SUSTAINABLE CASSAVA PRODUCTION AND SOIL PRODUCTIVITY THROUGH SOIL-BASED NUTRIENT MANAGEMENT: EXPERIENCE FROM A LONG TERM FERTILIZER EXPERIMENT AND FIELD VALIDATION TRIAL IN AN ULTISOL OF KERALA, INDIA

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ABSTRACT

Fertilizer recommendations based on soil nutrient availability and crop needs is one of the methods to increase the fertilizer use and economic efficiency. Soil nutrient availability is usually determined through soil testing, which provides information on the fertilizer requirement of a crop for that nutrient to achieve the crop production goal in addition to maintaining environmental quality.

Cassava is a crop grown by resource-poor farmers with low inputs and the traditional practice of continuous application of manures and fertilizers, which has resulted in a considerable build-up of nutrients like P without significant increases in yield and quality of roots. An effort was therefore made to study the effect of application of manures and fertilizers based on the actual soil nutrient status under the long-term fertilizer experiment underway at ICAR-CTCRI since 1977. In the third phase of this long-term experiment, which was initiated in 2004, a soil test-based fertilizer recommendation (STBF) treatment was included. In this treatment, manure and fertilizer applications varied yearly as their requirements were based on the status of organic carbon and available N, P and K to determine the requirement of N, P and K fertilizers and FYM (farmyard manure). The recommendation of FYM and NPK were evolved based on the above criteria, and in this paper the effect of this treatment for six consecutive years on root yield, root quality parameters, such as starch, cyanogenic glucosides and total dry matter production, as well as soil nutrient status, this is pH, organic carbon, available N, P, K, Ca, Mg, Fe, Cu, Mn and Zn and total plant uptake for the above nutrients were studied by following standard analytical procedures.

The long-term fertilizer experiment was conducted in a typic kandiustult (laterite) with a pH of 4.5-5, medium in organic carbon, while available N and K were low and P was high. For this paper, the STBF treatment was compared with the current standard recommendation known as the Package of Practices (POP), in which NPK was applied at the rate of 100:50:100 kg N, P_2O_5 and K_2O/ha, along with FYM at 12.5 t/ha. The STBF treatment varied from year to year as it was based on soil test data for each of the six years (2005-2010), but on average it consisted of the application of FYM at 8.3 t/ha and NPK at 89:0:67 kg/ha.

The scientific information generated on the superiority of STBF over POP was validated in farmers' fields in two districts of Kerala at 13 locations involving 17 farmers with a mean level of NPK of 80:7:70 kg/ha and FYM at 7 t/ha. The root yield data clearly indicated that, STBF was as effective in increasing yields as POP during all years except in 2007. Due to the lower levels of fertilizers and manures used, the benefit cost ratio was found higher for STBF compared to other treatments. In the case of quality attributes and total plant nutrient uptake, no significant difference was seen, but the quality traits, such as cyanogenic glucosides and starch were found improved by

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the use of STBF. The nutrient status of the soil also followed the same trend with organic carbon and available P registering a significantly lower level without a significant reduction in root yield, suggesting the need to apply fertilizers and manures based on soil nutrient availability.

Hence, the present study will be of immense application from the farmers' point of view to sustain yield, to maintain quality of the produce, to improve the nutrient use efficiency, to increase the farmers' income and to safeguard the environmental quality. Since fertilizer is one of the principle means to achieve global food security, the underlying principles of fertilizer management to use it efficiently and responsibly need to be practiced in all crops and cropping systems to optimize crop productivity as well as to maintain environmental quality

Key words: Root yield, root quality, soil test-based fertilizer recommendation, B:C ratio, secondary and micronutrients

INTRODUCTION

Root and tubers constitute the third most important food crops of man after cereals and grain legumes. They form either the staple or subsidiary food for about one fifth of the world population. They have a higher biological efficiency, and yield as much as 15-50 t/ha. They also have the ability to withstand adverse weather conditions and capacity to yield rather well in poor and marginal soils. These attributes make these crops ideal for cultivation in the less developed and developing countries of Asia, Africa and Latin America. In these countries, they are increasingly valued as a source of income and employment, besides being a food security crop. Globally, cassava is cultivated in an area of 20.73 million ha with a production of 276.72 million tonnes with an average yield of 13.35 t/ha. In India, the crop is grown in an area of 0.21 million ha with a production of 7.24 million tonnes and an average yield of 34.96 t/ha (FAO, 2013). In Kerala, cassava is the secondary staple with an annual production of 2.547 million tonnes from an area of 74,000 ha with a productivity of 34.42 t/ha (Farm Guide, 2014). As the world average cassava yield is only 13.5 t/ha, it is important to develop more effective cultivation technologies for increasing the productivity. Low soil fertility is one of the main constraints in cassava production and the elimination of all soil fertility constraints was estimated to increase cassava yields by 22% in Asia and 21% globally (Henry and Gottret, 1996). There is considerable scope for increasing cassava yields through better nutrient management since it is a crop that responds well to the application of manures and fertilizers.

The primary aim of agriculture is to maximize food production while maintaining the quality of our soil, water and environmental resources. Soil quality, and especially soil fertility is the key component which can be assessed through soil testing. Fertilizer recommendations based on soil nutrient availability and crop needs is one of the methods to enhance nutrient use efficiency. Colwell (1967) emphasized the importance of soil analyses to provide information on fertilizer requirements. As such, an attempt was made to develop manure and fertilizer recommendations for the major cassava growing soils of Kerala based on the fertility status of these soils and to demonstrate to the farmers the environmental and economic benefits of soil test-based fertilizer recommendations (STBFR) over the existing blanket recommendation known as the Package of Practices (POP).

MATERIALS AND METHODS

In order to develop the fertilizer recommendation based on soil and plant test data, the following methodologies/activities were undertaken:

1. Evaluation of the nutrient status of the soil

The fertilizer and manure recommendation based on soil test and plant tissue analysis data was arrived at based on the evaluation of the status of organic carbon, available P, K, Mg and Zn of the soils of the major cassava growing districts of Kerala State. They are briefly summarized below.

a. Rapid appraisal of the nutrient status of cassava growing soils of Kerala

The Central Tuber Crops Research Institute (CTCRI) in Thiruvananthapuram, Kerala, under the Indian Council of Agricultural Research (ICAR), conducted a random survey to evaluate the nutrient status of the major cassava growing soils of Kerala in order to develop fertilizer and manure recommendations based on soil data. Hence, districts having more than 5000 ha of cassava cultivation were selected for the study. In each selected district, the major blocks (sub districts) growing cassava and in each selected block, the main panchayats (villages) where cassava is a main crop were identified. In each panchayat, the agricultural officers were contacted and farmers were chosen. A total of 226 soil samples were collected at a depth of 0-20 cm representing 104 uplands/garden lands and 122 lowlands/wet lands.

b. Evaluation of the nutrient status of the soil used for growing cassava and the nutrient concentration in the cassava plants

CTCRI, in collaboration with Kerala State Land Use Board (KSLUB), evaluated the soil fertility status of the nine major cassava growing districts of Kerala. Soil samples were collected from the identified farmers' fields by KSLUB. Similarly, cassava tissue samples were also collected from the index leaf tissue, which is the youngest fully expanded leaf (YFEL) blade at 3-4 months after planting (MAP).

c. Long-term fertilizer experiment at CTCRI

A long-term fertilizer experiment had been initiated at ICAR-CTCRI in 1977 and the third phase of this experiment was started in 2004. In this phase, a soil test-based fertilizer recommendation (STBFR) treatment was included based on the annual collection and analyses of soil samples taken from the respective plots at a depth of 0-20 cm.

The soil samples collected from the selected farmers' fields and experimental plots were analyzed for pH using 1:2.5 soil:water suspension (Jackson, 1973). Available nitrogen (N) and phosphorus (P) were estimated by the alkaline permanganate method (Subbiah and Asija, 1956), and the molybdenum blue color method (Bray No.1) extract (Bray and Kurtz, 1945), respectively. Available potassium (K), calcium (Ca) and magnesium (Mg) were determined by extraction with neutral 1N ammonium acetate and direct reading in a flame photometer (Hanway and Heidal, 1952). Available sulfur (S) was determined by calcium chloride ($CaCl_2$) extraction followed by turbidimetric estimation (Tabatai, 1982). Of the micronutrients, iron (Fe), copper (Cu), manganese (Mn) and zinc (Zn) were determined by diethylene triamine-penta-acetic acid (DTPA) extraction (Lindsay and Norvell, 1978) followed by reading in an atomic absorption spectrophotometer (Analyst 100). The nutrient contents of the index leaf tissue were determined by di-acid digestion followed by standard procedures (Piper, 1970).

2. Criteria for categorization of the soil based on soil and plant analysis data

The soil samples collected were categorized based on different approaches:

a. General rating

For classification of soil into different fertility classes, the general rating proposed by Dev (1997) and Motsara (2002) were adopted and is given in **Table 1**.

Table 1. General rating of soils based on nutrient status as determined by the methods described above.

Nutrient	Low	Medium	High	Deficient	Sufficient	Reference
Organic carbon (%)	<0.5	0.5-0.75	>0.75	-	-	Dev (1997)
Available N (kg/ha)	<280	280-560	>560			Dev (1997)
Available P (kg/ha)	<10	10-25	>25	-	-	Dev (1997)
Available K (kg/ha)	<110	110-280	>280	-	-	Dev (1997)
Exchang. Ca (meq/100 g)	-	-	-	<1.5	≥1.5	Dev (1997)
Exchang. Mg (meq/100 g)	-	-	-	<1.0	≥1.0	Dev (1997)
Available Fe (ppm)	-	-	-	<4.0	4-6	Motsara (2002)
Available Cu (ppm)	-	-	-	<0.2	≥0.2	Motsara (2002)
Available Mn (ppm)	-	-	-	<3.00	≥3.00	Motsara (2002)
Available Zn (ppm)	-	-	-	<0.6	≥0.6	Motsara (2002)

b. Computation of soil nutrient index

The soil nutrient index (SNI), as suggested by Parker *et al*. (1951), was calculated by giving weights to the number of samples falling in low, medium and high fertility classes following the formula:

$$SNI = \frac{(Nl x 1) + (Nm x 2) + (Nh x 3)}{Nt}$$

where Nl, Nm, Nh and Nt are the number of samples in low, medium, high fertility classes and total number of samples, respectively. Based on the SNI computation, organic carbon, available N, P and K status were rated as low (<1.67), medium (1.67-2.33) and high (>2.33). The available N is based on the organic C status.

c. Classification based on soil nutritional requirements of cassava

According to Howeler (1996), the soils can also be classified based on the soil nutritional requirement for cassava as shown in **Table 2**.

Table 2. Approximate classification of soil chemical characteristics according to the nutritional requirements of cassava.

Soil parameter	Very low	Low	Medium	High	Very high
pH[1)]	<3.5	3.5-4.5	4.5-7	7-8	>8
Organic matter (%)[2)]	<1.0	1.0-2.0	2.0-4.0	>4.0	-
P (ppm)[3)]	<2	2-4	4-15	>15	-
K (meq/100 g)[3)]	<0.10	0.10-0.15	0.15-0.25	>0.25	-
Ca (meq/100 g)[3)]	<0.25	0.25-1.0	1.0-5.0	>5.0	-
Mg (meq/100 g)[3)]	<0.2	0.2-0.4	0.4-1.0	>1.0	-
S (ppm)[3)]	<20	20-40	40-70	>70	-
Cu (ppm)[4)]	<0.1	0.1-0.3	0.3-1.0	1-5	>5
Mn (ppm)[4)]	<5	5-10	10-100	100-250	>250
Fe (ppm)[4)]	<1	1-10	10-100	>100	
Zn (ppm)[4)]	<0.5	0.5-1.0	1.0-5.0	5-50	>50

[1)] pH in H_2O. 1:1
[2)] OM = Walkley and Black method.
[3)] P in Bray II; K, Ca and Mg in 1N NH_4-acetate; S in Ca phosphate.
[4)] Cu, Mn, Fe and Zn in 0.05 N HCl+0.025 N H_2SO_4.

d. Classification based on plant nutritional requirements of cassava

The nutrient concentration in the indicator tissue, that is the youngest fully-expanded leaf (YFEL) blades at 3-4 months after planting, was taken as the criteria to evaluate the nutritional status of the cassava plants according to the classification of Howeler (1996), which is shown in **Table 3**.

Table 3. Nutrient concentrations in YFEL blades of cassava at 3-4 months after planting.

	Nutritional status					
Nutrient	Very deficient	Deficient	Low	Sufficient	High	Toxic
N (%)	<4.0	4.1-4.8	4.8-5.1	5.1-5.8	>5.8	-
P (%)	<0.25	0.25-0.36	0.36-0.38	0.38-0.50	>0.50	-
K (%)	<0.85	0.85-1.26	1.26-1.42	1.42-1.88	1.88-2.40	>2.40
Ca (%)	<0.25	0.25-0.41	0.41-0.50	0.50-0.72	0.72-0.88	>0.88
Mg (%)	<0.15	0.15-0.22	0.22-0.24	0.24-0.29	>0.29	-
S (ppm)	<0.20	0.20-0.27	0.27-0.30	0.30-0.36	>0.36	-
Cu (ppm)	<1.5	1.5-4.8	4.8-6.0	6-10	10-15	>15
Fe (ppm)	<100	100-110	110-120	120-140	140-200	>200
Mn (ppm)	<30	30-40	40-50	50-150	150-250	>250
Zn (ppm)	<25	25-32	32-35	35 -57	57-120	>120

3. Development of fertilizer recommendation based on soil test and plant tissue analysis

a. Major nutrients (N, P and K)

The blanket recommendation according to the Package of Practices (POP) for cassava is NPK at 100:50:100 kg/ha plus FYM at 12.5 t/ha. In the case of fertilizer recommendations based on soil test data in Kerala, the methodology proposed by Aiyer and Nair (1985) is followed for all crops and is given in **Table 4**.

Table 4. Soil fertility classes and N, P, K recommendation for each class as per cent of the general recommendation.

Soil fertility class	Organic carbon (clayey/loamy soil) (%)	Recommendation of N as % of general (POP) recommendation	Available P (kg/ha)	Exchangeable K (kg/ha)	Recommendation of P and K as % of general (POP) recommendation
0	0.00-0.16	128	0.0-3.0	0-35	128
1	0.17-0.33	117	3.1-6.5	36-75	117
2	0.34-0.50	106	6.6-10.0	76-115	106
3	0.51-0.75	97	10.1-13.5	116-155	94
4	0.76-1.00	91	13.6-17.0	156-195	83
5	1.01-1.25	84	17.1-20.5	196-235	71
6	1.26-1.50	78	20.6-24.0	236-275	60
7	1.51-1.83	71	24.1-27.5	276-315	48
8	1.84-2.16	63	27.6-31.0	316-355	37
9	2.17-2.50	54	31.1-34.5	356-395	25

b. *Organic manure (FYM), secondary nutrient (Mg) and micronutrient (Zn) recommendations based on soil test data*

Based on the results obtained in the long-term fertilizer trial conducted at ICAR-CTCRI since 1990, the rate of application of Mg as magnesium sulfate ($MgSO_4$), Zn as zinc sulfate ($ZnSO_4$), and organic manure as farm yard manure (FYM), were standardized based on the data on root yield, soil nutrient status, plant nutrient concentration, their critical levels and nutritional requirements (Susan John *et al*., 2010) as shown in **Table 5**.

Table 5. Rate of application of FYM, Mg and Zn for cassava based on soil nutrient status.

Organic carbon (%)	Rate of application of FYM (t/ha)	Soil status of Mg (meq/100 g)	Rate of application of $MgSO_4$ (kg/ha)	Soil status of Zn (ppm)	Rate of application of $ZnSO_4$ (kg/ha)
<0.50	12.50	0-0.25	20	<0.2	12.5
0.5-0.75	10.00	0.25-0.50	15	0.2-0.3	10
0.75-1.00	7.50	0.50-0.75	10	0.3-0.4	7.5
1.00-1.50	5.00	0.75-1.00	5	0.4-0.6	5
>1.50	2.50	>1.00	2.5	>0.6	2.5

4. Field validation of the soil test-based fertilizer recommendation

The validation and demonstration of soil test-based fertilizer recommendations was undertaken through a State Horticulture Mission (SHM) funded project during 2007-2009 in 13 locations of the two selected districts of Kerala, this is Kollam and Pathanamthitta involving 17 farmers in an area of 5.28 ha. Soil samples collected before laying out the trial from these locations were analyzed for organic carbon, available P, K, Mg and Zn following standard analytical procedures (Jackson, 1973). The rate of application of N, P and K was determined following the earlier procedure of Aiyer and Nair (1985) and in the case of FYM, Mg and Zn as per Susan John *et al.* (2010) shown in **Tables 4** and **5**, respectively. The validation trials consisted of five treatments as follows:

T1- Farmer's practice

T2- Package of Practices (POP) recommendation for cassava (NPK at 100:50:100 kg/ha plus FYM at 12.5 t/ha)

T3- Application of FYM+ NPK and Mg based on soil test data

T4- Application of FYM+ NPK and Zn based on soil test data

T5- Application of FYM+ NPK based on soil test data

Root yields and root quality parameters, that is cyanogenic glucosides (Indira and Sinha, 1969), root starch (Chopra and Kanwar, 1976) and dry matter contents were determined. The economics of STBFR with and without the application of Mg and Zn was also computed by calculating parameters like gross income, production costs, net income and B/C ratios.

RESULTS AND DISCUSSION

The results obtained under the different activities on nutrient requirements, that is the assessment of the fertility status of the soil, the recommendation arrived at based on soil and plant analytical data, and the impact of STBFR in comparison to POP on yield in the on-station replicated long-term fertilizer experiment at CTCRI, and in the validation trials in different farmers' fields are briefly discussed below.

1. Evaluation of the nutritional status of cassava growing soils of Kerala

The rapid appraisal of the nutrient status of nine major cassava growing districts, conducted by ICAR-CTCRI, indicated wide variation in all the soil chemical characteristics including primary, secondary and micronutrient status, although there was not much difference between the upland and lowland soils within the same district. Both upland and lowland soils were acidic in soil reaction with mean pH values of 4.65 and 4.76, respectively. There are several reports indicating that, the soils of Kerala are acidic belonging to laterite soil type where cassava is a suitable crop as it is tolerant to high levels of aluminium (Al) and Mn and low levels of Ca, N and K (Nair *et al*., 2007; Natarajan *et al*., 2005; Soil Survey Organization, 2007).

With respect to the general rating, the evaluation of the nutrient status of the soils indicate that, the soil organic carbon status of the different districts ranged from low to high with a mean high status for the State, and the available N status was low to medium in the different districts with a mean low status for the State. The available P was high in 90-95% of the surveyed area indicating a very high content for the State as a whole, while the exchangeable K of the soils in the different districts ranged from low to high with a mean medium status for the State as a whole (Susan John *et al.,* 2009a). The exchangeable Ca content of the surveyed districts ranged from 0.52-2.06 meq/100 g with a mean value of 1.12 meq/100 g. However, in 75% of the appraised districts based on the general soil critical level (1.5 meq/100 g), the status was not sufficient. As regards to the exchangeable Mg status, the content ranged from 0.23-1.96 meq/100 g with a mean value of 0.90 meq/100 g, which was slightly below the critical level of 1 meq/100g. The status was sufficient in 50% of the surveyed districts according to the general critical level of 1 meq/100 g for Indian soils. In the case of micronutrients, that is Fe, Cu, Mn and Zn, based on the general critical levels, they were sufficient in 100% of the surveyed districts (Susan John *et al*., 2009b).

In the case of soil samples collected by KSLUB in collaboration with ICAR-CTCRI, the general rating indicated that, the nine districts belonged to the moderately acidic class (4.5-5.5) with organic carbon ranging from medium to high in 90% of the districts. The available N status of all the nine districts was low, but the P status was found high. Though the available K status of the cassava growing soils of Kerala in general was medium, the districts ranged from low to medium in available K except in a few districts where it was high, in a range of 0.35-0.62 meq/100 g. The exchangeable Ca status in all the districts was sufficient having values above the critical level. The available Mg status of the soils in all the districts was low. The S status was also found high in all these districts, with values well above the general critical level of 5 ppm for Indian soils, as determined with $CaCl_2$, which is different from the methods used in the classification shown in **Table 2**. The micronutrient status of the soils of all these districts was satisfactory with their status well above their respective critical levels (**Table 6**).

Regarding the computed Soil Nutrient Index (SNI), the cassava growing soils of Kerala were found to be medium in organic carbon (2.02) and K (2.12), low in N (1.37) and high in P (2.41). The SNI for organic carbon ranged from 1.17-3.00 with a mean value of 2.02, indicating that 56% of the surveyed area was considered high, 33% medium and 11% low. The SNI for available N was in the range of 1-2 for the uplands and lowlands of the different districts with 72% of the surveyed area belonging to low and 28% of the area in the medium category. In the case of available P, the SNI indicated a range of 2-3 with a mean value of 2.41, with 61% of the surveyed area considered to be in the high and 39% in the medium category. The SNI for exchangeable K had a value of 1-3 for the different districts with a mean value of 2.12, with 11, 50 and 39% of the surveyed area found to be in the low, medium and high classes, respectively (Susan John *et al.,* 2009a). In the case of all these nutrients, the high status was encountered mainly in the high altitude areas of Kerala, like in the districts of Kottayam, Idukki, Palakkad and Pathanamthitta, which can be attributed to their cropping history of rubber plantations. The shedding of their leaves may have contributed to the high nutrient status of the soils, which in turn may have favored cassava growth and productivity (Joseph *et al.,* 1990; Karthikakuttyamma *et al*., 1991). Since cassava requires soils rich in organic matter with high contents of basic cations for both root yield and quality, the soils of Kottayam, Idukki, Palakkad and Pathanamthitta were found to be the best for growing cassava (Susan John *et al.,* 2009a).

ICAR-CTCRI in collaboration with the Kerala State Land Use Board evaluated the soil fertility status of the nine major cassava growing districts of Kerala and these were categorized based on the soil and plant nutritional requirements for cassava as suggested by Howeler (1996). The results are presented in **Tables 6** and **7**. The nutritional status of the soils in these nine districts ranged from very low to high with respect to all nutrients. In all these districts, the soils were medium in soil pH while the organic carbon status ranged from very low to medium, and the available P content was high. In the case of available K, the levels ranged from low to high. Among the secondary nutrients, the exchangeable Ca was medium in all districts, except in three districts, where it was low. The exchangeable Mg status was also in the medium range in all the districts except in two districts where it was low, while the S status of these soils was found very low in all districts, except in one where it was low. As regards to the micronutrient status, Fe was medium, Cu was high, Mn was very low to medium, and Zn was also low to medium. As regards to the overall status of these nutrients for Kerala, the soil pH, available Ca, Mg, Fe, Mn and Zn were medium; organic carbon was low; and P, K and Cu were high.

Table 6. Nutrient contents of the soils in the major cassava growing districts of Kerala.

	pH	OC	N	P	K	Ca	Mg	S	Fe	Cu	Mn	Zn
Districts		%	kg/ha		me/100 g			ppm				
Trivandrum	4.57	0.93	266	35.3	0.24	1.24	0.38	7.65	57.9	3.77	9.2	1.16
Kollam	5.26	1.42	114	58.3	0.15	1.52	0.42	8.22	70.1	2.65	5.7	1.04
Kottayam	5.24	1.49	210	41.5	0.39	2.79	0.53	9.09	37.6	3.70	10.6	2.16
Pathanamthitta	4.51	1.23	226	30.0	0.21	1.01	0.39	6.75	49.8	5.07	14.7	1.04
Alapuzha	5.00	0.55	195	92.3	0.29	0.98	0.80	6.59	56.3	0.99	4.8	0.90
Ernakulam	4.49	1.50	245	67.5	0.13	1.66	0.44	20.16	70.8	3.63	11.9	0.95
Thrissur	5.09	0.66	137	65.5	0.35	1.87	0.76	8.88	46.1	4.38	30.6	1.23
Kozhikode	5.20	0.40	51	93.9	0.15	2.00	0.42	5.65	25.3	1.38	16.6	2.34
Malappuram	5.65	1.68	206	65.5	0.62	2.95	0.84	8.88	48.4	3.30	17.9	2.73
Mean	**5.00**	**1.09**	**183**	**61.1**	**0.28**	**1.78**	**0.55**	**9.10**	**51.4**	**3.21**	**13.6**	**1.50**

Table 7. Nutrient concentrations in the youngest fully expanded leaf blades of cassava at 3-4 months after planting.

	N	P	K	Ca	Mg	S	Cu	Zn	Fe	Mn
Districts	(%)					(ppm)				
Trivandrum	4.79	0.462	1.91	0.33	0.311	0.098	19.06	56.03	643.03	490.00
Kollam	3.70	0.370	1.90	1.16	0.309	0.090	14.10	55.43	208.80	269.50
Kottayam	3.96	0.502	1.76	0.93	0.183	0.096	13.71	57.26	316.17	166.40
Pathanamthitta	4.18	0.448	2.14	0.59	0.287	0.091	12.94	70.06	192.06	340.91
Alapuzha	3.33	0.361	1.65	0.64	0.370	0.087	14.28	44.72	261.03	816.00
Ernakulam	5.13	0.502	2.05	0.48	0.293	0.089	15.65	56.85	218.85	184.35
Thrissur	5.22	0.427	1.99	0.28	0.290	0.089	8.30	57.45	173.55	325.40
Kozhikode	3.49	0.451	1.90	0.40	0.355	0.096	13.00	51.60	217.20	604.80
Malappuram	3.23	0.325	2.68	1.10	0.466	0.130	22.20	58.20	458.39	215.30
Mean	**4.11**	**0.428**	**2.00**	**0.66**	**0.318**	**0.096**	**14.80**	**56.40**	**298.79**	**379.18**

Based on the classification made by Howeler (1996) (**Table 3**), the analyses of the indicator tissue at 3-4 months after planting (**Table 7**), indicates that, in general the concentrations of N and Ca were deficient; P, K, Mg, Cu and Zn were sufficient, and Fe and Mn concentrations were very high or toxic. The unusually low concentrations of S, as compared to the values shown in **Table 3**, may be due to the use of a different analytical procedure. No symptoms of S deficiency have been observed.

2. Soil test and plant tissue analysis based fertilizer recommendation for the major cassava growing districts of Kerala

The usefulness of soil test data as a guide in making fertilizer recommendations was suggested by many researchers (Goswami *et al.*, 1971). But Baker (2008) was of the opinion that, as there is a great variability among soils of different areas, it has not been possible to formulate uniform recommendations for a given soil and crop. Hence, an attempt was made to formulate fertilizer recommendations for the above districts for cassava comprising of farmyard manure, N, P, K and Mg and Zn using the procedures indicated earlier and as shown in **Table 8**.

Table 8. Fertilizer recommendations for nine major cassava growing districts in Kerala State based on soil tests and plant tissue analysis.

Districts	Organic manure	N	P_2O_5	K_2O	$ZnSO_4$	$MgSO_4$
	(t/ha)	(kg/ha)				
Trivandrum	12.0	107	25.0	79	5.0	5.7
Kollam	10.5	125	26.0	104	6.2	10.0
Kottayam	11.5	117	21.0	35	9.0	5.7
Pathanamthitta	12.0	115	28.0	85	3.4	12
Alapuzha	12.0	117	7.0	76	3.6	3.6
Ernakulam	12.5	113	5.0	99	8.0	0
Kozhikode	12.5	125	0	95	0	0
Malappuram	10.0	130	17.5	0	0	0
Thrissur	12.5	110	12.0	48	3.0	5
Mean	**12.0**	**118**	**16.0**	**69**	**4.35**	**4.70**

Compared to the POP recommendation for cassava (FYM at 12.5 t/ha along with chemical NPK fertilizers at the rate of 100:50:100 kg/ha, Mg at 3.2 kg/ha, Zn at 2.5 kg/ha), the STBFR-based recommendation included on average, the application of only 12 t/ha of manure, together with a slightly higher application of 118 kg N/ha, whereas the P, K, Mg and Zn recommendations were lower compared to the blanket POP recommendation. The recommendation indicated that, though the organic carbon status of the soils of the different districts are medium to high, resulting in not much reduction in FYM application, a comparatively high N requirement compared to POP was due to the low inherent status of N in these soils, as evidenced from the results of samples collected from the nine districts both by ICAR-CTCRI and also in collaboration with KSLUB (**Table 6**) as well as the low N content noticed in the indicator leaf tissues. The medium to high available P status in 90% of the surveyed districts suggested the possibility of reducing the application of P as indicated in **Table 8**. This is in conformity with the reports of Nambiar (1994) and Singh *et* *al.* (1998) that, in many long-term fertilizer trials the build-up of P reached a level where no more phosphate application was needed for the next few seasons. The high K content noticed in the soil as well as in the plant tissues resulted also in a lower recommended rate of application of K.

Though the Ca status of these soils were found deficient in more than 50% of the surveyed districts, as the response of cassava to lime application tend to be small due to the fact that, cassava is Al tolerant and Ca efficient (Edwards and Kang, 1978), there is no need to apply lime (Susan John and Venugopal, 2006). In the case of Mg, Howeler (1996) reported 0.2-1.0 meq/100 g to be the adequate range of soil Mg, which makes it likely that in many districts there will be a response to its application. Hence, the data on Mg status of both the soils and plant tissues of the different districts clearly indicated the need to apply $MgSO_4$ in these soils at the rate of 4-12 kg/ha, considerably below the general recommended application of $MgSO_4$ at 20 kg/ha. Susan John *et al.* (2005) reported that cassava absorbs 25-35 kg/ha Mg from the soil, which may cause depletion of both native and applied Mg through plant uptake and leaching.

In the case of Zn, based on the results from the long-term fertilizer experiment, it was recommended to apply $ZnSO_4$ at the rate of 12.5 kg/ha (Susan John *et al*., 2005). The Zn status in the lowland and upland soils of the districts surveyed showed that, these soils contain sufficient Zn, based on the soil critical level of 0.6 ppm as reported by Dev (1997). Hence, the Zn status of the soil indicates that, there is no need for its application. However, taking into account the Zn uptake by cassava at1-2 kg/ha (Susan John *et al*., 2005) and the additional yield gain as well as root quality improvement observed, the recommended rates of Zn application were calculated (**Table 8**). According to Howeler (1996), Zn has to be applied when the soil Zn status ranges from 0.5-5.0 ppm. In this case, based on both soil Zn status and plant Zn concentration, the rate of application of $ZnSO_4$ ranged from 3-9 kg/ha. In a fertilizer recommendation comprising organic manure, major, secondary and micronutrients, the significance of secondary and micronutrients was highlighted by Portch and Stauffer (2005). They suggested that, basing fertilizer recommendations on incomplete analyses, ignoring micro- and secondary-nutrients, may lead to low yields.

3. A comparison of STBFR with POP

In the long-term fertilizer experiment at CTCRI, one treatment using a soil test-based fertilizer recommendation (STBFR) for organic manure, N, P and K has been included since 2004, using the same procedure as in Kerala (Aiyer and Nair, 1985). During the following six years, the organic carbon content of the soil was found to be high (>0.5%), so the recommendation for FYM was reduced to the level of 7.5-10 t/ha with an overall mean value of 8 t/ha. In the case of N and K, the overall average STBFR of 92 and 67 kg/ha, respectively, was lower during all these years compared to POP. Also, the available P status of the soil remained very high, hence its application was completely omitted (**Table 9**).

Comparing the root yields of treatments using POP, STBFR and the absolute control (AC), it is seen that, during all these years, with 100% savings in P fertilizer, 3-9% savings in N, 6-75% savings in K fertilizer and 25% savings in organic manure, the yields obtained using POP or STBF were not statistically different, indicating the need to make fertilizer recommendations for cassava based on the soil's nutrient status. There are several reports showing the significance of balanced fertilizer application including FYM in maintaining high root yields and root quality (Asokan *et al.,* 1988; Susan John *et al*., 1998).

Table 9. Comparison of fertilizer application based on Soil Test-Based Fertilizer Recommendation (STBFR) with the application based on the previously recommended Package of Practices (POP) in the long-term fertilizer experiment at ICAR- CTCRI in Thiruvananthapuram, Kerala.

	Soil test results in the STBF treatment			Soil test-based fertilizer and manure recommendation				Root yield			
Year	Or.C	P	K	FYM	N	P_2O_5	K_2O	POP	STBF	AC	CD
	(%)	kg/ha		t/ha	kg/ha			t/ha			0.05
2004-05	0.706	56.3	145.6	10	97	0	94	22.81	20.41	16.19	2.52
2005-06	0.897	158.1	206.1	7.5	91	0	71	23.80	23.55	17.02	3.09
2006-07	0.915	139.9	233.0	7.5	91	0	71	12.62	15.85	6.58	2.00
2007-08	0.778	80.8	192.6	7.5	91	0	83	30.96	31.06	18.00	3.20
2008-09	0.939	56.5	267.5	7.5	91	0	60	31.02	26.16	13.08	7.93
2009-10	0.931	82.5	400.3	7.5	91	0	25	29.23	26.24	15.93	8.09
Mean	**0.861**	**95.7**	**240.8**	**8.0**	**92**	**0**	**67**	**25.07**	**23.88**	**14.47**	**4.47**

FYM=farmyard manure; POP=Package of Practices, STBF=Soil Test-Based Fertilizer Recommendation, AC=Absolute Control (no fertilizers and manures); CD=coefficient of determination

The change of the soil nutrient status with respect to organic carbon, available N, P and K using either POP or STBFR are shown in **Figures 1, 2, 3** and **4**. It can be seen that, there was a slight to drastic decline in the level of all these nutrients except in the case of available N during two years.

4. Validation and popularization trial for STBFR in cassava

In this demonstration trial, the organic manure and fertilizer recommendations were made based on the initial nutrient status of the soil with respect to organic carbon, available P, K, Mg and Zn. The location and nutrient status of these sites, as well as the soil test-based fertilizer recommendation are presented in **Table 10**.

In general, the soil organic carbon and P levels in these locations of the two districts were found to be very high, whereas the K, Mg and Zn levels were low indicating a recommendation comprising of a comparatively lower rate of application of organic manure and N at about 6 t/ha and 80 kg/ha, respectively, and P at only 7 kg/ha. Since the content of Mg and Zn were found to be very low in these locations (well below their critical levels of 1 meq/100 g and 0.6 ppm for Mg and Zn, respectively), all these locations needed their application at 2.5-20 and 2.5-12.5 kg/ha of Mg- and Zn-sulfates, respectively.

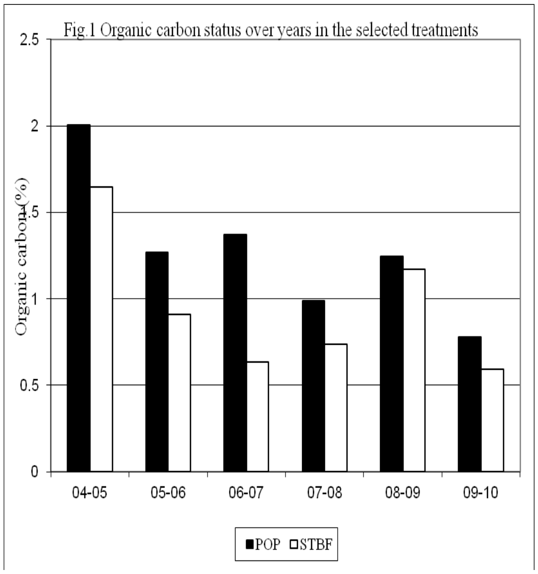

Fig.1 Organic carbon status over years in the selected treatments

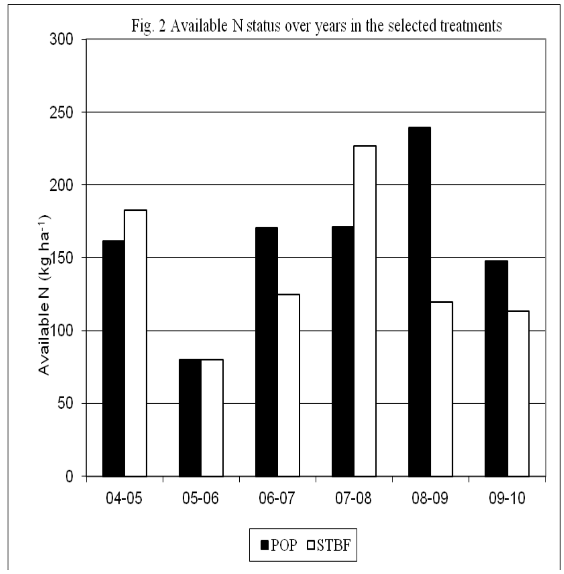

Fig. 2 Available N status over years in the selected treatments

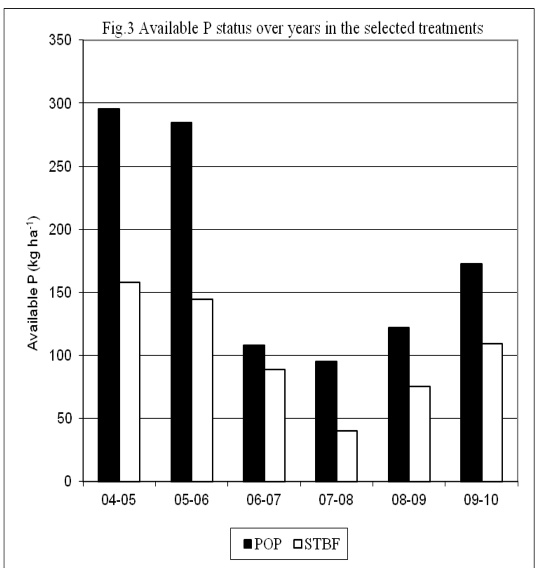

Fig.3 Available P status over years in the selected treatments

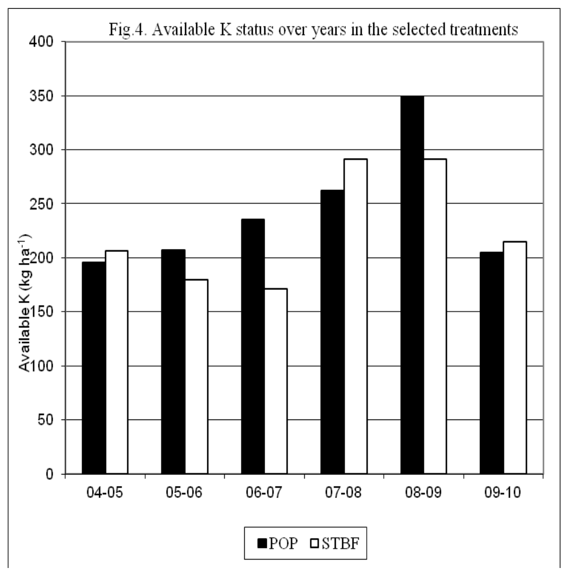

Fig.4. Available K status over years in the selected treatments

The effect of these treatments on cassava root yield and quality parameters, i.e. dry matter, starch and cyanogenic glucosides contents, and economic parameters such as gross income, production costs, net income and B/C ratio were also studied and the average results are shown in **Table 11.**

Table 10. Nutrient status of selected locations and soil test-based fertilizer recommendations.

	Locations	Soil test results					Soil test-based fertilizer recommendations					
I	**Kollam**	OC	P	K	Mg	Zn	FYM	N	P	K	Mg	Zn
1	Sakthikulangara	0.46	58.9	191.2	0.66	0.66	12.5	91	0	83	10	2.5
2	Chadayamangalam	1.92	24.9	212.8	0.62	0.24	5	63	24	71	10	10
3	Kadakkal	1.02	216.2	349.4	0.35	0.57	5	84	0	37	15	5
4	Anchal	1.29	133.4	439.0	0.29	0.37	5	78	0	25	15	7.5
5	Ezhukone	2.40	39.2	78.4	0.48	0.85	5	54	0	106	15	2.5
6	Kalayapuram	1.18	203.2	268.8	0.20	0.24	5	84	0	60	20	10
7	Panaveli	1.14	110.2	185.9	0.36	0.55	5	84	0	83	15	5
8	Pallickal	1.08	123.7	145.4	0.26	0.19	5	84	0	83	15	12.5
II	**Pathanamthitta**											
9	Adoor	1.44	83.0	206.1	2.21	0.25	5	78	0	71	2.5	10
10	Thumpamon	1.02	27.5	199.4	0.51	0.26	5	84	24	71	10	10
11	Thumpamon	1.08	51.2	190.4	0.34	0.58	5	84	0	83	15	5
12	Elanthur	1.56	200.4	306.9	0.49	0.37	5	71	0	48	15	7.5
13	Adoor	0.72	12.6	165.8	0.20	0.86	10	97	47	83	20	2.5
	Mean	**1.26**	**98.8**	**226.1**	**0.54**	**0.46**	**6**	**80**	**7**	**70**	**13.65**	**7.0**

The data in **Table 11** showed that, the soil test-based fertilizer treatment (T4) applied as FYM at the rate of 6 t/ha, NPK fertilizers at 80:7:70 kg/ha, and $ZnSO_4$ at 7 kg/ha resulted in the highest root yield of 42.19 t/ha. This was not significantly different from the soil test-based application of organic manure and NPK fertilizers along with Mg as $MgSO_4$ at 13.65 kg/ha (T3). The soil test based application of FYM at 6 t/ha together with NPK at 80:7:70 kg/ha (T5) resulted in a root yield of 34.63 t/ha, which in turn was statistically equivalent to the POP treatment in which FYM was applied at 12.5 t/ha along with NPK at 100:50:100 kg/ha (T2), which resulted in a yield of 33.18 t/ha. Among the five treatments, the farmers' practice, using mostly organic manures in the form of FYM, bone meal and ash along with chemical fertilizers like Factomphos (NPKS at 20:20:0:15) and potassium chloride, applied in comparatively large quantities, equivalent to NPK of about 125:100:150 kg/ha (T1), resulted in the lowest root yield of 28.95 t/ha. Kamaraj *et al.* (2008) also reported cassava root yield increases by 23-34% through the application of major, secondary and micro-nutrients based on soil test data in two villages of Tamil Nadu. Moreover, balanced nutrient application in pulses – mainly green gram and black gram −

with the required quantity of micronutrients along with macronutrients was found to be an effective way for getting higher grain yields of these crops in red and lateritic soils (Bhattacharya *et al*., 2004), and in rainfed rice in West Bengal (Mukhopadhyay *et al*., 2008), and in sugarcane in Uttar Pradesh (Singh *et al*., 2008). According to Sharma and Biswas (2007), the investments in macronutrients alone will not give the desired results unless the micronutrient deficiencies are corrected. Ghosh *et al*., (2008) in West Bengal also reported the importance of soil test-based nutrient management in a rice-based cropping sequence to attain targeted yields, and they confirmed that compared to state recommended rates, the approach based on soil testing did lead to higher crop yields, net returns and relative agronomic efficiencies.

Table 11. Influence of various soil test-based nutrient management treatments on cassava root yield, root quality and economic parameters.

Treat-ments[1)]	Root yield (t/ha)	Root quality			Economic parameters			
		Dry matter (%)	Starch content (%)	Cyanogenic glucosides (ppm)	Gross income (Rs/ha)	Production costs (Rs/ha)	Net income (Rs/ha)	B:C ratio
T1	28.95	35.53	21.48	56.12	72,365	66,451	5,914	1.09
T2	33.18	35.41	22.96	53.58	89,960	65,512	17,448	1.27
T3	38.84	37.88	23.08	37.88	97,110	60,011	37,099	1.62
T4	42.19	38.03	21.16	34.08	1,05,468	60,343	45,125	1.75
T5	34.63	35.28	21.16	43.62	86,563	59,692	26,871	1.45
CD (0.05)	4.21	0.60	1.11	3.75	-	-	-	-

[1)] T1 = Farmer's Practice: FYM, bone meal and wood ash plus ~125:100:150 kg/ha of $N:P_2O_5:K_20$
T2 = POP: 12.5 t/ha of FYM plus 100:50:100 kg/ha of $N:P_2O_5:K_20$
T3 = STBFR: 6 t/ha of FYM plus 80:7:70 kg/ha of $N:P_2O_5:K_20$ plus 13.65 kg/ha of $MgSO_4$
T4 = STBFR: 6 t/ha of FYM plus 80:7:70 kg/ha of $N:P_2O_5:K_20$ plus 7 kg/ha of $ZnSO_4$
T5 = STBFR: 6 t/ha of FYM plus 80:7:70 kg/ha of $N:P_2O_5:K_20$

As regards to the quality attributes, the root dry matter content was highest with Zn application, which in turn was on par with the additional application of Mg. In the case of the other three treatments, they were on par with respect to dry matter production. Starch content of the roots was highest with Mg (23.08%), which in turn was on par with the POP treatment (22.96%). The effect of all other treatments was similar with respect to starch yield. Application of Zn resulted in the lowest cyanogenic glucoside content of 34.08 ppm followed by the Mg treatment (37.88 ppm). The farmer's practice and POP treatments resulted in the highest levels of cyanogenic glucosides, while this was significantly lower (43.62 ppm) in the roots in the STBFR treatment. This is in agreement with the reports by Yadav (1993) that sugar recovery was higher due to balanced and judicious application of manures and fertilizers based on soil test data in sugarcane.

The economic parameters, such as gross income, total production costs, net income and B:C ratio indicate that, the highest gross income, net income and B:C ratio were obtained with the additional application of Zn (T4) followed by the treatment with Mg (T3). Treatment T5, having a lower level of organic manure and NPK than the POP treatment (T2), resulted in a higher B:C ratio of 1.45 compared to 1.27 in the case of T2 (Susan John *et al*., 2011). All these parameters thus clearly point out the need for changing the present blanket POP fertilizer recommendation to a more need-based recommendation based on soil tests and plant analytical data.

5. Nutrient management plan for agro ecosystems of Kerala

The Department of Agriculture of the Government of Kerala, in collaboration with 14 agricultural governmental institutions involving 27 soil testing laboratories are involved in developing a soil test-based nutrient management plan for 23 agro-ecological units of Kerala. Under this program, analysis of around 150,000 soil samples, out of a total of 225,000 soil samples collected, indicated the deficiencies of secondary nutrients, Ca and Mg, and the micronutrient B. The very high level of organic carbon, P, S and other micronutrients such as Fe, Cu, Mn and Zn was reflected in their respective recommendations indicating the need either to reduce their dose or to omit their use entirely. The nutrient management plan being prepared for the different panchayats, blocks and districts indicated the need to rationalize the existing fertilizer recommendation based on soil and plant analyses. The present nutrient management plan preparation based on soil test data is a web-based agricultural information system with facilities to get information on independent farmer details including the rate, time, type and method of application of soil amendments, organic manures and fertilizers including primary, secondary and micronutrients. The demonstration trials conducted to validate this information supported the need to resort to a soil test-based fertilizer recommendation for cassava so as to avoid the present indiscriminate use of fertilizers so as to minimize the cost of cultivation as well as to maintain soil health.

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