DEVELOPMENT AND APPLICATION OF CUSTOMIZED FERTILIZERS: EXPERIENCE IN TROPICAL TUBER CROPS

भाकृअनुप-केन्द्रीय कन्द फसल अनुसंधान संस्थान

(भारतीय कृषि अनुसंधान परिषद्)

श्रीकार्यम, तिरूवनन्तपुरम 695 017, केरल,भारत

ICAR-Central Tuber Crops Research Institute

(Indian Council of Agricultural Research)

SREEKARIYAM, THIRUVANANTHAPURAM 695 017, KERALA, INDIA

DEVELOPMENT AND APPLICATION OF CUSTOMIZED FERTILIZERS: EXPERIENCE IN TROPICAL TUBER CROPS

K. SUSAN JOHN & P.S. ANJU

भाकृअनुप-केन्द्रीय कन्द फसल अनुसंधान संस्थान
(भारतीय कृषि अनुसंधान परिषद्)
श्रीकार्यम, तिरूवनन्तपुरम 695 017, केरल,भारत
ICAR-Central Tuber Crops Research Institute
(Indian Council of Agricultural Research)
SREEKARIYAM, THIRUVANANTHAPURAM 695 017, KERALA, INDIA

Diamond Jubilee of ICAR-CTCRI

ICAR-Central Tuber Crops Research Institute
Sreekariyam, Thiruvananthapuram 695 017
Kerala, India
Tel.No. : (91) (471) 2598551 to 2598554
E-mail: director.ctcri@icar.gov.in
Website: https://www.ctcri.org

Published by
Dr. G. Byju
Director

Correct Citation
Susan John, K. and Anju, P.S. 2023. *Development and application of customized fertilizers: Experience in tropical tuber crops*, Technical Bulletin No.**100**. ICAR-Central Tuber Crops Research Institute, Sreekariyam, Thiruvananthapuram, Kerala, India, 50p.

November 2023

Design, Layout & Printing
Aden Digital Signage, Thiruvananthapuram, Kerala.
Email:adentvm2018@gmail.com / Web:www.adendigital.in
Mob: 9605206323

Contents

ICAR-Central Tuber Crops Research Institute
Sreekariyam 695 017, Thiruvananthapuram, Kerala, India

Dr. G. BYJU
Director

Phone: 0471- 2598431
Email: director.ctcri@icar.gov.in

From the Director

Among the different crop management practices, nutrient management is considered as very important especially for tropical tuber crops having high biological efficiency. During the previous years, while the thrust was on achieving high crop productivity, the present day focus is conservation of environment along with both quantity and quality improvement of the produce. Hence, the strategy of crop management too changed in such a way as to maintain the sustainability in terms of crop production as well as to protect agro ecosystem. Here comes the relevance of crop and agro ecological zone/unit specific nutrient recommendations in the form of designed/customized fertilizers which are developed taking into account both soil nutrient status of the zone as well as crop nutrient requirement. Since these formulations contain both macro and micronutrients, in addition to satisfying the crop demand, indiscriminate use of fertilizers too can be avoided to a great extent.

This technical bulletin describes the protocol we have developed in evolving customized fertilizers for elephant foot yam (*Amorphophallus paeoniifolius*) under intercropping in coconut gardens of the two major agro ecological units (AEUs) of Kerala as well as the testing of the same in selecting the best grade as well as the appropriate rate of application for tropical tuber crops. Since FCO recommends customized fertilizers for nutrient based subsidy, there are initiatives from different research organizations to develop these formulations for different crops. Hence, I hope that, this technical bulletin will be a good reference guide to help them in developing these fertilizer mixtures.

I appreciate the efforts of the authors in describing the scientific procedure in the most simplest and systematic way which can definitely enable the users as a very valuable resource in the field of customized fertilizers.

23 November 2023

G. BYJU
Director

Introduction

As pressure on agricultural land and human population is increasing, improved productivity of crops is needed for meeting the food demand of the growing world. The rough estimate says that, the diet of one billion people are deficient in energy and about the same number suffering from diseases due to energy surplus and around two billion suffer from the 'hidden hunger' due to micronutrient deficiencies. Since the minerals and nutrients in our food come from the soil in which it is grown, it is inevitable to nourish the soil sufficiently with all essential nutrients to meet the crop requirement. In this respect, balanced plant nutrition is one of the options to replenish the removed nutrients from the soil to sustain crop productivity and maintain soil health. According to Bhuiyan et al., (1991), a crop production system with high yield targets cannot be sustainable unless balanced nutrient inputs are supplied to soil against the nutrients removed by crops. Balanced nutrition helps in making the crops as well as the humans and animals consuming it to be healthy. Among the different approaches for balanced nutrition under sustainable agricultural intensification, integrated nutrient management (INM) holds great promise to close the yield gap as well as to minimize the environmental hazards without further expanding the agricultural land . In order to ensure balanced nutrition for crops under INM, there are different nutrient management approaches.

Blanket recommendation

In the Package of Practices (PoP) blanket recommendation, the nutrient rates were arrived based on fertilizer level/rate experiments conducted without taking into account either the nutrient status of the soil or the crop requirement of nutrients. In the fertilizer rate experiments, after laying out field experiments with different levels of NPK, the rate or dose which was found optimum for maximum yield which in turn is economic with respect to the B:C ratio will be taken as the fertilizer dose. This recommendation comprised of mainly major nutrients *viz.,* N, P and K and may lead to under use/ over use / indiscriminate use of fertilizers. Moreover, continuous use of fertilizers as per blanket recommendation leads to build up of nutrients like P in laterite soils. This in turn can affect the chemical soil properties especially the status of micronutrients like Zn due to high P build up which can ultimately result in causing adverse impact on soil without substantial yield increase and incidentally monetary loss. The blanket fertilizer recommendations for all tuber crops evolved at ICAR-CTCRI is given in Table 1.

Table 1. Blanket fertilizer recommendation for tropical tuber crops

Crop	FYM	N	P_2O_5	K_2O
	(t ha^{-1})		(kg ha^{-1})	
Cassava	12.5	100	50	100
Sweet potato	5.00	50	25	50
Taro	12.5	80	25	100
Tannia	25.0	80	50	150
Lesser yam	10.0	80	60	80
Greater yam	10.0	80	60	80
Elephant foot yam	25.0	100	50	150
Chinese potato	10.0	60	60	100
Arrowroot	10.0	50	25	75

Soil test based nutrient recommendation

Soil testing indicates the status of nutrients in a particular soil and the quantity of nutrients to be applied to that soil to support optimal plant growth. Without correct knowledge about the soil nutrient status, application of fertilizers will lead to an adverse effect on crops and soil nutrient balance (Ray et al., 2000). Moreover, intensive cultivation practices and indiscriminate fertilizer application causes depletion of macronutrients and micronutrients from the soil (Susan John et al., 2005). Many studies in this direction were conducted for the enhancement of soil fertility as well as yield (Hong et al., 2009).

At ICAR-CTCRI, the criteria for arriving at the soil test based recommendation of N,P,K is based on Aiyer and Nair (1985) where the application rate of the above nutrients is as per the existing standard / general recommendation/ PoP (Table 2)

As continuous application of secondary nutrient, Mg and micronutrients, Zn and B did not produce any significant effect on tuber yield though there is a concomitant increase in soil status of these nutrients above their critical levels, at ICAR-CTCRI, based on the results of the long term fertilizer experiment (LTFE), Susan John et al., (2010) standardized the soil test based recommendation of these nutrients as below (Table 3).

Table 2. Nutrient recommendation based on soil test values followed in Kerala

Soil fertility class No.	% Soil Organic C (SOC) Sandy	Clayey/ loamy	Recommendation of N (% of GR*)	Available P (kg ha^{-1})	Exchangeable K (kg ha^{-1})	Recommendation of P & K (% of GR*)
0	0.00-0.10	0.00-0.16	128	0-3.0	0-35	128
1	0.11-0.20	0.17-0.33	117	3.1-6.5	36-75	117
2	0.21-0.30	0.34-0.50	106	6.6-10.0	76-115	106
3	0.31-0.45	0.51-0.75	97	10.1-13.5	116-155	94
4	0.46-0.60	0.76-1.00	91	13.6-17.0	156-195	83
5	0.61-0.75	1.01-1.25	84	17.1-20.5	196-235	71
6	0.76-0.90	1.26-1.50	78	20.6-24.0	236-275	60
7	0.91-1.10	1.51-1.83	71	24.1-27.5	276-315	48
8	1.11-1.30	1.84-2.16	63	27.6-31.0	316-355	37
9	1.31-1.50	2.17-2.50	54	31.1-34.5	356-395	25

*GR = General recommendation as per PoP recommendations of KAU

For N, maximum recommendation is 133% of GR and minimum is 50% of GR, 100% of GR is for 0.3% OC in sandy and 0.5% OC in clay/loam soil. For P and K, maximum recommendation is 133% of GR and minimum is 25% of GR as maintenance dose, 100% is for 10 kg ha^{-1} P and 115 kg ha^{-1} K, respectively.

Table 3. Soil test based recommendation of Mg, Zn and B for cassava

Soil Mg status	Rate of application of $MgSO_4$	Soil Zn status	Rate of application of $ZnSO_4$	Soil B status	Rate of application of borax
(meq 100g^{-1})	(kg ha^{-1})	(ppm)	(kg ha^{-1})	(ppm)	(kg ha^{-1})
0–0.25	20	<0.2	12.5	<0.2	10
0.25–0.50	15	0.2–0.3	10	0.2–0.5	7.5
0.50–0.75	10	0.3–0.4	7.5	0.5–1.0	5 .0
0.75–1.00	5	0.4–0.6	5	1–2	2.5
>1.00	2.5	>0.6	2.5	>2	0

Systematic approach in fertilizer use

This is another approach in INM which involves the determination and elimination of soil nutrient constraints for balanced supply of all potentially deficient essential nutrients for sustainable high yield. In the systematic approach of determining optimum nutrients, the critical level of nutrients, original nutrient status of the soil, its sorption capacity and confirmation of the limiting nutrients through green house/screen house study were considered (Hunter, 1980). In cassava, this approach was tested in the red loam soils of Kerala which gave an yield of 43.41 t ha^{-1} during a time span of 6-7 months (Susan John et al., 2007).

Soil test crop response (STCR) approach

In situations of widespread nutrient deficiencies, there is the real need of systematic application of fertilizers and manures to soils and crops (Mahajan et al., 2013) by adopting unique concepts like inductive cum targeted yield model as proposed by Ramamoorthy et al., (1967) through the development of proper manure cum fertilizer prescription equations. Compared to blanket recommendation/PoP, STCR approach takes into account soil, crop and ecosystem sustainability. In this approach, both macro and secondary nutrients were applied at rates that are required to meet the crop removal and micronutrients were applied at blanket recommendations when the soil testing reported is marginal or deficient.

In cassava, fertilizer adjustment equations for a targeted tuber yield of 40 t ha^{-1} was developed by Selvakumari et al., (2001) in Tamil Nadu which could save on an average, 40 kg N, 22 kg P and 40 kg K compared to PoP. Swadija and Sreedharan (1998) developed fertilizer prescription equations for targeted yields of cassava in laterite soils (Ultisols) of Kerala. Suganya and Manickam (2016) found that, in cassava, the innovative nutrition practice of STCR based integrated plant nutrient supply (IPNS) for targeted yield plays a vital role in balanced nutrition, sustainable crop productivity and better profit. Sreelatha et al., (1999) developed similar equations for sweet potato in the same soils for a yield target of 15 t ha^{-1} and obtained a BC ratio of 2.07.

Nutrient omission plot experiments

The objective of nutrient omission plot technique is to determine the optimum N, P, K requirements. This technique helps in determining the native soil fertility and to arrive at the amount of nutrients needed to obtain optimum plant growth (Khatun and Saleque., 2010, Anju et al., 2020a). For estimating the inherent status of major nutrients (N, P or K) in an omission trial, two of the major nutrients are supplied by omitting the other one in question (Wanyama et al., 2015). The yield in such an omission plot is related to the indigenous soil nutrient supplying capacity (IS) of the omitted nutrient as described by Janssen et al., (1990) which is based on the principle that, when the supply of a particular nutrient is inadequate in relation to other nutrients, the whole requirement of that nutrient will be met by the crop from that soil only. It reflects the inherent soil fertility and can be used as a guideline for fertilizer recommendation. Dobermann et al., (2003) stated that, yield is one of the major factors and yield response was related to indigenous nutrient supply which determines the yield in omission plot trials. Yield Response (YR) can be used to evaluate the soil nutrient supply capacity (Xu et al., 2014) and soil nutrient status is very important in arriving at the correct fertilizer application rates. The yield gap between the target yield and the yield in the omission plots is used to calculate the fertilizer requirements.

Nutrient level experiments

These are conducted for secondary and micronutrients to arrive at the optimum level of application of these nutrients. Usually, different levels of the nutrients in question like Ca, Mg, Zn or B which are critical/limiting for the particular soil/crop is given as treatments by keeping the level of other nutrients as optimum(Anju et al., 2020a).

Customized fertilizers

In a natural environment, the nutrients removed through crop harvest need to be replenished through crop nutrition for further crop production. The replenishment should be with correct quantity; otherwise, it will cause environmental pollution. Unbalanced over fertilization in North America, Western Europe, China and India caused environmental pollution, while under fertilization in Africa, Eurasia and parts of Latin America caused soil deterioration (Hu, 2018). Hence, there is a need to integrate different nutrient sources in the soil in correct quantity so that, it will maintain the soil fertility for continuous cultivation of crops. The results from large number of experiments clearly showed that, even at recommended rates of NPK application based on soil test, the yield of crops or the cropping system could not be maintained at higher levels continuously (Ananda and Patil, 2005). In this regard, customized fertilizers (CF) ensure significance as an emerging trend of fertilizers. Custom made fertilizers emerged as a new idea in this era of scientific research under the field of nutrient management specific to soils and crops. According to Fertilizer Control Order (FCO), these fertilizers are generally assumed to maximize crop yields while minimizing unwanted impacts on the environment and hence on human health. It is generally formulated based on a series of experiments to arrive at the nutrient optimum specific to soils and crops other than taking into account the consumer preference especially with respect to the application rates.

Concept of customized fertilizers

CF can be considered as the first step towards precision nutrient management. Kalra et al., (2011) defined CFs as a fertilizer mixture whose composition/grade has been customized as per the demand of a specific crop and as per the soil fertility condition of the growing region of the crop. In principle, it is a complete crop nutrition solution as a basal fertilizer containing all crucial primary, secondary and micronutrients essential to obtain a definite target yield. On the whole, CFs are unique and ready to use granulated fertilizers, formulated on sound scientific plant nutrition principles integrated with soil information, extensive laboratory studies and evaluated through field research. This eco-friendly approach to farming combines farmers' traditional knowledge with modern technologies adapted to the needs of small scale to large scale producers.

CFs being crop, soil and area specific, they hold a good promise in maintaining soil health by ensuring appropriate fertilization. Information on farmers nutrient application rate, tuber yield, plant uptake, pre and post soil test data are required for arriving at the parameters like nutrient uptake, nutrient requirement, percentage contribution from soil and fertilizer use efficiency to find out the amount of nutrients to be applied through fertilizers to develop CF formulations. In designing the CFs, grades of the component nutrients and their levels of application are important.

Kalra et al., (2011) elaborated the approach in developing CF and it includes the following procedures:

- Selecting the target area and crop
- Building database
- Concept of fertility management zones
- Establishment of nutrient requirement
- Grade fixation for CF
- Grade preparation and validation
- Commercialization of CF

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.

Significance of customized fertilizers

CFs are combination of fertilizers containing secondary and micronutrients added to key nutrients like N, P and K in a proportion that suits specific crops and soil patterns. Sung et al., (2016) found that, the CF is different from general chemical fertilizers with respect to the amount of N, P or K to be applied differently to the soil chemical properties. It is imperative that, for high quality and safe agricultural products, soil mineral status based fertilization is essential to ensure stable supply of agricultural produce. Under CF concept, the addition of macro, secondary and micronutrients in sufficient amounts as per crop requirement might be contributing to increased productivity. Hence, for avoiding the occurrence of deficiencies of secondary nutrients and micronutrients, CFs are the most efficient as they are carriers of these nutrients, hence, providing an excellent opportunity for ease and regular supply of essential nutrients.

Impact of customized fertilizers in different crops

In wheat, there are several reports of different grades of the CF containing nutrients like N, P, K, S and Zn in enhancing plant growth characters, grain and straw yield, grain quality and soil nutrient status there by increasing the B:C ratio over the recommended dose of fertilizers (Dwivedi et al., 2014; Shekhon et al., 2012; Goswami , 2007; Singh et al.,2012; Reddy et al., 2009; Mandal et al., 2004; Singh, 2006; Das et al., 2003). This is due to the presence of required amounts of secondary and micronutrients in the formulation along with primary nutrients. Sharshar and Said (2000) attributed the reason being greater availability of essential nutrients to plants, improvement of soil environment which facilitate better root proliferation leading to higher absorption of water and nutrients. In potato, CFs having nutrients such as N, P, K, Zn, B, and S could improve growth characters, yield attributes, quality of produce as well as dry matter production significantly over existing practice (Irfan et al., 2017). In pomegranate grown in an Inceptisol, a customized fertilizer grade of N: P: K: S: Mg: Zn: Fe @ 20: 10:10: 5: 2: 0.5: 0.2 could result in the highest yield compared to University practice and farmers' practice . There are reports in crops like finger millet where a CF grade of N: P: K: S: Zn @ 20: 17: 11: 4: 0.4 caused better response in yield. Bhaskaran and Subramanyam (2011) reported substantial yield in rice at Warangal and maize in Guntur district of Andhra Pradesh due to CF application compared to farmers' practice. In onion, significant effect of CF on bulb yield as well as good improvement in post harvest soil properties like electrical conductivity, available N, P and K was reported by Kamble and Kathmale (2015).

Advantages of customized fertilizers

The current approaches of nutrient management through customized fertilizers have several advantages over traditional practice of nutrient management as given below:

- CF provides a readymade product containing all crucial nutrients in desirable proportions for a definite region and for a specific crop
- As the availability of individual sources of nutrients being limited at times, the CF mixture will be helpful to farmers to meet the nutrients demand
- CF increases crop yield and improves produce quality thus fetching better return on investment
- CF reduces soil mining of nutrients and thus improves soil health
- Balanced use of nutrients through CF improves agronomic efficiency of the nutrients
- CF enables uniform distribution of all nutrients (especially micronutrients) throughout the field
- Uniformity in composition of superior quality CF ensures better and balanced crop nutrition

Economics of using customized fertilizers

In the present scenario of sharp rise in fertilizer prices, there is every need to improve the efficiency of fertilizer use. CF mixtures can definitely increase yield with less fertilizers thereby ensuring improved fertilizer use efficiency and incidentally better profitability especially for small holder farms of India. In crops like wheat (Dwivedi et al., 2014; Vikas et al., 2016), potato (Irfan et al., 2017), pomegranate (Goel et al., 2009), pearl millet (Goud, 2012) and onion (Kamble and Kathmale, 2015), there are reports of maximum net return and hence B:C ratio ranging from 1.8-2.8 under CF mixtures over existing practices.

Environmental benefits with customized fertilizers

As the application of nutrients under CF approach is purely on the basis of knowledge intensive methods, CF will definitely ensure improved fertilizer use efficiency with increased agricultural productivity. Since the CF contains macronutrients, secondary and micronutrients, maintenance of soil fertility and environment protection is ensured with CFs. Since CF is specific to soils and crops, it will not provide even a micro granule of excess unwanted nutrients to soils and crops. This definitely is beneficial to farmers, soils, crops and ultimately to the ecosystem as a whole in preventing processes like eutrophication. Currently, the emphasis is to improve the use efficiency of fertilizers through the 4R nutrient stewardship principle, which involves the use of fertilizers from the right source, at the right rate, at the right time, with the right method of application (IPNI, 2014).

Protocol for the development of customized fertilizers

The research work on evolving customized fertilizer formulations involved a systematic protocol as follows:

- Arriving at the mean weighted average data of the chemical parameters of the selected agro ecological units (AEUs)
- Evolution of soil test based nutrient recommendation (theoretical) based on mean weighted average data of the AEUs
- Nutrient omission plot experiment to arrive at the optimum level of N, P, K for the soils of the AEUs
- Nutrient level experiment to standardize the levels of secondary and micronutrients for the soils of the AEUs
- Arriving at the nutrient use efficiency parameters to find out the grades of the CF formulations
- Survey among elephant foot yam growers to arrive at the level of application of the CF formulations
- Testing of the CFs in farmers' fields to arrive at the best CF grade and the best level of application

At ICAR-CTCRI, the above protocol was used in arriving at the CF grades for elephant foot yam (*Amorphophallus paeoniifolius* (Dennst.) Nicolson) under intercropping in coconut plantations for two AEUs of Kerala (AEU 3 & 9). The methodology involved optimization of all required nutrients based on the weighted average data of the soil chemical properties of the two AEUs followed by validation of the optimum fixed through nutrient omission and nutrient level plot experiments in farmers' fields and on station. Information on farmers' nutrient application rate, tuber yield, plant uptake, pre and post experiment soil test data were used to arrive at parameters like nutrient uptake, nutrient requirement, percentage contribution from soil, fertilizer use efficiency and hence the nutrient to be applied through fertilizers. The grades of the component nutrients and their levels of application for the two AEUs were designed by fitting these parameters using STCR approach for a specific yield target and response curve (RC) approaches.

The procedure involved is described in detail below:

Development of CF for elephant foot yam under intercropping in coconut: Experience of ICAR-CTCRI

Development and use of need based fertilizer mixtures containing the required essential elements is a viable option to earn better profit to farmers in the case of crops which are high yielding and highly nutrient demanding. In the present scenario of plant nutrient management, in addition to enhancing agricultural productivity, protection of the environment *viz.,* soil, water and atmosphere are also very important to sustain the well being of the inhabitants on it.

Significance of the crop: Elephant foot yam (*Amorphophallus paeoniifolius* (Dennst.) Nicolson)

Elephant foot yam (EFY) is a herbaceous, perennial C3 crop, basically of South East Asian origin. It has long been used as a local staple food in many countries such as the Philippines, Java, Indonesia, Sumatra, Malaysia, Bangladesh, India, China and South East Asian countries. It is commercially cultivated due to its production potential and popularity as a vegetable in various delicious Indian cuisines. In India, it is cultivated in Andhra Pradesh, West Bengal, Gujarat, Kerala, Tamil Nadu, Maharashtra, Uttar Pradesh, Jharkhand and many northern and eastern States. In Kerala, EFY is cultivated in an area of 5522 ha of land area comprising mostly in Wayanad, Kollam, Pathanamthitta, Alappuzha, Kottayam and Thiruvananthapuram districts (Farm guide, 2023). Elephant foot yam comes up well in all types of environments and is tolerant to pests and diseases. So, farmers usually get a reasonable income with average management practices compared to other common vegetable crops.

EFY is popularly called as Jimikand and Suran, scientifically known as *Amorphophallus paeoniifolius* (Dennst.) Nicolson. The genus *Amorphophallus* is a tuberous herb belonging to the family Araceae. It is a paleotropical aroid comprising of more than 200 species. *A. paeoniifolius* possesses a smooth, bright green petiole with white blotches and leaflet bases having three main petioles. It has a round corm with or without very small cormels. The corms, cormels, young petiole and unopened inflorescence of this cultivated species are used as vegetable. These parts are rich in carbohydrate, protein, minerals like calcium (Ca), iron (Fe), phosphorous (P), vitamin A, B, C, flavnoids and fibre. Sree Padma, Gajendra, Sree Athira (hybrid), Bidhan Kusum and NDA-9 are some of the high yielding EFY varieties released for cultivation in India (Ravi et al., 2009).

The wild and local cultivars of EFY are generally being used for making vegetable pickles and some ayurvedic medicines for various ailments due to its high pharmaceutical and neutraceutical properties. Important medicinal attributes of *Amorphophallus* are hepato protective, antioxidant and uterus stimulating ability (Singh et al., 2011). Corms are said to be very effective against heart related diseases, alleviates intestinal disorders, improve immunity, act as carminative, anti-inflammatory agent and detoxifier. Tubers are recommended for diabetic patients for its blood sugar reducing action and are a rich source of trace elements like K, Mg, Se, Zn, P and Ca, which in turn help in improving mental concentration and memory. The presence of various antioxidants in EFY tubers helps in subsiding early ageing and maintaining healthy hormonal levels in the body (Jayaraman et al., 2010).

It is an ideal intercrop under plantations of coconut, banana, arecanut, turmeric and rubber in Kerala especially in agro ecological units *viz.,* AEU 3 (Onattukara sandy plain) and AEU 9 (south central laterites) having sandy loam and laterite soil types respectively.

Need for nutrient management in EFY

Though the crop is highly responsive to fertilizers and manures, the present blanket use of fertilizers is not beneficial to the crop during all situations especially with respect to soil health and its sustainability. Hence, the use of scientific technologies need to be put forward to link higher crop production potential with environmental sustainability specifically from the point of view of soil health. Though we have the package of practices (PoP) recommendation available for this crop, development of CF formulations is now the need of the hour as regards to improving crop productivity, reduction in the application of unnecessary nutrients to maintain a sustainable ecosystem and for enhancing the farmers' income. The present nutrient recommendations for EFY (NPK @ 100:50:150 kg ha^{-1} + FYM @ 25 t ha^{-1}) (Nair and Mohankumar, 1991), under sole cropping system which in turn comprised of only major nutrients, results in widespread deficiency of secondary and micronutrients especially in tropical soils.

Among the different nutrient management approaches already in place at present, customizing the nutrients (major, secondary and micronutrients) requirement of crops with respect to specific agro ecological units (AEUs) based on the nutrient uptake of the crop and innate nutrient supplying capacity of the soil is the newest technology which can avoid the indiscriminate fertilizer use thereby increases the nutrient use efficiency (NUE), reduces the environmental pollution and ultimately sustains the net profit too. Hence, studies were conducted to develop multi nutrient mixtures known as 'custom made/customized fertilizers' containing primary, secondary and micronutrients specific to crops and soils by taking into account the crop requirement, limiting nutrients in that particular soil and the present farmers' nutrient management schedule. This holistic approach resulted in evolving a customized nutrient package comprising of major, secondary and micronutrients for elephant foot yam intercropped in coconut gardens of the two agro ecological units (AEU 3 and AEU 9) of Kerala for enabling high productivity, better farmer income, good tuber quality and sustainable soil quality.

Experimental locations

The experiments were conducted in Onattukkara sandy plain (AEU 3) extends mainly in two districts such as Alappuzha and Kollam, and South Central laterites (AEU 9) which covers the six districts such as Thiruvananthapuram, Kollam, Alappuzha, Pathanamthitta, Kottayam and Ernakulam of Kerala State.

AEU 3 extends into the mid lands from coast covering 43 panchayats under eight blocks and two municipalities spread over Kollam and Alappuzha districts covering Karthikkappaly, Karungappally and Mavelikkara taluks. Climate is tropical humid monsoon type with mean annual temperature of 27.6 ^{0}C and rainfall of 2492 mm with sandy soil type which is coarse textured with immature profiles. Probability of annual drought is negligible in this AEU. The major land use is coconut plantations on uplands and rice on lowlands covering an area of 67,447 ha, which is 1.74 % of the State. The soil is acidic and deficient in major plant nutrients with poor cation exchange capacity (CEC), low nutrient and water retention capacity. The major cropping system prevailing in the upland ecosystem is coconut based cropping system with tuber crops as the main component crops. In olden days, this region was considered as a region of agricultural prosperity, but now it has become an area of low productivity with many constraints like water and nutrient stress.

AEU 9 represent the mid land laterite terrain with typical laterite soils having short dry period. AEU 9 covers around 3, 65,932 ha of land area in Kerala. AEU 9 has 161 panchayats under 34 blocks and six municipalities. It mainly occupies the mid lands under districts of Thiruvananthapuram, Kollam, Pathanamthitta, Alappuzha, Kottayam and Ernakulam. The climate is typically tropical humid monsoon type with mean annual temperature of 26.5^{0}C and the rainfall is 2827 mm. The soil is strongly acidic, laterite clay type with gravels underlined by plinthite. The low lands have strongly acid, low activity, non gravelly clay soils with impeded drainage conditions. Monocropped rubber and coconut intercropped with a variety of annual crops specifically tuber crops and other perennial crops is the major land use on uplands. Rice, tuber crops (mainly cassava, elephant foot yam, taro, tannia), banana and vegetables are the major crops grown in lowlands.

In the present experiment, the location selected in AEU 3 is Chettikulangara in Alappuzha district, AEU 9(1) is Kozhencherry in Pathanamthitta district and AEU 9(2) is Sreekariyam in Thiruvananthapuram district (ICAR-CTCRI). The detailed methodology as per the protocol indicated above which is followed for the development of CF grades for EFY under intercropping in coconut plantation is described below (Anju et al., 2020b):

Arriving at the mean weighted average data of the soil chemical parameters of the AEUs

The methodology for the evolution of the CF formulations started with building up of crop and soil database of elephant foot yam 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 co-ordinated project on 'Soil based plant nutrient management plans for agro ecosystems of Kerala'. The soil test data on pH, electrical conductivity (EC), organic carbon, available P, K, Ca, Mg, Fe, Cu, Mn, Zn and B of 40 panchayats out of the 43 panchayats of AEU 3 and 135 panchayats out of 161 panchayats in AEU 9 were taken.

The weighted average of the soil chemical parameters of the comprising panchayats of the two AEUs was computed by using the average soil chemical parameters of each panchayat with respect to its area. Based on the chemical properties of the soil samples collected from independent farmers of each panchayat, the average of the chemical properties of the panchayat was evolved. The area of each panchayat of both the AEUs was taken from the website on the 'Panchayats of Kerala State'. From these data, the percentage area of each panchayat under the AEUs was arrived following the formula.

$$\text{\% area of the panchayat in the AEU} = \frac{\text{Area of the panchayat} \times 100}{\text{Total area of the AEU}}$$

From this, the weighted average data of each soil parameter was evolved following the formula:

$$\text{Weighted average data of the chemical parameter} = \frac{\dfrac{\text{Average data of the chemical parameter of the particular panchayat} \times \text{\% area of the}}{\text{panchayat in the AEU}}}{100}$$

From the weighted average data of the chemical parameter of each panchayat of the AEUs, the mean weighted average data of each chemical parameter of the AEUs was arrived by adding the weighted average data of each chemical parameter of all panchayats of the AEU (Anju et al.,2019).

Table 6. Mean weighted average data of soil chemical parameters of the two AEUs

Parameters	AEU 3 (40 panchayats)	AEU 9 (135 panchayats)	Unit
pH	5.70	5.50	
Electrical conductivity (EC)	0.29	0.28	dSm^{-1}
Organic carbon	0.937	1.386	%
Available P	60.47	64.60	kg ha^{-1}
Exchangeable K	209.00	271.00	kg ha^{-1}
Exchangeable Ca	109.30	555.00	ppm
Exchangeable Mg	36.80	105.00	ppm
Available S	4.68	20.20	ppm
Available Zn	3.74	5.30	ppm
Available Cu	1.76	3.43	ppm
Available Fe	99.00	60.83	ppm
Available Mn	18.70	35.02	ppm
Available B	0.683	0.78	ppm

The mean weighted average data of the two AEUs (Table 6) indicated not much difference between parameters in the case of soil properties like pH, EC, available P and available B. The other parameters *viz.,* soil organic carbon, exchangeable K, Ca, Mg, S, Zn, Cu, Fe and Mn showed wide variation between the two AEUs.

Evolving soil test based fertilizer recommendation of EFY for the AEUs

The mean weighted average data of each AEU was taken as the basis for evolving the soil test based fertilizer cum manurial recommendation as per Aiyer and Nair (1985) for major nutrients (N, P, K) and soil critical level for secondary and micronutrients as per KAU (2012). Following the same, the soil test based fertilizer (STBF) recommendation (theoretical) was arrived and was N, P, K, Mg, Zn, B, dolomite @71 :12.5 :106.5 :12.8 : 4.2 :1.31 :1000 kg ha^{-1} for AEU 3and 78 :12.5 : 90 : 12.8 : 4.2 : 1.31 : 1000 kg ha^{-1} for AEU 9.

Standardization of the optimum doses of nutrients through farmers' field experiments

In the case of major nutrients *viz.*, N, P, K, the optimum doses were standardized using nutrient omission plot (NOP) experiments and that of dolomite, Mg, Zn and B were standardized through nutrient level (NL) experiments. The procedures followed were as follows:

Nutrient Omission Plot (NOP) experiment

The objective of this experiment was to arrive at the optimum level of the major nutrients *viz.*, N, P, K by conducting experiment with different levels of the nutrients *viz.*, N, P, K arrived based on the mean weighted average data of the soil chemical parameters. The different treatments for this experiment were fixed as follows:

In the case of N and K, in addition to the omission treatment (minus), one sub optimal (¾ of the recommended dose as per soil test) and two super optimal levels (1½ and 2 times of the recommended dose as per soil test) was taken. In the case of P, based on soil test, as the recommended rate was zero, a maintenance dose of 25% (1/4) of PoP was taken as the optimum and the super optimal 1 and 2 were 1.25 times and 1.5 times of the optimum dose (Table 7). The levels of nutrients *viz.*, Mg, Zn, B and dolomite were kept optimum in both the AEUs.

Table 7. Treatment details of the NOP experiment

Treat No.	Treatment description	Notation	Rate of application
T1	Optimum based on STBF (NPK)	NPK_{Opt}	Optimum rate of NPK, dolomite, Mg, Zn, B
T2	Optimum-Nitrogen (N)	-N	No N
T3	Optimum + Sub optimal N	N1	0.75 N
T4	Optimum + Super optimal N-1	N2	1.5 N
T5	Optimum + Super optimal N-2	N3	2N
T6	Optimum-Phosphorus (P)	-P	No P
T7	Optimum + Super optimal P-1	P1	1.25 P
T8	Optimum + Super optimal P-2	P2	1.5 P
T9	Optimum-Potassium (K)	-K	No K
T10	Optimum + Sub optimal K	K1	0.75 K
T11	Optimum + Super optimal K-1	K2	1.5 K
T12	Optimum + Super optimal K-2	K3	2 K
T13	Farmers' practice	FP	FP
T14	Package of practices (PoP)	PoP	PoP
T15	Absolute control	AC	AC

The farmers' practice included in the treatment set was based on the survey conducted among the EFY farmers of the two AEUs. It was arrived as factomphos (N:P:K:S @ 20:20:0:13) @ 500 kg ha^{-1} along with muriate of potash (MoP) @ 750 kg ha^{-1} and urea @ 500 kg ha^{-1} in addition to FYM @ 25 t ha^{-1}. The package of practices (PoP) recommendation included in the treatment set was NPK @ 100:50:150 kg ha^{-1} along with FYM @ 25 t ha^{-1}.

Theoretical optimum STBF recommendation based on the mean weighted average data was N :P:K @ 71: 12.5: 106.5 kg ha^{-1} for AEU 3 and 78: 12.5: 90 kg ha^{-1}for AEU 9. Hence, as per the treatments as in Table 7, the rate of application of nutrients are presented in Table 8.

Table 8. Treatments for NOP experiment for standardization of NPK for the AEUs

Treat No.	Treatment description	Rate of nutrients (N :P_2O_5: K_2O kg ha^{-1})	
		AEU 3	AEU 9
T1	Optimum based on STBF	71: 12.5:106.5	78:12.5:90
T2	Optimum-N*	0: 12.5: 106.5	0:12.5:90
T3	Optimum + Sub optimal N1 (0.75 N)	53: 12.5:106.5	59:12.5:90
T4	Optimum + Super optimal N2 (1.5 N)	107:12.5:106.5	117:12.5:90
T5	Optimum + Super optimal N3 (2N)	142:12.5:106.5	156:12.5:90
T6	Optimum-P*	71:0:106.5	78:0:90
T7	Optimum+ Super optimal P1 (1.25P)	71:16: 106.5	78:16:90
T8	Optimum+ Super optimal P2 (1.5P)	71:19:106.5	71:19:90
T9	Optimum-K*	71:12.5:0	78:12.5:0
T10	Optimum+ Sub optimal K1 (0.75K)	71:12.5:80	78:12.5:68
T11	Optimum+Super optimal K2 (1.5K)	71:12.5:160	78:12.5:135
T12	Optimum+ Super optimal K3(2K)	71:12.5:213	78:12.5:180
T13	Farmers' practice	As indicated in text	As indicated in text
T14	PoP+FYM*	100:50:150	100:50:150
T15	Absolute control	0:0:0	0:0:0

*FYM- Farm yard manure, *N-Nitrogen, *P-Phosphorus (as P_2O_5), *K- Potassium (as K_2O)

Tuber yield

The tuber yield data of the above experiment was taken as the basis to arrive at the best optimum level out of the different levels tried for the various nutrients. NOP experiment one each in AEU 3 and AEU 9 were conducted in addition to the on station experiment conducted at ICAR-CTCRI. The tuber yield under the NOP experiment is presented in Table 9. In the first experiment, N was applied at five rates as minus N, optimum N, 0.75 N (sub optimal), 1.5 N (super optimal 1) and 2N (super optimal 2) for AEU 3 and AEU 9. The tuber yield data indicated 2N as significantly highest giving a tuber yield of 45.954 t ha^{-1} in AEU 3. In AEU 9(1), optimum N (33.612 t ha^{-1}) was on par with 1.5 N (38.739 t ha^{-1}) and 2N (45.179 t ha^{-1}). But AEU 9(2), 2N (43.877 t ha^{-1}) was on par with 1.5 N (36.012 t ha^{-1}). However, the average data of the two locations of AEU 9 indicated 2N (45.003 t ha^{-1}) as significantly highest over other treatments. Hence, 2N (142 kg ha^{-1}, 156 kg ha^{-1} for AEU 3 and AEU 9 respectively) was taken as the optimum for the two AEUs (Table 9).

Table 9. Tuber yield (t ha^{-1}) under NOP experiment in three locations of AEU 3 and AEU 9

Treat.No	Description	AEU 3	AEU 9(1)	AEU 9(2)	AEU 9 Mean
T1	Opt	32.406	**33.612**	**27.022**	**30.317**
T2	-N	19.013	26.740	21.936	24.338
T3	0.75N	28.971	29.934	23.301	26.618
T4	1.5N	38.366	38.739	36.012	37.376
T5	2N	**45.954**	**45.179**	**43.877**	**45.003**
T6	-P	25.462	27.910	24.432	26.171
T7	1.25P	29.161	29.485	30.113	29.799
T8	1.5P	**36.597**	33.085	31.670	32.378
T9	-K	20.742	27.814	24.168	25.991
T10	0.75K	27.395	31.629	25.566	28.598
T11	1.5K	37.141	40.183	28.040	34.112
T12	2K	**46.405**	**47.005**	**43.732**	**45.369**
T13	FP	34.660	29.291	35.329	32.31
T14	PoP	33.127	28.848	30.875	29.862
T15	AC	17.341	20.346	28.363	24.354
SEm±		1.1164	3.9190	3.6819	2.534
CD (0.05)		3.3862	11.8872	11.1678	11.5275

As regards to P, four levels of P as minus P, Optimum P, 1.25 P (super optimal 1) and 1.5 P (super optimal 2) were taken where the optimum P was 25% of recommended P_2O_5 (0.25 P is P @ 12.5 kg ha^{-1}). In AEU 3, 1.5 P recorded significantly the highest tuber yield (36.597 t ha^{-1}). In AEU 9, in both 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}) as 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 9).

In the case of K, there were 5 levels as minus K, 0.75 K (sub optimal), optimal K, 1.5 K (super optimal 1) and 2K (super optimal 2). Among the five levels, in AEU 3, 2K as K @ 212 kg ha^{-1} gave significantly the highest tuber yield (46.405 t ha^{-1}). In AEU 9(1), 2K (47.005 t ha^{-1}) was on par with 1.5 K (40.183 t ha^{-1}). In AEU 9(2), 2K was significantly the highest with a tuber yield of 43.732 t ha^{-1}. The mean over two locations of AEU 9 showed 2K (45.714 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 9). Hence, in AEU 3 and AEU 9, the practical optimum fixed based on NOPT is NPK @ 142:19:213 and 156:12.5:180 kg ha^{-1} respectively.

Nutrient Level (NL) experiment

This experiment was conducted in the same farmer's fields and on station at ICAR-CTCRI where the nutrient omission plot experiment was conducted. Except for the treatments, all other details were similar to that described under NOP experiment. NPK were applied as per the theoretical optimum arrived at based on the mean weighted average data. The secondary and micronutrients tested 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). For Ca and Mg, dolomite was chosen as the amendment as Susan John et al., (2013) already reported dolomite as the best soil amendment for tuber crops in the Ultisols of Kerala. The treatment details of the nutrient level experiment are presented in Table 10.

Table 10. Treatment details of NL experiment

Treat No.	Treatment description	Notation	Rate of application
T1	Optimum based on STBF (N,P,K, Dolomite, Mg, Zn and B)	Opt	Optimum rate of N,P,K, dolomite, Mg, Zn and B
T2	Optimum + Sub optimal Dolomite (D)	D1	0.5 D
T3	Optimum + Super optimal Dolomite-1	D2	1.5 D
T4	Optimum + Super optimal Dolomite-2	D3	2 D
T5	Optimum + Sub optimal B	B1	0.5 B
T6	Optimum + Super optimal B-1	B2	1.25 B
T7	Optimum + Super optimal B-2	B3	1.5 B
T8	Optimum-Dolomite+ optimal Mg	M-D	M
T9	Optimum-Dolomite + Sub optimal Mg-1	M1-D	0.25 M
T10	Optimum-Dolomite + Sub optimal Mg-2	M2-D	0.5 M
T11	Optimum-Dolomite + Super optimal Mg	M3-D	1.5 M
T12	Optimum-Dolomite (Opt) + Mg (M2)	M2-D	0.5 M-D
T13	Optimum + Sub optimal Zn	Zn1	0.5 Zn
T14	Optimum + Super optimal Zn-1	Zn2	1.5 Zn
T15	Optimum + Super optimal Zn-2	Zn3	2 Zn

Mg treatments were applied without dolomite to understand the precise effect of Mg alone. The theoretical optimum of Mg, Zn, B and dolomite arrived for both AEUs was 12.8: 4.2: 1.31: 1000 kg ha^{-1} and different levels of these nutrients were taken as treatments. Hence, for standardization of dolomite and Zn, the sub optimal levels were half of optimum and the super optimal levels were 1.5 and 2 times the level of optimum. For Mg, there were two suboptimal levels *viz*., 0.25 and 0.5 times of the recommended dose of Mg and the super optimal was 1.5 times of the recommended dose. For B, the optimal level was 1.31 kg B (12.5 kg Borax) and the sub optimal level was 0.5 B and the super optimal levels were 1.25 B and 1.5 B. The exact recommendation for Mg, Zn, B and dolomite is presented in Table 11 which in turn was as per the adhoc recommendation given by KAU (2012) for secondary and micronutrients and hence it was same for both AEU's.

Table 11. Treatments for NL experiment for standardization of secondary and micronutrients for the two AEUs

Treat No.	Treatment description	Mg, Zn, B, Dolomite (kg ha^{-1}) AEU 3 & AEU 9
T1	Optimum based on STBF (NPK, dolomite, Mg, Zn, B)	12.8:4.2:1.31:1000
T2	Optimum (NPK, Zn, B) + Sub optimal D1 (0.5D*)	500
T3	Optimum (NPK, Zn, B) + Super optimal D2 (1.5D)	1500
T4	Optimum (NPK, Zn, B) + Super optimal D3 (2D)	2000
T5	Optimum (NPK, Dolomite, Zn, Mg) + Sub optimal B1 (0.5B*)	0.65
T6	Optimum (NPK, Dolomite, Zn, Mg) + Super optimal B2 (1.25B)	1.575
T7	Optimum (NPK, Dolomite, Zn, Mg) + Super optimal B3 (1.5B)	1.975
T8	Optimum (NPK, Zn, B)+ Optimal Mg (M*)	12.8
T9	Optimum (NPK, Zn, B)+ Sub optimal M1 (0.25 M)	3.2
T10	Optimum (NPK, Zn, B) + Sub optimal M2 (0.5M)	6.4
T11	Optimum (NPK, Zn, B)+Super optimal M3 (1.5M)	19.2
T12	Optimum (NPK, Dolomite, B, Mg) + Optimum Zn (Zn*)	4.2
T13	Optimum (NPK, Dolomite, B, Mg) + Sub optimal Zn1 (0.5 Zn)	2.1
T14	Optimum (NPK, Dolomite, B, Mg) + Super optimal Zn2 (1.5 Zn)	6.3
T15	Optimum(NPK, Dolomite, B, Mg) + Super optimal Zn3 (2Zn)	8.4

*D- Dolomite, *B- Boron, *Mg- Magnesium, *Zn- Zinc

Tuber yield

As regards to the tuber yield under dolomite, in AEU 3 and 9, 2D was on par with 1.5D (Table 12) and hence in both AEUs, dolomite @ 1.5 t ha^{-1} was recommended as the optimum. In the case of Mg, in both AEU's, 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. In AEU 3, though 1.5 B recorded highest tuber yield, it was on par with 1.25 B, hence it was taken as the optimum. Similarly in AEU 9, in the two locations as well as the mean of the AEU 9 showed 1.5 B as the optimum as it gave a significantly higher yield over all the other levels.

Table 12. Tuber yield (t ha^{-1}) under different treatments of NL experiment in three locations of the two AEUs

Treat.No	Description	AEU 3	AEU 9(1)	AEU 9(2)	AEU 9 Mean
T1	OPT	32.176	37.276	31.003	33.485
T2	0.5 D	24.497	33.696	27.214	28.469
T3	1.5D	**35.397**	**41.621**	**37.134**	**38.051**
T4	2D	42.029	45.356	40.731	42.705
T5	0.5B	26.745	32.216	29.046	30.631
T6	1.25B	**39.423**	33.269	33.705	33.487
T7	1.5B	40.303	**43.154**	**39.032**	**41.093**
T8	M	26.666	37.967	37.225	27.637
T9	0.25M	17.497	25.616	14.508	19.207
T10	0.5M	23.727	26.108	18.277	29.020
T11	1.5M	**33.877**	**40.771**	**46.597**	**40.415**
T12	Zn	**29.188**	29.284	27.191	28.234
T13	0.5Zn	23.326	28.965	27.368	28.167
T14	1.5Zn	28.196	**36.115**	**37.905**	**34.072**
T15	2Zn	31.081	39.419	33.540	34.680
SEm±		2.205	1.797	4.944	2.464
CD (0.05)	-	6.690	5.4519	4.996	5.769

In AEU 3, the highest tuber yield was recorded under 2 Zn which in turn was on par with all levels except 0.5 Zn and hence optimum (Zn) (4.2) was taken as the best optimum. In AEU 9, the mean of the two locations including location 1 and 2 indicated 2 Zn was on par with 1.5 Zn and hence 1.5 Zn (6.3) was taken as the best optimum (Table 12). Based on the tuber yield data of the two AEUs, the optimum nutrient rate for secondary (Mg), micronutrients (Zn, B) and dolomite were standardized for the two AEUs as Mg: Zn: B: Dolomite @ 19.2: 4.2: 1.575: 1500 kg ha^{-1} for AEU 3 and 19.2: 6.3: 1.975:1500 kg ha^{-1} for AEU 9.

Based on the optimum rates of primary, secondary and micronutrients arrived through nutrient omission and nutrient level experiments, the best practical optimum nutrient doses for these two AEUs were evolved as N: P: K: Mg: Zn: B: Dolomite @ 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.

Arriving at the nutrient use efficiency (NUE) parameters to calculate the grades of the customized fertilizer (CF) formulations

The two approaches used in this regard were Soil Test Crop Response (STCR) and Response Curve (RC) approaches. In the STCR approach, the yield target was fixed as 45 t ha^{-1} and hence the nutrient requirement for this yield was computed from the Nutrient Requirement (NR) determined based on the NOPT and NL experiments.

The basic nutrient use efficiency parameters computed for arriving at the grades of the CF formulations included

- Nutrient requirement
- Total soil available nutrient supply
- Innate nutrient supply
- Total plant nutrient uptake
- Percentage nutrient contribution from the soil
- Soil nutrient supply
- Nutrient to be taken up from the fertilizer
- Fertilizer use efficiency
- Fertilizer application requirement

These parameters were computed for each nutrient under experimentation *viz.,* N, P, and K through NOP experiment and Mg, Zn, B and dolomite through NL experiments.

Nutrient requirement

Nutrient requirement (NR) is the total quantity of nutrients taken up in kilogram for producing one ton of tuber and is arrived as per the formula

$$NR = \frac{\text{Total plant nutrient uptake (kg ha}^{-1})}{\text{Total tuber yield (t ha}^{-1})}$$

The nutrient requirement with respect to nutrients *viz.,* 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 13.

As regards to the NR for N (total N uptake per ton of tuber), the N uptake under different levels of N was considered. The mean NR at different levels of N in AEU 3, AEU 9 and mean of AEU 3 and 9 were of 3.76, 3.61 and 3.68 respectively. This mean value was taken further for computation of grades for both AEUs.

In the case of NR of P, the same procedure as in the case of N was followed and the NR for P (P uptake under P level plots only) for AEU 3, AEU 9 and mean of AEU 3 and 9 were calculated (Table 13) as 0.64, 0.76 and 0.70 respectively and these values were taken for further grade calculation of the CF mixture formulation. As regards to the NR for K , as in the case of N and P, the K requirement at different K levels only were taken and was arrived as 3.37, 5.57 and 4.47 respectively for AEU 3, AEU 9 and mean of AEU 3 and 9 (Table 13).

Table 13. Nutrient requirement (NR) of N, P and K in the two AEUs under NOP experiment

Treat.No	Description	AEU 3	AEU 9	AEU 3 & 9
T1	Opt	3.26	3.96	3.61
T2	-N	5.21	3.4	4.31
T3	0.5N	3.84	4.00	3.92
T4	1.5N	4.18	3.18	3.68
T5	2N	2.29	3.52	2.91
Mean		4.023	3.754	3.89
SEm±		0.663	0.620	0.528
CD (0.05)		2.0097	NS	NS
Mean N(N plots alone)		3.76	3.61	**3.68**
Treat.No	Description	AEU 3	AEU 9	AEU 3 & 9
T6	-P	0.80	0.82	0.81
T7	1.25P	0.65	0.80	0.72
T8	1.5P	0.46	0.70	0.58
Mean		0.613	0.712	0.66
SEm±		0.100	0.141	0.105
CD(0.05)		0.3022	NS	0.302
Mean P(P plots alone)		0.64	0.76	**0.70**
Treat.No	Description	AEU 3	AEU 9	AEU 3 & 9
T9	-K	3.96	6.95	5.45
T10	0.75K	2.76	6.36	4.56
T11	1.5K	2.52	4.62	3.57
T12	2K	4.47	4.86	4.66
Mean		3.291	5.369	4.33
SEm±		0.727	0.906	0.623
CD(0.05)		NS	NS	NS
Mean K(K plots alone)		3.37	5.57	**4.47**

Hence, for further computation of grades, the NR for N, P and K was taken as 3.68, 0.7 and 4.47 kg per ton of tuber which is the average value of AEU 3 and AEU 9. In the case of nutrients *viz.*, Mg, Zn and B, from the nutrient level experiment, the level at which the highest tuber yield obtained was taken and for Mg, Zn, B and dolomite, it was taken as 19.2, 4.2, 1.575 kg ha^{-1} and 1.5 t ha^{-1} respectively. For AEU 9, the levels were 19.2, 6.3, 1.975 kg ha^{-1} and 1.5 t ha^{-1} respectively (Table 12).

Nutrient uptake

Based on the NR arrived as 3.68 kg N, 0.7 kg P and 4.47 kg K to produce one ton of tuber, for the target yield of 45 t ha^{-1}, the uptake of N, P and K was calculated as 166 kg N, 32 kg P and 201 kg K respectively.

Initial soil available nutrient supply (NPK)

The initial soil available nutrient supply for crop growth and yield for the particular season is taken as the sum of the initial soil nutrient status and the nutrient added through farm yard manure (FYM).

In the present study, the initial soil available N, P and K content of independent plots were determined and the mean of these values were calculated and taken. In the case of soil available, N, P_2O_5, K_2O, the values for AEU3, AEU 9(1), AEU 9(2) and mean AEU (9) were determined as 105.9, 106.63, 104.92 and 105.9 kg ha^{-1}N, 45.11, 50.1, 48.1 and 49.11 kg ha^{-1}P and 112.3, 170.5, 177.2 and 173.85 kg ha^{-1}K respectively.

The N, P, K content of FYM was 0.562, 0.0963 and 0.58% respectively. Considering the FYM as well dried with 33% moisture (67% dry matter), the N, P, K added through 25 t ha^{-1} FYM was determined as 92.73, 15.89 and 97.15 kg ha^{-1}respectively.

Calculation

Dry matter contained in 25 tonnes t of FYM = 67×25/100 = 16.75 t

N added through 16.75 t FYM = 0.562×16.75/100=0.0941 t=94.1 kg N

P added through 16.75 t FYM = 0.0963×16.75/100=0.0161 t=16.13 kg P

K added through 16.75 t FYM= 0.58×16.75/100= 0.0972 t= 97.2 kg K

Adding the initial soil N, P, K supply with N, P, K added through FYM, the initial soil available nutrient supply arrived for AEU 3 and AEU 9 was 200 (105.9+94.1), 200 (105.9+94.1) kg ha^{-1}N, 61(45.11+16.13), 65 (49.11+16.13) kg ha^{-1} P and 209.5 (112.3+97.2), 271 (173.85+97.2) kg ha^{-1} K respectively.

Percentage contribution (innate soil nutrient supply) from the soil

In the computation of grades of the CF mixture, the initial soil available N, P, K of AEU 3 was taken as 200, 61 and 209 and in AEU 9 as 200, 65, 271 kg ha^{-1} respectively. These values in turn were used to arrive at the percentage contribution (innate soil nutrient supply) from the soil after considering the uptake of N,P, K from plots omitted with these nutrients. It was arrived by dividing the N, P, K uptake in the respective N, P, K omitted plots with total initial soil available N, P, K supply.

Percentage contribution from the soil (INS, IPS, IKS %) OR Innate soil nutrient supply = N, P, K uptake in the respective N, P, K omitted plots/ total initial soil available N, P, K supply. The N,P, K uptake in the N,P, K omitted plots derived from NOP experiment were presented in Table 14.

N uptake in –N plots under AEU 3, AEU 9(1), 9(2) and mean of AEU 9 are 111.19, 61.28, 69.99 and 65.64 respectively. In the case of P, these values were 20.29, 21.56, 21.71 and 21.64 respectively for AEU 3, AEU 9(1), 9(2) and mean AEU 9. The K uptake values for K omitted plots were 92.62, 139.49, 123.32 and 131.41 respectively under AEU 3, AEU 9(1), 9(2) and mean AEU 9. In other words, based on the initial total available soil nutrient supply, the innate nutrient supplying capacity of the soil or percentage contribution of soil alone for nutrients is computed as 53.60 (119.19/200), 33.30 (20.29/61) and 44.30 (92.62/209) % N, P, K for AEU 3 and 32.82(65.64/200), 33.28 (21.64/65) and 48.49 (131.41/271) % N, P, K for AEU 9 respectively (Table 14).

Table 14. NPK uptake in NPK omitted plots and innate N,P, K supply from soil

NPK uptake in NPK omitted plots									
Nutrients	AEU 3	AEU 9(1)	AEU 9(2)	AEU 9 (Mean)		AEU 3	AEU 9(1)	AEU 9(2)	AEU 9 (Mean)
-N	111.19	61.28	69.99	65.64	INS (%)	55.60	30.28	35.40	32.82
-P	20.29	21.56	21.71	21.64	IPS (%)	33.30	32.67	33.92	33.28
-K	92.62	139.49	123.32	131.41	IKS (%)	44.30	52.11	44.94	48.49

e. Nutrient supply from the soil

The nutrient supply from the soil (kg ha^{-1}) is calculated (Table 15) by multiplying the soil available nutrient supply with innate nutrient supplying capacity of the soil.

In the case of AEU 3, it was calculated as

Nutrient supply from soil (N) = 200×55.6=111.2 kg ha^{-1}

Nutrient supply from soil (P) = 61×33.3 = 20.31kg ha^{-1}

Nutrient supply from soil (K) = 209.5× 44.30 = 92.81 kg ha^{-1}

In the case of AEU 9, it was calculated as

Nutrient supply from soil (N) = 200 × 32.82=65.64 kg ha^{-1}

Nutrient supply from soil (P) = 65 × 33.28 = 21.63 kg ha^{-1}

Nutrient supply from soil (K) = 271× 48.49 = 131.41 kg ha^{-1}

Computation of nutrient use efficiency (NUE) parameters: agronomic/fertilizer use efficiency

The NUE parameters computed under this experiment for nutrients *viz*., N, P, K is fertilizer use efficiency (FUE) (agronomic efficiency). The fertilizer use efficiency computed from the nutrient omission plot experiment for the three locations of AEU 3 and AEU 9 is used in arriving at the grades of the CF and is presented below.

It is the quantity of tuber produced (kg) for each kg of nutrient (N, P, K) applied. While computing the FUE, the yield obtained under –N, -P, -K is deducted from the treatment yields viz., 0.75N, N, 1.5N, 2N (N treatments), P, 1.25P, 1.5P (P treatments) and 0.75 K, K, 1.5K, 2K (K treatments) and divided by the nutrient applied like 53, 71, 107, 142 kg ha^{-1} (AEU 3) and 59, 78, 117, 156 kg ha^{-1} (AEU 9) in the case of N, 12.5, 16, 19 kg ha^{-1} (AEU3,9) in the case of P and 80, 106.5, 160, 213 kg ha^{-1} (AEU 3) and 68,90,135, 180 kg ha^{-1} (AEU 9) for K.

Example:

$$\text{Agronomic efficiency of N at optimum N} = \frac{(\text{Tuber yield at optimum N} - \text{Tuber yield at 0N}) \times 1000}{\text{N added under optimum (71 under AEU 3 and 78 under AEU 9)}}$$

Similarly, calculate the agronomic efficiency of N, P, K at the different levels as above as per the equation above by changing tuber yield at different levels of N, P, K in the numerator and corresponding levels of N, P, K added in the denominator. Though we have computed the agronomic efficiency at all the levels of N, P and K, for the purpose of arriving at the grades, the level of N, P, K at which there is highest/maximum tuber yield obtained was taken. At AEU 3, the fertilizer use efficiency of N, P and K was taken as 27.1 (2N), 48.5 (1.5 P) and 90.0 (2K) respectively and for AEU 9 as 54 (1.5N), 40 (P) and 48 (2K) respectively where the highest/ maximum tuber yield was obtained (Table 9).

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

A Survey was conducted to assess the general nutrient management strategy in place by the EFY growing farmers of the two AEUs of Kerala. This was intended for getting an overview of the type of organic manures, chemical fertilizers, their rate and mode of application when EFY is grown under coconut as intercrops which in turn will help to decide on the rate of application of the CF developed in parity with farmers' application rate. A total of 72 farmers belonging to the different places of AEU 3 and AEU 9 were interviewed for this purpose and the data obtained was tabulated in excel sheet and used in arriving at the level of application of the CF designed.

For this purpose, a questionnaire was prepared based on the model received from Tata Agri Solutions, Aligarh, U.P, for the crop nutrition survey conducted for potato while developing the CF formulation for potato. The questionnaire consisted mainly of personal details, details on general crop nutrition, specific crop nutrition of elephant foot yam *viz.,* soil testing, organic, bio fertilizers, chemical fertilizers including secondary and micronutrients, water soluble, foliar and plant growth promoters used in the last three years.

The farmers' survey indicated the general application rate as factomphos containing N:P:K:S (20:20:0:13) @ 500 kg ha^{-1}, MOP @ 750 kg ha^{-1} and urea @ 500 kg ha^{-1} along with FYM @ 25 t ha^{-1}. It is also known that, progressive farmers are applying 14 (900 kg) bags of chemical fertilizers and normal farmers are going for 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 formulations

The basic NUE 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 dose. The grades were designed based on soil test crop response (STCR) approach 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 based on the farmers' survey details.

STCR Approach

The parameters computed for arriving at the CF grades of the two AEUs included , Nutrient requirement , Soil available nutrient , Innate nutrient supply (%) , Nutrient supply from soil , Nutrient uptake and Fertilizer use efficiency. From these parameters, the nutrients to be supplied through fertilizers (NTF) was calculated as nutrient uptake for the targeted yield- innate nutrient supply from soil.

Nutrient supply through fertilizer

Nutrient to be applied through the fertilizer = Nutrient uptake for the targeted yield- nutrient supply from the soil (Table 15).

Nutrient uptake for the targeted yield (45 t ha^{-1}) = Nutrient uptake (N, P, K per ton of tuber) × 45

N uptake/requirement= 3.68 × 45 = 165.6 kg ha^{-1}

P uptake/ requirement = 0.70 × 45= 31.5 kg ha^{-1}

K uptake/requirement = 4.47 × 45 = 201.15 kg ha^{-1}

It was found same for both AEU's (Table 13)

Nutrient supply from the soil was calculated as 111.2 kg N, 20.31 kg P and 92.81 kg K under AEU 3 and 65.64 kg N, 21.63 kg P and 131.41 kg K per hectare under AEU 9

In AEU 3

Nutrient to be supplied through fertilizer (N) = 166-111 = 55 kg N

Nutrient to be supplied through fertilizer (P) = 32-20 = 12 kg P

Nutrient to be supplied through fertilizer (K) = 201-93 = 108 kg K In AEU 9

Table 15. Parameters computed for AEU 3 and AEU 9 for arriving at CF grade

	AEU 3						AEU 9					
Parameters	N	P_2O_5	K_2O	Mg	Zn	B	N	P_2O_5	K_2O	Mg	Zn	B
NR[1] ($kg\ t^{-1}$)	3.68	0.70	4.47	19.2	4.2	1.58	3.68	0.70*	4.47*	19.2	6.3	1.97
SAN[2] ($kg\ ha^{-1}$)	200	61	209				200	65	271			
INS[3] (%)	55.6	33.3	44.3				32.8	33.3	48.5			
NSS[4] ($kg\ ha^{-1}$)	111	20	93				66	21	131			
NU [5]($45\ t\ ha^{-1}$)	166	32	201				166	32	201			
NS F (NU-NSS)	55	12	108				100	11	70			
FUE[6] (%)	27.1	48.5	90				54	40	48			
NTF($kg\ ha^{-1}$)	203	57	145				185	63	175			
**CF G (%)	8	11	20	3.84	0.84	0.32	7	13	25	3.84	1.26	0.4

[1]Nutrient Requirement, : [2]Soil Available Nutrient, : [3]Innate Nutrient Supply , : [4]NSS: Nutrient supply from soil, : [5]Nutrient uptake, : [6]Fertilizer use efficiency, NTF : Nutrient to be supplied through fertilizer

Based on these calculations, the quantity of nutrients N, P and K to be applied through the fertilizers were arrived as 55,12, 108 kg N, P, K for AEU 3 and 100, 11,70 kg N, P, K for AEU 9.

The detailed calculations were as follows:

Total plant uptake ($kg\ ha^{-1}$) (NU) = {Dry weight per plant (leaf lamina) × % nutrient content (leaf lamina) + dry weight per plant (pseudostem) × % nutrient content (pseudostem) + dry weight per plant (tuber) × % nutrient content (tuber)} × number of plants ha^{-1}. Nutrient requirement (kg nutrient / ton of tuber) (NR) = Total plant nutrient uptake ($kg\ ha^{-1}$) / total tuber yield ($t\ ha^{-1}$).

Total soil available nutrient supply ($kg\ ha^{-1}$) (SAN) = Initial soil status + nutrients supplied through organic manures

% contribution from soil /Innate nutrient supply(%) (INS) = Nutrient uptake under minus

N/P/K plots (-N,-P,-K) / total soil available nutrient supply × 100.

Nutrient supply from soil (kg ha^{-1}) (NSS) = Total soil available nutrient supply × % contribution from soil

Fertilizer (NPK) use efficiency (FUE) = Tuber yield (kg) per kg of N/P/K. Nutrient to be applied through fertilizer = Total plant uptake (kg ha^{-1}) for the target yield – Nutrient supplied through soil

Calculation of grades of the CF formulation: Example AEU 3

In AEU 3, the quantity of N, P, K to be applied through fertilizer was arrived as 55, 12 and 108 kg ha^{-1} respectively. After accounting the fertilizer use efficiency (N:27.1%, P: 48.5%, K: 90%) and converting P and K to P_2O_5 (P×2.29) and K_2O (K×1.21) , the quantity of N, P_2O_5, K_2O were computed as 203 (55×100/27.1), 57 (12×100×2.29/48.5) and 145 (108×100×1.21/90) kg ha^{-1} respectively. Hence, the quantity of N, P_2O_5, K_2O was arrived as 203, 57 and 145 kg ha^{-1} respectively (Table 15)..

In AEU 3, since the CF formulation has 20% N, full P and 70% K, hence the grade was calculated as N @ 40.2 (203×0.2), P_2O_5 @ 57 (57×1) and K_2O @ 101.5 (145×0.7). Since the rate of application based on farmers' practice was fixed as 500 kg ha^{-1} the final grade of N: P_2O_5 : K_2O was arrived as 8 (40.2 × 100/ 500) : 11 (57× 100/500) : 20 (101.5×100/500) . In the case of nutrients *viz.,* Mg, Zn and B, based on their optimum level contributed to maximum tuber yield as 19.2 kg Mg, 4.2 kg Zn and 1.575 kg B, the grades were 3.84 (19.2×100/500), 0.84 (4.2×100/500) and 0.315 (1.575×100/500) respectively. Finally, the grade of the CF mixture developed for AEU 3 as per STCR approach was arrived as N: P_2O_5: K_2O: Mg: Zn: B @ 8: 11: 20: 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.

As in the case of AEU 3, the same calculation made for AEU 9, resulted in the content of N: P_2O_5: K_2O is @ 7: 13: 2 (%). In the case of nutrients *viz.,* Mg, Zn and B, based on their optimum level contributed to maximum tuber yield as 19.2 kg Mg, 6.3 kg Zn and 1.975 kg B, the grades were 3.84, 1.26 and 0.394 respectively. Finally, the grade of the CF mixture developed for AEU 9 as per STCR approach was arrived as N: P_2O_5: K_2O: M: Zn: B @ 7: 13: 25: 3.84: 1.26: 0.4. The parameters arrived for the formulation of two grades of the CF mixture for AEU 3 and AEU 9 is presented in Table 15.

Arriving at the 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_2O application requirement is 203 and 145 kg ha^{-1} for an application rate of 500 kg ha^{-1} (Table 15). As the CF mixture contains 20% N and 70% K, the rest 80% N and 30% K needs to be top dressed which in turn is calculated as N @ 162.4 kg ha^{-1} (203×0.8) which in turn is equal to 353 kg urea (162.4×100/46) and K_2O @ 43.5 kg ha^{-1} (145×0.3) which is calculated as 73 kg ha^{-1} MOP (43.5 × 100/60). For AEU 9, the total N and K_2O application requirements were calculated as 185 and 175 kg ha^{-1} (Table 15) and for top dressing the N and K_2O requirements were calculated as 148 and 52.5 kg ha^{-1} respectively accounting the N and K_2O content to be top dressed as 80 and 30% respectively of total N and K_2O requirements. This is worked out as urea and MOP to the tune of 322 and 88 kg ha^{-1} respectively for top dressing as per the calculation made for AEU 3.

Response Curve Approach

AEU 3

In the response curve approach, the response curve was fitted for secondary (Mg) and micronutrients (Zn, B) by plotting tuber yield against the different levels of the nutrients added (Fig.1, 2, 3).

Fig. 1. Response curve for Mg

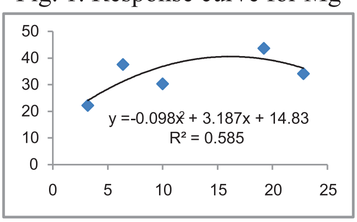


Fig. 2. Response curve for Zn

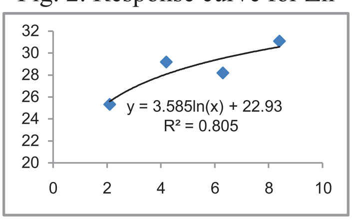
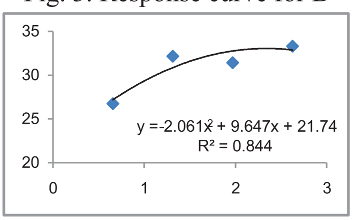


Fig. 3. Response curve for B



The regression coefficient in each of the nutrients indicated positive correlation between levels of nutrients and tuber yield. Hence, in this approach, the level of the above nutrients at which the highest/maximum yield was obtained was taken as the optimum level for arriving at the grades. The same approach was followed in the case of major nutrients *viz.*, N, P and K. The response curves fitted for AEU 3 showed the levels of N, P_2O_5, K_2O, Mg, Zn and B where the highest yield recorded was 142, 12.5, 213, 19.2, 4.2 and 1.6 respectively.

Calculation for arriving grades

Keeping the above levels and following the basic concept that, CF has 20% N, full P and 70% K, and full Mg, Zn and B, the above nutrient contents on per hectare basis will be 28.4 kg N (142×0.2), 12.5 kg P_2O_5, 149.1 kg K_2O (213×0.7), 19.2 kg Mg, 4.2 kg Zn and 1.6 kg B. For an application rate of 500 kg ha^{-1} of the CF mixture, the grade (% nutrient content) of N, P_2O_5, K_2O, Mg, Zn and B as 5.68 (28.4×100/500), 2.5 (12.5×100/500), 29.82 (149.1×100/500), 3.84 (19.2×100/500), 0.84, (4.2×100/500) 0.32 (1.6×100/500) respectively. The final grade as per the response curve approach for AEU 3 was arrived as N: P_2O_5: K_2O: Mg: Zn: B was 6: 3: 30: 3.5: 0.8: 0.3.

AEU 9

The same procedure as in the case of AEU 3 was followed for AEU 9. The regression equation developed for Mg, Zn and B is depicted below:

Fig. 4. Response curve for Mg

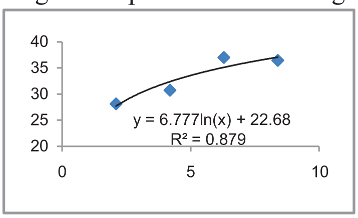


Fig. 5. Response curve for Zn

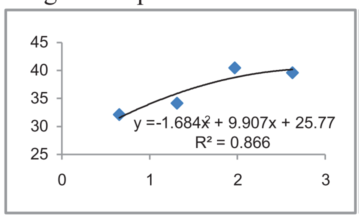
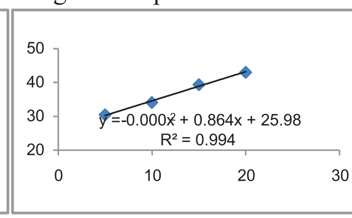


Fig. 6. Response curve for B



In AEU 9, the optimum level of N, P_2O_5, K_2O, Mg, Zn and B at which the maximum yield obtained was 156, 12.5, 180, 19.2, 6.3 and 1.975 kg ha^{-1} respectively. The nutrient content in the CF mixture with 20%N, 70% K and full P,Mg, Zn and B was worked out as N, P_2O_5, K_2O, Mg, Zn and B @ 31.2, 12.5, 126, 19.2, 6.3, 1.975 kg ha^{-1}. On calculating the grade for an application rate of 500 kg ha^{-1}, the per cent nutrient content was found as N, P_2O_5, K_2O, Mg, Zn and B @ 6.24, 2.5, 25.2, 3.84, 1.26, 0.395. Hence, the final grade arrived for AEU 9 as per response curve approach was N: P_2O_5: K_2O: Mg: Zn: B @ 7: 3: 25: 4: 1.25: 0.4. Finally, the four grades of the customized fertilizer mixture arrived for AEU 3 and AEU 9 based on STCR approach and RC approach for an application rate of 500 kg ha^{-1} was as follows:

Table 16. Grades of the developed CF mixtures and quantity of fertilizers for top dressing

AEU	Approach	Grades	Notation
3	STCR	N: P_2O_5: K_2O: Mg: Zn: B @8: 11: 20: 3.84: 0.84: 0.315	CF1
9	STCR	N: P_2O_5: K_2O: Mg: Zn: B @7: 13: 25: 3.84: 1.26: 0.4.	CF2
3	RC	N: P_2O_5: K_2O: Mg: Zn: B @ 6: 3: 30: 3.5: 0.8: 0.3	CF3
9	RC	N: P_2O_5: K_2O: Mg: Zn: B @ 7: 3: 25: 4: 1.25: 0.4	CF4
Quantity of N and K need to be applied for top dressing:		AEU 3 N: 162 kg ha^{-1}, K_2O: 44 kg ha^{-1} Urea: 353 kg ha^{-1}, MoP: 73 kg ha^{-1}	
		AEU 9 N: 148 kg ha^{-1}, K_2O: 53 kg ha^{-1} Urea: 322 kg ha^{-1}, MoP: 88 kg ha^{-1}	

In the preparation of the CF grades for field level application, 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. The above mixtures as per the above grades were prepared by grinding the fertilizers in a grinder and then mixing for uniform composition.

Calculation of raw materials for the preparation of CF mixtures

Aspects to be taken care

* Desirable N:P ratio is 1.6 to 2.2, any value beyond that increases difficulty for granule formation, and reduces the run time of the plant

* Total solids should be in the range of 980-988 kg t^{-1} (98 to 98.8%); rest 12 to 20 kg should be kept for water during granule formation

* Ideally, share of filler (inert material like dolomite/gypsum) should be 80 - 120 kg t^{-1} of the product (8 to 12%)

* DAP ideally should be 30-35% of the final product for better granulation, any increase in share decreases run time of the plant

* DAP:TSP ratio should be 70:30 or more

* If K content of the grade is 20% or above, granule formation is easy

* Size distribution: More than 70% of the total material between 2 to 4 mm where FCO recommends more than 90% in 1.4 to 4 mm category.

CF1: AEU 3 –STCR Approach

Grade (Nutrient contents) : N:P_2O_5:K_2O:Mg:Zn:B @8:11:21:3.5:1:0.3

P:K ratio: 0.524 , K: P ratio: 1.9

Nutrient content in the component fertilizers

Name of fertilizers	Content of nutrients
Urea	46% N
Ammonium sulphate	20.6% N
Diammonium phosphate (DAP)	18% N, 46% P_2O_5
Muriate of potash (MoP)	60% K_2O
Magnesium sulphate ($MgSO_4$)	16% MgO
Zinc sulphate monohydrate	33%ZnO
Borax	10.5% B

Arriving at the quantity of component fertilizers for the preparation of 1 ton of CF: Calculation

1. Quantity of DAP = $\frac{P_2O_5 \text{ content in the grade (11)} \times \text{\% of } P_2O_5 \text{ in DAP (46)} \times 1000}{100}$ = 239.1 kg

2. Quantity of MoP = $\frac{K_2O \text{ content in the grade (21)} \times \text{\% of } K_2O \text{ in MoP (60)} \times 1000}{100}$ = 350 kg

3. Quantity of $MgSO_4$ = $\frac{\text{Mg content in the grade (3.5)} \times \text{\% of Mg in } MgSO_4 \text{(16)} \times 1000}{100}$ = 218.8 kg

4. Quantity of $ZnSO_4$ = $\frac{\text{Zn content in the grade (1)} \times \text{\% of Zn in } ZnSO_4 \text{(33)} \times 1000}{100}$ = 30.3 kg

5. Quantity of Borax = $\frac{\text{B content in the grade (0.3)} \times \text{\% of B in borax (10.5)} \times 1000}{100}$ = 28.6 kg

6. Quantity of Urea= $\frac{\text{N content in grade (8)} \times 1000 \times \text{\% N content in urea (46)}}{100} - \frac{\text{Quantity of DAP (239.1)} \times \text{\% N content in DAP(18)}}{100}$ = 80.3 kg

Total mass of fertilizers = 947.1 kg (950 kg) where the total solid required is in the range of 980-990 kg
Quantity of filler= 990-950= 40 kg
Steam= 10 kg

NB: For the preparation of 1 kg of the CF mixture, the quantity in kg may be read as grams.

Following the same calculation, the quantity of component fertilizers was arrived for the other three grades and is given below (Table 17):

Table 17: Quantity of fertilizers to prepare one to of CF mixtures for all four grades

Sl. No.	Materials	Quantity of fertilizers required (g/kg or kg/ton of the CF mixture)			
		CF1	CF2	CF3	CF4
1	Urea	80	50	55	65
2.	Ammonium sulphate	Nil	Nil	120	140
3	Di ammonium phosphate (DAP)**	240	260	65	65
4	Muriate of potash (MoP)	350	400	500	420
5	Magnesium sulphate ($MgSO_4$)	220	155	155	185
6	Zn sulfate (Mono) ($ZnSO_4$)	30	40	30	35
7	Borax	30	35	30	40
8	Total mass without filler	950	940	955	955
9	Filler (gypsum/dolomite/lime)	40	45	30	35
10	Total mass	990	985	985	990
11	Steam/water	10	15	15	10

**In the case of CF1, if DAP is not available, mix 95 g or 95 kg urea (in addition to 80 g /80 kg urea) and 550g or 550 kg Mussooriphos/Rajphos for each kg or ton of the CF mixture. Similarly for CF2, mix 103g/ 103kg urea (in addition to 50g/50 kg urea) and 596 g or 596 kg Mussooriphos/Rajphos for each kg or ton of the CF mixture.

Application of CF formulations for EFY under intercropping in coconut

Though we have developed four grades of the CF, only three (CF1, CF2 and CF4) were tested for arriving at the best rate of application as well as the best grade.

Screening the best rate of application

Though we have evolved the grades by fixing the rate of application as 500 kg ha^{-1}, another rate *viz.,* 625 kg ha^{-1} too was tested to find out the best rate between the two. For that purpose, field experiments were conducted with elephant foot yam variety Gajendra, in three locations consisting of one in AEU 3 and two in AEU 9 with eight treatments replicated thrice in RCBD.

Spacing: 90 × 90 cm

Plot size: 4.5×4.5m, Number of plants: 25 (Border: 16, Inner: 9)

The treatment details were given in Table 18.

Table 18: Treatment details of the field experiment

Treatments	Details	Description (Approach for AEUs)
Treat 1	CF 1 @ 500 kg ha^{-1}	STCR AEU 3
Treat 2	CF 2 @ 500 kg ha^{-1}	STCR AEU 9
Treat 3	CF 3 @ 500 kg ha^{-1}	RC AEU 9
Treat 4	CF 1 @ 625 kg ha^{-1}	STCR AEU 3
Treat 5	CF 2 @ 625kg ha^{-1}	STCR AEU 9
Treat 6	CF 3 @ 625 kg ha^{-1}	RC AEU 9
Treat 7	PoP	Package of Practices
Treat 8	FP	Farmers' Practice

The treatments included the three CF formulations in two rates as 500 and 625 kg ha^{-1} along with package of practices (PoP) recommendation for EFY as NPK @ 100:50:150 kg ha^{-1} along with FYM @25 t ha^{-1}. In the case of application of CF @ 500 kg ha^{-1}, the application rate was 41 g plant (in the case of EFY, the number of plants is 12345 in one hectare and hence the per plant application rate is 500×1000/12345=41 g). When applied @ 625 kg ha^{-1}, the application rate was 51 g per plant. This was applied as basal within two months of planting EFY. Urea and MoP was top dressed as per Table 16.

The farmers' practice was based on the survey conducted and a uniform practice as given below was adopted by all farmers. It was factomphos (N:P:K:S @ 20:20:0:15) @ 500 kg ha^{-1} along with muriate of potash (MoP) @ 750 kg ha^{-1} and urea @ 500 kg ha^{-1} in addition to FYM @ 25 t ha^{-1}.

As per the package of practices available, the crop was raised and the above treatments were imposed. The major observations recorded included growth characters, pre and post experiment soil characters, total plant dry matter, fresh weight of the vegetative parts (leaf and pseudostem) at the active growth stage before the senescence of the crop (6 MAP), tuber yield at harvest, nutrient content in the different plant parts, nutrient uptake, biochemical and phytochemical constituents of the different plant parts, soil enzyme activity, soil quality indices and economic benefits.

Tuber yield

Though we have taken all these observations, the main factors for arriving at the best rate of application was tuber yield and economics (B:C ratio). The tuber yield data is presented in Table 19.

Table 19: Effect of treatments on tuber yield (t ha^{-1})

Treat. No.	Description	AEU3	AEU 9		AEU 9	AEUs
		Site 1	Site 1	Site 2	Mean	Mean
T1	CF 1 @ 500 kg ha^{-1}	14.250	41.392	26.296	33.844	27.313
T2	CF 2 @ 500 kg ha^{-1}	13.391	47.000	29.444	38.222	29.945
T3	CF 3 @ 500 kg ha^{-1}	15.447	47.825	30.088	38.957	31.120
T4	CF 1 @ 625 kg ha^{-1}	19.026	46.695	31.543	39.119	32.421
T5	CF 2 @ 625 kg ha^{-1}	18.127	53.875	35.802	44.839	35.935
T6	CF 3 @ 625 kg ha^{-1}	20.217	53.310	35.500	44.155	36.342
T7	Package of practices (PoP)	15.237	35.274	26.177	30.726	25.563
T8	Farmers' Practice (FP)	16.209	33.752	24.879	29.316	24.947
Mean (Locations)		16.488	44.890	29.966	37.441	26.96
SEm ±		1.54	4.61	3.1836	3.6291	2.160
CD (Treat)		3.139	5.511	3.376	2.295	3.055
CD (Locations)		-	-	-	-	1.405
CD (Treat x Locations)		-	-	-	-	3.975

Statistical analysis of the data indicated significant effect of treatments, locations and their interactions on tuber yield.

AEU 3: All the three CFs @ 625 kg ha^{-1} was significantly higher in tuber yield over these CFs @ 500 kg ha^{-1}. However, the three CFs @ 625 kg ha^{-1} were on par.

AEU 9: 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. Among the two AEUs, significant effect of location was seen with AEU 9 which in turn resulted in a significantly higher yield over AEU 3. Between the two sites under AEU 9, site 1 recorded significantly higher yield than site 2. As regards to the interaction effect of treatments and location, CF2 @ 625 kg ha^{-1} at site 1 under AEU 9 resulted in significantly higher yield on par with CF3 @ 625 kg ha^{-1}. Hence, for EFY under intercropping in coconut, CF2/CF3 @ 625 kg ha^{-1} was 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. Since all the CFs @ 625 kg ha^{-1} were on par at AEU 3 and almost a similar trend was observed with 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.

B: C ratio

The economic analysis on the use of two doses of CFs *viz.*, 500 and 625 kg ha^{-1} along with FP and PoP is presented in Table 20.

Table 20: Economic analysis on the use of CF mixtures at two different rates

Treatment description	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
CF1 @500 kg ha^{-1}	369053	14.250	33.844	427511	1015320	58457	1015319	1.16	2.75
CF2@500 kg ha^{-1}	369995	13.391	38.222	401718	1146669	31723	1146668	1.09	3.10
CF3@500 kg ha^{-1}	367462	15.447	38.957	463395	1168695	95933	1168694	1.26	3.18
CF1@625 kg ha^{-1}	372388	19.026	39.119	570777	1173568	198389	1173566	1.53	3.15
CF2@625 kg ha^{-1}	381218	18.127	44.839	543810	1345160	162591	1345158	1.43	3.53
CF3@625 kg ha^{-1}	370364	20.217	44.405	606497	1332151	236133	1332150	1.64	3.60
PoP	354701	15.237	30.726	457099	921766	102398	921765	1.29	2.60
Farmers' Practice	369465	16.209	29.316	486270	879466.5	116805	879465	1.32	2.38

Gross 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 computed by deducting the cost of cultivation from gross income. The B: C ratio was computed by dividing the total income by total cost of cultivation. A higher BC ratio under AEU 9 compared to AEU 3 was seen. In both the AEUs, CF3 @ 625 kg ha^{-1} resulted in the highest BC ratio of 1.64 and 3.60 respectively in AEU 3 and AEU 9. The mean of the two AEUs also indicated CF3@ 625 kg ha^{-1} as the best with a BC ratio of 2.62. In AEU 3, the three CFs @ 625 kg ha^{-1} gave the higher BC ratios as CF3, CF1, CF2 to the tune of 1.53, 1.43 and 1.64 respectively. Similarly in AEU 9, CF3, CF2 and CF1 @ 625 kg ha^{-1} resulted in BC ratio of 3.60,3.53 and 3.15 respectively. The mean of the two AEU's also followed the same trend with CF3, CF2, CF1 @ 625 kg ha^{-1} caused BC ratios to the tune of 2.62, 2.48, 2.34 respectively. CFs @ 500 kg ha^{-1} resulted in BC ratios lesser than PoP and FP in AEU 3. The mean values of the two AEUs also followed the same trend as CFs @ 625 kg ha^{-1} followed by CFs @ 500 kg ha^{-1}, FP and PoP (Table 19). Hence, the experiment indicated, the best rate of application as 625 kg ha^{-1}.

Other significant results under the experiment to fix the best rate of application of CF

The biometric characters *viz.,* pseudostem height, pseudostem girth, canopy spread of three locations showed significant effect under CF treatments compared to both PoP and FP. The post harvest soil properties over the pre planting soil characters in all the locations showed considerable increase for pH and nutrients *viz.,* soil organic carbon, available N, P, K, Ca and B especially high for CF @ 625 kg ha^{-1} over CF @ 500 kg ha^{-1}, PoP and FP. The total plant dry matter production though high under CF, it was on par with PoP and FP. In the case of N, P, K uptake, CF1 @ 625 kg ha^{-1} followed by CF3 at the same rate was highest in both locations and was significantly higher than PoP and FP. In the case of Mg, Zn and B, the same trend with CF treatments showing higher values over the others were noted.

The tuber quality attributes *viz.,* starch, sugar, crude protein, total phenols, crude fat, crude fiber and ash showed high values under CF treatments over PoP and FP. However, the anti nutritional factor *viz.,* calcium oxalate was comparatively low under CF. Similarly, the chlorophyll content of leaf samples *viz.,* chlorophyll a, b and total chlorophyll was significantly higher under CF and similar results were found in the case of soil quality indices too.

Screening the best CF mixture

After finding out the best application rate as 625 kg ha^{-1}, the next trial was to find out the best

CF grade out of the three grades evolved. For that purpose, experiments were conducted in five locations in large plots of the five major elephant foot yam growing districts of Kerala *viz.,* Thiruvananthapuram, Kollam, Pathanamthitta, Kottayam and Ernakulam. The technical programme of the experiment included five treatments and the treatment details are given in Table 21.

Table 21: Treatment details of the experiment

Treatment No.	Treatment description
T1	FP (Farmers' practice)
T2	PoP (Package of Practices)
T3	CF1@625 kg ha^{-1}
T4	CF2@625 kg ha^{-1}
T5	CF3@625 kg ha^{-1}

Tuber yield

The experiment conducted was considered as a multi location trial with five treatments replicated in five locations. Statistical analysis of the data revealed significant effect of treatments with CF2 (67.561 t ha^{-1}) on par with CF3 (62.623 t ha^{-1}) and CF1 (58.708 t ha^{-1}). Though all the three CFs were on par, CF2 was taken as the best. Among the five districts under the two AEUs, the yield was highest at Kottayam (73.576 t ha^{-1}) followed by Thiruvananthapuram (60.038 t ha^{-1}), Pathanamthitta (58.217 t ha^{-1}), Kollam (57.704 t ha^{-1}) and Ernakulam (38.362 t ha^{-1}). However, farmers' practice (51.645 t ha^{-1}) and PoP (47.360 t ha^{-1}) recorded significantly low tuber yield and they were on par (Table 21).

Table 22: Effect of treatments on tuber yield (t ha^{-1})

Treatments	TVPM*	Kollam	Kottayam	Ernakulam	PTA**	Mean (Treat)
FP	53.907	54.671	64.194	29.782	55.672	51.645
PoP	55.553	55.905	38.270	39.504	47.569	47.360
CF1 @625 kg ha^{-1}	60.079	57.316	77.774	39.195	59.176	58.708
CF2@625 kg ha^{-1}	65.840	62.607	98.760	45.368	65.229	67.561
CF3@625 kg ha^{-1}	64.811	58.022	88.884	37.961	63.437	62.623
Mean (L)	60.038	57.704	73.576	38.362	58.217	
SEm ±	5.8390					
CD	12.378					
p-Value	0.021					
CV (%)	21.8					

TVPM* Thiruvananthapuram, PTA** Pathanamthitta

B: C ratio

The mean tuber yield of the five locations under the two AEUs 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 (Table 22). 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 23. Economic analysis of different grades of CF

Treat.	Treat description	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	51.645	1549350	1221100	4.19
T2	PoP	26451	354701	47.36	1420800	1092550	4.01
T3	CF1 @625 kg ha^{-1}	44138	372388	58.708	1761240	1432990	4.73
T4	CF2@625 kg ha^{-1}	44158	372408	67.561	2026830	1698580	5.44
T5	CF3@625 kg ha^{-1}	42885	371135	62.623	1878690	1550440	5.06

Hence, taking into account, all the laboratory and field experiment results, CFs @ 625 kg ha^{-1} especially CF with the grade having N: P_2O_5: K_2O: Mg: Zn: B @ 7:13:25:4:1.25:0.4 (AEU 9 through STCR)was found best for EFY.

In addition to these major deciding parameters, the effect of treatments on other parameters are described below in brief.

Other significant results under the experiment to fix the best rate of application of CF

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.

Moreover, the SQI values showed higher range under CF than FP and PoP.

Demonstration and popularization of CF through KVKs & ICAR Institutes

The validation trials on the suitability of different grades of the CFs in tuber crops *viz.,* cassava, EFY and yams were carried out by different KVKs of Kerala. In EFY, the trial was undertaken at KVK Kollam and KVK Idukki and in cassava, at KVK Idukki and KVK Alapuzha.

1. KVK, Kollam

The trial was taken up in EFY local variety prevalent in the respective areas in farmers' fields with CF2 and CF1 @625 kgha^{-1} along with the existing PoP. The yield recorded with CF2 @ 625 kgha^{-1} was 30.25 t ha^{-1} where as the average yield was 26.75 t ha^{-1} and the check recorded a yield of 23.25 t ha^{-1} and the percentage increase in yield was 15.05 and the BC ratio was 1.56.

2. KVK, Idukki

KVK, Idukki conducted five trials each in cassava and EFY with four treatments comprising of farmers' practice and PoP and found CF1 and CF2 @ 500 kg ha^{-1} as best for cassava and CF1 and CF2 @ 625 kg ha^{-1} as best for EFY. In cassava CF1 @ 500 kg ha^{-1} performed well over other practices with a yield increase of 25% over farmers' practice with a BC ratio of 2.3. In EFY, the yield increase was 30% with BC ratio of 2.0.

3.KVK, Alapuzha

Cf1 and CF2 @ 500 kg ha^{-1} in cassava along with PoP and farmers' practice was tested in five farmers' fields and indicated the superiority of CF1 @500 kgha^{-1} over farmers' practice and PoP.

4. ICAR-CPCRI-RS, Kayamkulam

In collaboration with ICAR-CPCRI, in farmers' fields, testing of CF1 and CF2 @625 kgha^{-1} along with farmers' practice and PoP was undertaken for greater yam under intercropping in coconut. The yield impact due to CF mixtures was visible only in EFY and in yams, the yield increase was marginal only. In EFY, yield improvement was 18 to 23 percent with the mixtures and the response was almost same with both the mixtures.

5.ICAR-CTCRI, Thiruvananthapuram

At ICAR-CTCRI, the three grades of the CF at two levels were tested in three cassava genotypes (Sree Pavithra, CI-905, CI-906) under intercropping in coconut and found that, CF1 and CF2 @ 500 kg ha^{-1} was suitable with yields as 53.77 and 53.47 t ha^{-1} respectively over CF3@500 kg ha^{-1}. CF1, CF2, CF3 @ 625 kg ha^{-1} resulted a yield of 41.73, 44.43 and 40.46 t ha^{-1} respectively. Testing of CF's at the above levels in sweet potato (var. Sree Arun) and EFY (var. Gajendra) under sole cropping showed CF1 and CF3 @ 500 kg ha^{-1} as suitable.

Taking into account all the experiments, the final recommendation to farmers is to use either CF1 or CF2 for tuber crops *viz.*, cassava, EFY yams and sweet potato. In the case of cassava, CF1 and CF2 @ 500 kg ha^{-1} is best with an application rate of 41 g plant^{-1} and top dressing with urea and MoP @ 29 and 14 and 27 and 15 g plant^{-1} for CF1 and CF2 respectively. In the case of greater yam, the same grades @ 625 kg ha^{-1} was found good with an application rate of 51 g plant^{-1} and top dressing with urea and MoP @ 36 and 18 and 33 and 21 g plant^{-1} for CF1 and CF2 respectively. In the case of EFY, CF2 @ 625 kg ha^{-1} was found better with an application rate of 51 g plant^{-1} and top dressing of urea and MoP @ 33 and 21g plant^{-1} respectively (Table24).

Table 24. Quantity of application CF mixtures and urea and potash for top dressing suitable for different tuber crops

CF mixture	Rate (kg ha^{-1})	Tuber crops	Quantity of CF mixtures (g plant^{-1})	Quantity of fertilizers for top dressing ((g plant^{-1})	
				Urea	MoP
CF-1	500	Cassava	41	29	14
CF-2	500	Cassava	41	27	15
CF-1	625	Greater yam	51	36	18
CF-2	625	Greater yam, EFY	51	33	21

All these crops are planted at a spacing of 90×90 cm and the number of plants in one hectare is 12345 and hence calculated the above rates.

The grades of CF1 and CF2 (Table 16) along with preparation details (Table 17) may be seen for its application in tuber crops.

Conclusion

The concept of designer fertilizers /customized fertilizers specific to crops and soils aimed in evolving a holistic balanced nutrient management solution (taking into account all the constraint nutrients) for the present non judicious fertilizer application schedule which inturn is having deteriorating effect on soil health. The research programme to arrive at the customized fertilizer formulation for elephant foot yam under intercropping in coconut gardens of the two AEUs of Kerala comprised of evolving the weighted average data of the soil chemical parameters of the two AEUs, arriving at the soil test based fertilizer recommendation based on the weighted average, finding out the optimum rate of application of N, P, K, dolomite, Mg, Zn and B based on nutrient omission plot (NOP) and nutrient level (NL) experiments, computing the nutrient use efficiency parameters to design the grades of the customized fertilizer (CF) mixtures based on two approaches and finally testing of the developed formulations in different rates to see the best CF including its rate of application. The salient findings from the different field and laboratory experiments conducted to realize the objectives are as follows:

The mean weighted average data of AEU 3 comprising of 40 and AEU 9 comprising of 135 panchayats with respect to soil chemical parameters like pH, electrical conductivity, organic carbon, available P, exchangeable K, Ca, Mg, available S, Zn, Cu, Fe, Mn and B was 5.7, 0.29 dSm^{-1}, 0.937%, 60.47 kg ha^{-1}, 209 kg ha^{-1}, 109.3 ppm, 36.8 ppm, 4.68 ppm, 3.74 ppm, 1.76 ppm, 99 ppm, 18.7 ppm and 0.683 ppm for AEU 3 and 5.5, 0.28 dSm^{-1}, 1.386%, 64.6 kg ha^{-1}, 271 kg ha^{-1}, 555,105 ppm, 20.2 ppm, 5.3 ppm, 3.43 ppm, 60.83 ppm, 35.02 ppm and 0.78 ppm for AEU 9 respectively.

The soil test based fertilizer cum manurial recommendation arrived based on weighted average data of the soil chemical properties were N, P, K, Mg, Zn, B, dolomite @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. Based on NOP and NL experiments, the optimum nutrient doses for nutrients *viz.*, N, P, K, Mg, Zn, B and dolomite, based on the tuber yield data was N: P: K: Mg: Zn: B: dolomite @ 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.

Nutrient requirement (NR) computed to arrive at the grades of CF formulations based on soil test crop response (STCR) and response curve (RC) approaches were 3.68, 0.70 and 4.47 kg N, P, K respectively per ton of tuber for the two AEU's. The innate nutrient supplying power of the soil computed to arrive at the grades were 55.6, 33.3, 44.3 and 32.8, 33.3 and 48.5 per cent N, P, K respectively for AEU 3 and AEU 9. The fertilizer use efficiency of N, P, K for AEU 3 and AEU 9 respectively were 27.1, 48.5, 90 and 54, 40, 48 per cent. The grades of the CF evolved based on STCR approach was 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: 4: 1.25: 0.4 for AEU 9 (CF2). RC approach based on the level of nutrients at which the maximum tuber yield was obtained resulted in the grade as N: P_2O_5: K_2O: Mg: Zn: B is 6:3 :30 :3.5: 1: 0.3 for AEU 3 (Not selected for field trial) and 7: 3:25: 4: 1.25: 0.4 for AEU 9 (CF3). Evaluation of the two rates *viz.,* 500 kg ha^{-1} and 625 kg ha^{-1} of the three CF's in three locations of the two AEU's indicated, all CF's @ 625kg ha^{-1} as the best. Trials conducted in five locations of the five districts of Kerala to screen the best CF out of the three showed the CF developed for AEU 9 through STCR approach having the grade as N: P_2O_5: K_2O: Mg: Zn: B @ 7: 12: 24: 4: 1.25: 0.4 as the best in terms of tuber yield (67.56 t ha^{-1}), BC ratio (5.44), tuber quality and soil quality indices. Hence, for EFY under intercropping in coconut gardens of Kerala, CF formulation with the above grade was selected for popularizing among farmers

The novel concept on evolving designer fertilizer mixtures based on soil and plant requirement was materialized for EFY under intercropping in coconut gardens of the two AEUs of Kerala under a research project initiated in 2015 which in turn helped in realizing effective crop management benefits better than the existing nutrient management practices. The study helped in evolving three customized fertilizer formulations and testing of these formulations in two rates and understanding their effect on both soil and plant attributes. The programe realised this approach as the best integrated nutrient management strategy in terms of high tuber yield, better quality tubers, high BC ratio and in sustaining soil and plant health over the existing farmers' practice and package of practices recommendations.

Future line of research

- Since these CFs were developed specifically for EFY under intercropping in coconut, CFS can be developed for other tuber crops which are suitable intercrops in coconut gardens like cassava, yams, tannia and arrowroot.
- Since the three formulations are developed for the two major AEUs of Kerala growing tuber crops, these can be tested for other AEUs of Kerala growing tuber crops.
- Studies on the effect of long term application of these CF mixtures for tuber crops with respect to yield, soil and plant attributes, correction of soil nutrient deficiencies and plant nutritional disorders and economic parameters.
- Demonstration and popularization of these CF mixtures among farming community through OFTs by KVKs mediated by ICAR institutions.

Acknowledgements

The authors place on record their gratefulness to the following organizations and persons

- Kerala State Council for Science, Technology and Environment (KSCSTE), Thiruvananthapuram
- Kerala State Planning Board (KSPB), Thiruvananthapuram
- Dr. G. Byju, Director, ICAR-CTCRI, Thiruvananthapuram
- Dr. S.K. Chakraborti, Dr. James George, Dr. (Mrs.) Archana Mukherjee and Dr. V. Ravi, Former Directors, ICAR-CTCRI, Thiruvananthapuram
- The Farmers involved in the different field experiments
- Dr. S.B. Ray, Former Principal Scientist & Head, Crop Nutrition, Tata Agri Solutions, Aligarh, Uttar Pradesh
- Dr. Sunitha, S. Principal Scientist (Agronomy), Division of Crop Production, ICAR-CTCRI, Thiruvananthapuram
- Dr. Veena, S.S., Principal Scientist (Plant Pathology), Division of Crop Protection, ICAR-CTCRI, Thiruvananthapuram

- Dr. Jeena Mathew, Senior Scientist (Soil Science), ICAR-CPCRI, Regional Station, Kayamkulam, Alapuzha, Kerala
- Shri, K. Ramakrishnan, Former Technical Officer, ICAR-CTCRI, Thiruvananthapuram
- Shri, B. Satheesan, Senior Technician, ICAR-CTCRI, Thiruvananthapuram
- Shri, Monu, S.R. and Shri. Renjith, B.R., Former Field Assistants, KSPB Project
- Smt. Suja, G., Former Project Assistant, KSPB Project

References

Aiyer, R.S. and Nair, H.K. 1985. *Soils of India and their management*. Fertilizer Association of India, New Delhi, India, pp.445.

Ananda, N. and Patil, B.N. 2005. Effect of micronutrients (Zn and Fe) and the time of nitrogen application on growth and yield of durum wheat, Karnataka. *Journal of Agricultural Sciences,* **18**(3): 604-608.

Anju, P.S., Susan John, K., Bhadraray, S., Jeena Mathew, Sunitha, S. and Veena, S.S. 2020a. Optimum nutrient requirement of elephant foot yam. *Journal of Root Crops*, **46**(1): 18-24.

Anju, P.S., Susan John, K. and Ray, S.B. 2019. Weighted average method in evolving the nutrient status of soils under cropping systems involving tuber crops in AEU 3 and AEU 9 of .Kerala. *Journal of Root Crops*, **45**(2), 33–41.

Anju, P.S., Susan John, K., Bhadraray, S., Suja, G., Jeena Mathew, Nair, K.M., Sunitha, S. and Veena, S.S. 2020. Customized fertilizer formulations for elephant foot yam (*Amorphophallus paeoniifolius* (Dennst.) Nicolson) under intercropping in coconut gardens of Kerala, India. *Journal of the Indian Society of Soil Science,* **68**(2): 221-235.

Bhaskaran, M.N. and Subhramanyam, S.V.S. 2011. Marketing strategy for customized and innovative specialty fertilizers. *Indian Journal of Fertilizers,* **7**(9): 70-76.

Bhuiyan, N.I., Shaha, A.L. and Panaullah, G.M. 1991. Effect of NPK fertilizer on the grain yield of transplanted rice and soil fertility long term study. *Bangladesh Journal of Soil Science*, **22** (1&2): 41-50.

Chowdhury T., Ayam, G.P., Gupta, S.B., Das, G.K. and Pradhan, M.K. 2007. Internal nutrient supply capacity of Vertisols for rice in Chhattisgarh agro-climatic conditions of India, *Bangladesh. Journal of Agricultural Research,* **32**: 501-507.

Das, K., Medhi, D.N. and Guha, B. 2003. Application of crop residues in combination with chemical fertilizers for sustainable productivity in rice (*Oryza sativa*) wheat (*Triticum aestivum*) system. *Indian Journal of Agronomy*, **48**(1): 8-11.

Dobermann, A., Witt, C., Abdulrachman, H.C., Gines, R., Nagarajan, T.T., Son, P.S., Tan, G.H., Wang, N.V., Chien, V.T.K., Thoa, C.V., Phung, P., Stalin, P., Muthukrishnan, V. Ravi, V., Babu, G.C., Simbahan, M.A., Adviento, M. and Bartolome, V. 2003. Estimating indigenous nutrient supplies for site-specific nutrient management in irrigated rice. *Journal of Agronomy*, **95**: 924-935.

Dwivedi, S.K., Meshram, M.R. and Pandey, N. 2014. Response of customized fertilizer on wheat (*Triticum aestivum*) under Chhattisgarh condition. *The Bioscan,* **9**(4): 1509-1512.

Farm Guide, 2023. Agriculture Development and Farmers' welfare Department, Government of Kerala, 269 pp.

Goud, B.R. 2012. Effect of customized fertilizers on the productivity of finger millet (*Eleusine coracana* (L.) gaertn.) *M.Sc. Thesis*, Department of Agronomy, University of Agricultural Sciences, GKVK, Bangalore.

Goswami, R. 2007. Response of wheat (*Triticum aestivum*) to nitrogen and zinc application. *Annual Agricultural Research*, **28**(1): 90-91.

Hong, S.Y., Zhang, Y.S., Hyun, B.K., Sonn, Y.K., Kim, Y.H., Jung, S.J., Park, C.W., Song, K.C., Jang, B.C., Choe, E.Y., Lee, Y.J., Ha, S.K., Kim, M.S., Lee, J.S., Jung, G.B., Ko, B.G. and Kim, G.Y. 2009. An introduction of Korean soil information system. *Korean Journal of Soil Science and Fertilizers,* **42**: 21-28.

Hu, J. 2018. Human alteration of the nitrogen cycle and its impact on the environment. *Journal of Physics Conference Series: Earth and Environmental Science,* 178.

Hunter, A.H. 1980. *Laboratory and green house techniques for nutrient survey to determine the soil amendments required for optimum plant growth*. Mimeograph. Agro Service International (ASI), Florida, USA, 91p.

IPNI. 2014. 4 R Plant Nutrition: A Manual for improving the management of plant nutrition, International Plant Nutrition Institute.

Irfan, M., Singh, B.N. and Singh, R.G. 2017. Effect of moisture regime and customized fertilizer on water use efficiency and economics of potato (*Solanum tuberosum* L.). *International Journal of Current Science and Applied Microbiology*, **6**(3): 2215-2220.

Janssen, B.H., Guiking, F.C.T., Van der Eijk, D., Smaling, E.M.A., Wolf, J. and Van Reuler, H.1990. A system for quantitative evaluation of the fertility of tropical soils (QUEFTS). *Geoderma*, **46**: 299-318.

Jayaraman, S., Chalabi, Z., Perel, P., Guerriero, C. and Roberts, I. 2010. The risk of transfusion transmitted infections in sub Saharan Africa. *Transfusion,* **50**: 433-441.

Kalra, N., Bhadraray, S. and Manish, S. 2011.'Customized Fertilizer' for holistic crop nutrition solution: Case study of Western Uttar Pradesh. *In:Proceedings of International School Choice and Reform Conference*, 240-246 pp.

Kamble, B.M. and Kathmale, D.K. 2015. Effect of different levels of customized fertilizer on soil nutrient availability, yield and economics of onion. *Journal of Applied and Natural Science***,** **7**(2): 817–821.

KAU, 2012. Kerala Agricultural University (KAU). Adhoc recommendations for management of secondary and micronutrients in Kerala*,* Thrissur, Kerala, India.

Khatun, A. and Saleque, M.A. 2010. Farmers' participatory field specific nutrient management in tidal flooded soil for HYV AUS rice. *Bangladesh Journal of Scientific Research,***23**(1): 73-80.

KSPB, 2013. Kerala State Planning Board (KSPB). *Soil fertility assessment and information management for enhancing crop productivity in Kerala.* P. Rajasekharan, K.M. Nair, G. Rajasree, P. Suresh Kumar and M.C. Narayan Kutty (eds.), Kerala State Planning Board, Thiruvananthapuram, Kerala, India.

Mandal, D., Mandal, S. and Chattopadhyay, G.N. 2004. Soil test based management of nutrient stress for rice cultivation in red and lateritic soils. *Indian Agriculturist,* **48**(1&2): 15-18.

Mahajan, G., Pandey, R.N., Datta, S., Kumar, D., Sahoo, R. and Parsad, R. 2013. Soil test based fertilizer recommendation of nitrogen, phosphorus and sulphur in wheat (*Triticum aestivum* L.) in an alluvial soil. *International Journal of Agriculture, Environment and Biotechnology,* **6**: 271-281.

Nair, P.G. and Mohankumar, C.R. 1991. Dry matter accumulation and nutrient concentration in *Amorphophallus campanulatus* at different stages of growth as influenced by NPK nutrition. *Journal of Root Crops,* **17**: 158-160.

Ramamoorthy, B., Narasimham, R.L. and Dinesh, R.S. 1967. Fertilizer Application for specific yield targets on Sonora 64 (Wheat). *Indian Farming,***17**(5): 43-45.

Ravi, V., Ravindran, C.S. and Suja. G. 2009. Growth and productivity of elephant foot yam (*Amorphophallus paeoniifolius* (Dennst.) Nicolson): An Overview. *Journal of Root Crops,* **35**: 131-140.

Ray, P.K., Jana, A.K., Maitra, D.N., Saha, M.N., Chaudhury, J., Saha, S. and Saha, A.R. 2000.

Fertilizer prescriptions on soil test basis for jute, rice and wheat in Typic Ustochrept. *Journal of Indian Society of Soil Science,* **48**: 79-84.

Reddy, M.G.B., Hebbera, M., Patil, V.C. and Patil, S.G. 2009. Response of transplanted rice to level and timing of NPK application, effect of growth, grain yield and economics. *Asian Journal of Soil Science,* **4**(2): 248-253.

Sharshar, M.S. and Said, A.S.E. 2000. Evaluation of some wheat cultivars and lines under low and high inputs. *Journal of Agricultural Sciences,* **25**(6): 3109-3127.

Shekhon, B.S., Kaur, S. and Singh, P. 2012. Evaluation of a customized fertilizer on wheat. *Indian Journal of Ecology,* **39**(1):71-75.

Selvakumari, G., Santhi, R. and Natesan, R. 2001. Fertilizer recommendations based on STCR technology for the State of Tamil Nadu. *In:* P. Subba Rao and S. Srivastava (Eds.). *Soil Test based Fertilizer Recommendations for Targeted Yields of Crops*. All-India Coordinated Research Project for Investigations on Soil Test Crop Response Correlation. Indian Institute of Soil Science, Bhopal, Madhya Pradesh, 267-297 pp.

Singh, O., Kumar, S. and Awanish. 2012. Productivity and profitability of rice as influenced by high fertility levels and their residual effect on wheat. *Indian Journal of Agronomy*, **57**(2): 143-147.

Singh, V. 2006. Productivity and economics of rice (*Oryza sativa*) wheat (*Triticum aestivum*) cropping system under integrated nutrient management cropping system supply system in recently reclaimed sodic soil. *Indian Journal of Agronomy*, **51**(2): 81-84.

Singh, S., Kushwaha, B.P., Nag, S.K., Mishra, A.K., Bhattacharya, S., Gupta, P.K. and Singh, A. 2011. *In vitro* methane emission from Indian dry roughages in relation to chemical composition. *Current Science*, **101**(1): 57-65.

Sreelatha, A. K., Ravindran,C. S. and Kabeerathumma, S. 1999. Fertilizer recommendation based on soil tests for targeted yield of sweetpotato *Tropical Tuber Crops: in Food Security and Nutrition* C. Balagopalan, T.V.R. Nayar, S. Sundaresan, T. Premkumar and K.R. Lakshmi (eds.), Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi, 328–330 pp.

Suganya, S. and Manickam, S. 2016. Soil test crop response based on integrated plant nutrient supply for cassava in a Typic Rhodustalf of Tamil Nadu for sustainable livelihood. *Journal of Root crops,* **42**(2): 39-43.

Sung, J., Yejin, L., Hyenjung, C.Y. and Jongsik, L. 2016. Effect of customized fertilizer application and soil properties on amino acids composition in rice grain. *Korean Journal of Soil Science and Fertilizers,* **48**(5): 464-468.

Susan John, K., Ravindran, C.S. and James George. 2005. *Long term fertilizer experiments:Three decades experience in cassava. Technical bulletin Series No. 45*, Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, 83 p.

Susan John K., Ravindran, C.S., Suja, G. and Prathapan, K. 2010. Soil test based fertilizer cum manurial recommendation for cassava growing soils of Kerala. *Journal of Root Crops,* **36***(*1*):* 44-52.

Susan John, K., Remya Raj, R.T. and Suja, G. 2013. Dolomite: the best soil ameliorant for tannia in an Ultisol of Kerala. *Indian Journal of Fertilizers,* **9**: 44-55.

Susan John, K., Anju, P.S., Chithra, S., Shanida Beegum, S.U., Suja, G., Anjana Devi, I.P., Ravindran, C.S., James George, Sheela, M.N., Ravi, V., Manikantan Nair, M., Pallavi Nair, K. and Remya, D. 2019. Recent Advances in the Integrated Nutrient Management (INM) Practices of Tropical Tuber Crops. *Technical Bulletin Series No.75*, ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, India, 68 p.

Susan John, K., Venugopal, V.K. and Saraswati, P. 2007. Yield maximization in cassava through a systematic approach in fertilizer use. *Communications in Soil Science and Plant Analysis*, **38**(5&6):779-794.

Swadija, O.K. and Sreedharan, C. 1998. Fertilizer prescription equation for targeted yields of cassava in laterite soil. *Journal of Root Crops,* **24**(2): 137-142.

Tittonell, P. 2014. Ecological intensification of agriculture sustainable by nature. *Current Opinion and Environmental Sustainability,* **8**, 53–61.

Vikas K., Vimal, K.S., Pankaj, K. and Chaudhary, A. 2016. A study of customized fertilizer on wheat. *Agriways,* **4**(2): 132-137.

Wanyama, I., Ochwoh, V.A., Nankya, E. and Van Asten, P.J.A. 2015. Optimization of major nutrients (N, P and K) for low land rice production in Eastern Uganda: *Journal of Agronomy and Agricultural Research***, 7(**2): 218-227.

Xu, X.P., He, P., Pampolino, M.F., Johnston, A.M., Qiu, S.J. and Zhao, S.C. 2014. Fertilizer recommendation for maize in China based on yield response and agronomic efficiency. *Field Crops Research,* **157**: 27–34.

Tuber Crops for ………………..
Food, Health, Wealth and Prosperity

ICAR-Central Tuber Crops Research Institute
Sreekariyam, Thiruvananthapuram 695 017, Kerala, India
Phone: (91) (471) 2598551 to 2598554
E-mail: director.ctcri@icar.gov.in
Website: https://www.ctcri.org