1} for AEU 9, respectively.

The general application rate was found to be factomphos containing NPKS @ 20:20:0:15 at 500 kg ha^{-1}, MOP @ 750 kg ha^{-1} and urea @ 500 kg ha^{-1} along with farmyard manure @ 25 t ha^{-1}. While progressive farmers applied 6 bags (300 kg), others applied on an average 4 (200 kg) bags of chemical fertilizers per hectare. Based on these details, CFs were designed to be applied @ 10-15 bags ha^{-1} (500-750 kg ha^{-1}). The grades of the fertilizer mixtures for the two AEUs were arrived using soil test crop response and response curve approaches. The technical and scientific expertise of Tata Chemicals (Centre for Agri solutions), now Yara Fertilisers India Limited, Aligarh, Uttar Pradesh, who are the pioneers in the development of customized fertilizers, was utilized for conducting different experiments and arriving at the grades of the CFs for the present study.

Data generated from the two experiments conducted in the first year at different locations were used to arrive at different parameters and the same are presented in **Table 2**. In the case of secondary and micronutrients, the optimum rates of 19.2 kg Mg, 4.2 kg Zn and 1.575 kg B ha^{-1} for AEU 3 and 19.2 kg Mg, 6.3 kg Zn and 1.96 kg B ha^{-1} for AEU 9 were taken for arriving at the nutrient grade of the CF. Hence, the grades of Mg, Zn and B for the CF for the AEU 3 and AEU 9 were fixed at 3.84, 0.84 and 0.3% and 2.5, 1.25 and 0.4%, respectively taking into account that the CF developed had to be applied @ 500 kg ha^{-1}. The final grade of CF (application rate of 500 kg ha^{-1}) for elephant foot yam intercropped in coconut gardens based on STCR approach for a yield target of 45 t ha^{-1} was N: P_2O_5: K_2O: Mg: Zn : B as 8:11:21:3.5:1:0.3 for AEU 3 and 7:12:24:2.5:1.3:0.4 for AEU 9.

In the response curve approach, the optima for each of the nutrients were arrived at by plotting the response curve (levels of each nutrient *vs*. tuber yield) and the optima for N, P_2O_5, K_2O, Mg, Zn and B were arrived at 142, 12.5, 213, 19.2, 4.2 and 1.6 kg ha^{-1} and 156, 12.5, 180, 19.2, 6.3 and 2 kg ha^{-1} for AEU 3 and AEU 9, respectively. Based on these, the grades of the component nutrients in the CF were evolved with 20% N, full P and 70% K and other nutrients full for an application rate of 500 kg ha^{-1} as N, P_2O_5, K_2O, Mg, Zn, B @ 6:3: 30: 3.5: 0.8: 0.3% for AEU 3 and for AEU 9, the grades were 7:3:25: 4:1.25: 0.4%. In arriving at the four different grades of the CF for AEU 3 and AEU 9 based on STCR and RC approach, the manufacturing tips for better granulation of the product like N:P ratio, percentage of steam and filler, type of P fertilizer, DAP:TSP ratio, percentage share of K fertilizer were taken into consideration. Final grades of customized fertilizers developed for the two AEUs based on the two approaches are given in **Table 3**. As the CF contained 20% N and 70% K, the rest 80% N and 30% K were designed to be top-dressed in the form of urea and MOP, respectively.

Byju *et al*. (2016) based on QUEFTS model, developed CF for EFY with grade 12:4:18:3:0.4:0.2 as N:P: K: Mg: Zn:B for the three districts of Kerala *viz*., Malappuram, Wyanad and Ernakulam to be applied as 650 kg ha^{-1}.

The tuber yield data of the experiment conducted during the year 2016-17 with treatments, whose details are given in **Table 1,** is presented in **Figure 1**. There was significant effect of treatments at all the three sites of AEU 3 and AEU 9. However, all the three CFs applied at 625 kg ha^{-1}

Table 2. Parameters computed and grades of the customized fertilizer arrived at for two agroecological units (AEUs) of Kerala

Parameters	AEU 3			AEU 9		
	N	P	K	N	P	K
Nutrient requirement (NR) (kg nutrient t^{-1} of tuber)	3.68	0.70	4.47	3.68	0.70	4.47
Nutrient uptake (kg ha^{-1})	166	32	201	166	32	201
Soil available nutrient supply (kg ha^{-1})	200	61	209	200	65	271
Contribution from soil (%)	55.6	33.0	44.3	32.8	33.0	48.5
Nutrient taken up from soil (kg ha^{-1})	111	20	93	66	21	131
Nutrient to be taken up from fertilizer (kg ha^{-1})	54	11	109	100	10	70
Fertilizer use efficiency (%)	27.1	48.5	90	54	40	48
Fertilizer nutrient application requirement*	203	54	145	185	58	174
Fertilizer grade for the mixture* (provided the CF has 20% N, full P and 70%K)	40	54	102	37	58	122
Nutrient content in CF* (If applied @ 500 kg ha^{-1})	8	11	21	7	12	24

*N, P_2O_5, K_2O (kg ha^{-1})

Table 3. Grades of customized fertilizer developed for elephant foot yam (EFY) intercropped in coconut gardens of the two AEU's of Kerala

AEU no.	Approach	Nutrient content (%)					
		N	P_2O_5	K_2O	Mg	Zn	B
AEU 3	STCR	8	11	21	3.5	1	0.3
AEU 3	RC	6	3	30	2.5	1	0.3
AEU 9	STCR	7	12	24	2.5	1.25	0.4
AEU 9	RC	7	3	25	3	1.25	0.4

were more effective than the same applied at 500 kg ha^{-1}; benefit:cost ratio also depicted similar trend (**Figure 2**). Among the three CFs tested at 625 kg ha^{-1} during the third season, CF2 gave highest tuber yield (67.56 t ha^{-1}) with the highest B:C ratio (8.49) (**Figure 3**) in the major five EFY-growing districts of Kerala *viz.*, Thiruvananthapuram, Kollam, Pathanamthitta, Kottayam and Ernakulam.

Analysis of the tuber samples of the second season experiment indicated significant effect of treatments on crude fat, crude protein, oxalate, sugar and total phenol, with CFs having highest fat, protein and sugar and lower oxalate content. However, CF1 applied at 625 kg ha^{-1} was found to be better with respect to all quality parameters and was comparable to the farmers' practice (FP) and package of practices (PoP) developed by the Kerala Agricultural University (**Figures 4a,b**).

Three CFs developed for EFY under intercropping in coconut were also tested for cassava with three genotypes (Sree Pavithra, CI-905, CI-906) under two levels of the three CFs *viz.*, 500 and 625 kg ha^{-1} along with FP and PoP. Among the CFs, CF1 and CF2 applied at 500 kg ha^{-1} produced significantly higher yields. The same CFs tested for sweet potato for three seasons at the above rates indicated that the CF1 and CF3 at 500 kg ha^{-1} were good in sustaining tuber yields.

Response of other tuber crops to different grades of CFs was evaluated in other sets of experiments. In cassava, CF1 and CF2 @500 kg ha^{-1} were found to be the best. Sweet potato gave better results with CF1 and CF3 @500 kg ha^{-1}. In the case of yam, no conclusive results were obtained. It requires further trials for confirmation.

Conclusions

Though the concept of designer fertilizers /customized fertilizers specific to crops and soils is new experience with many crops like

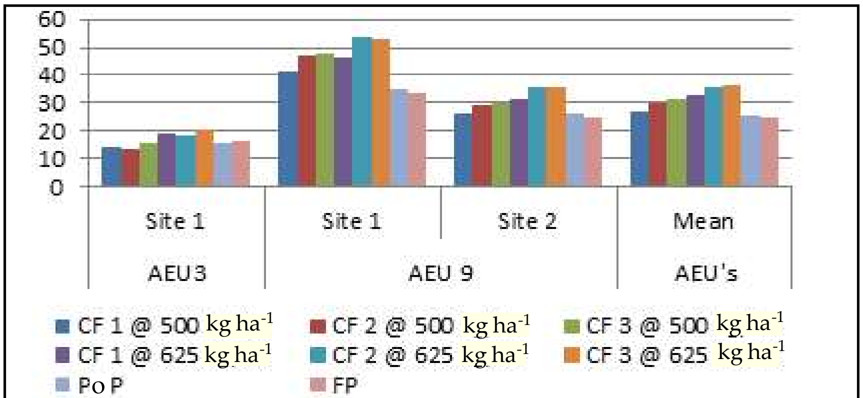


Figure 1. Tuber yield of elephant foot yam (EFY) (t ha^{-1}) under different treatments

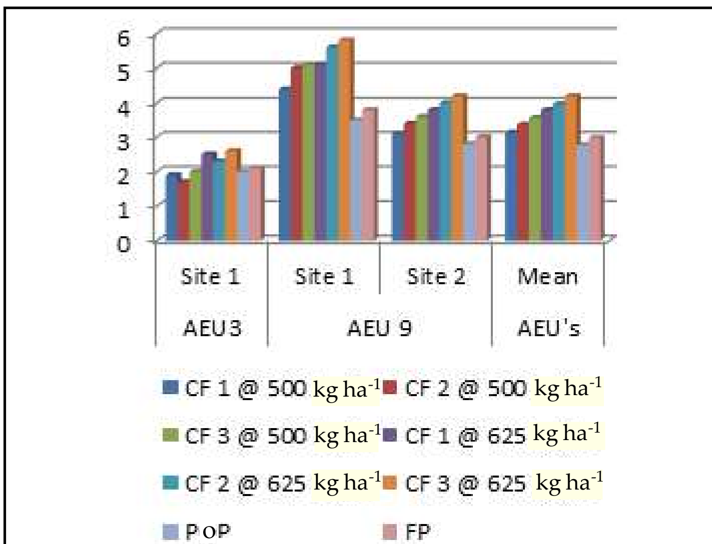


Figure 2. Benefit:cost (B:C) ratio (Rs. Re^{-1}) of raising elephant foot yam under different treatments

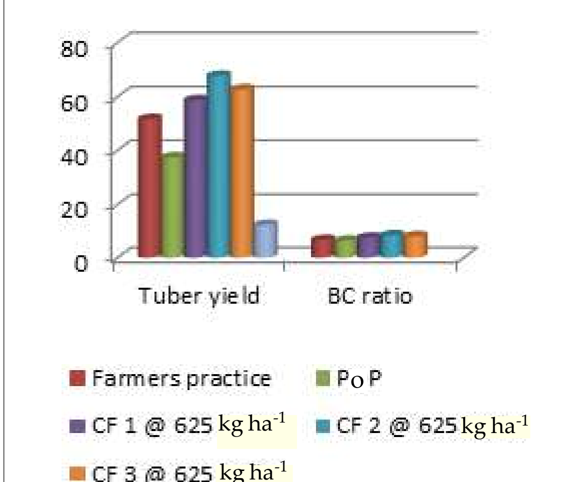
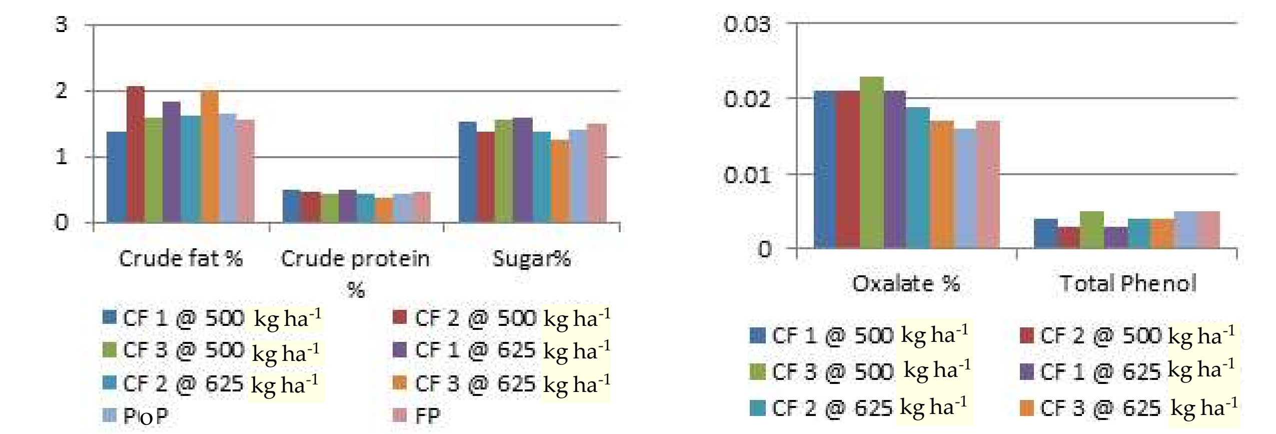


Figure 3. Effect of customized fertilzers on tuber yield (t ha^{-1}) in 2016-17 and B:C ratio (Rs. Re^{-1}) **in 2017-18**



Figures 4a,b. Biochemical properties (fresh weight basis) of EFY tubers under different treatments

potato, sugarcane, wheat, maize, onion in different agro-ecological zones of the country indicates that this holistic solution presents a sustainable alternative to current imbalanced and improper nutrient management strategies. As the basic philosophy in the development of custom-made fertilizers involves proactive 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, will definitely go a long way in improving crop and soil productivity, having quality produce, and enhancing the profitability with better nutrient use efficiency. Current development of the designer fertilizer for EFY intercropped in coconut gardens of Kerala can help in realizing the above-mentioned crop management benefits better than the existing nutrient management practices.

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