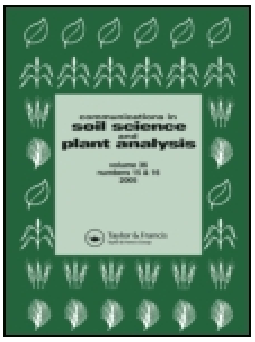

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Soil Test and Plant Tissue Analysis as Diagnostic Tools for Fertilizer Recommendations for Cassava in an Ultisol

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Soil- and plant-based fertilizer recommendations hold promise for increasing farmers' incomes with high-input crops such as cassava. Considering the significance of cassava for the food, nutritional, and economic security of a half billion people globally and the positive response of the crop to fertilizer and manure applications in terms of tuber yield and quality through starch improvement and cyanogenic glucoside reduction, these recommendations were validated and popularized in two districts of Kerala State. Soil and plant samples from nine major cassava-growing districts of Kerala were analyzed for soil reaction, organic carbon, and essential nutrients, which formed the basis for the recommendation. The soil-test-based recommendation [nitrogen (N)–phosphorus (P)–potassium (K)–zinc (Zn) at 82:6.3:68:2 kg ha^{-1} along with farmyard manure (FYM) at 6.25 t ha^{-1}] resulted in the greatest benefit–cost ratio of 1.75 with improvements in tuber and soil quality.

Keywords Field validation trials, major, micronutrients, nutritional requirement, secondary, soil nutrient status, soil-test-based fertilizer recommendation

Introduction

Root and tubers constitute the third most important food crop for humans after cereals and grain legumes. They form either the staple or subsidiary food for about one fifth of the world's population. They have greater biological efficiency and yield of about 15–50 t ha^{-1} with the ability to withstand adverse weather conditions and the capacity to yield 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 m ha, produces 276.72 mt, and has productivity of 13.35 t ha^{-1}, whereas in India it is grown on 0.21 m ha, produces 7.24 mt, and has productivity of 34.96 t ha^{-1} (FAO Stat 2013). In Kerala, cassava is the secondary staple with an annual production of 25.47 lakh tons from an area of 0.74 lakh hectares with a productivity of 34.42 t ha^{-1} (Farm Guide 2014). As regards to the significance of soil fertility in cassava production, the world

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average productivity of cassava is only 13.5 t ha^{-1}, which necessitates highly effective cultivation technologies to enhance the productivity. Low soil fertility is one of the constraints in production, and management of soil fertility can increase cassava yield by 32 percent (Henry and Gottret 1996). There is scope for increasing its productivity through nutrient management because the crop responds well to the application of manures and fertilizers.

The primary aim of agriculture at the dawn of the twenty-first century is to maximize food production and sustain soil, water, and environmental quality. As soil health is directly related to human health, maintenance of soil quality through balanced application of manures and fertilizers is one of the main areas of nutrient-management strategy and is possible through evaluation of soil fertility and assessment of crop demand for nutrients. As regards to soil quality, soil fertility is the key component, which can be assessed through soil testing. Fertilizer recommendations based on soil nutrient availability and crop needs enhance nutrient-use efficiency. Colwell (1967) emphasized the importance of soil testing in relation to crop yield response to provide information on fertilizer requirements. Taking into account various factors including profitability of cassava cultivation, indiscriminate and nonjudicious use of chemical fertilizers, escalating fertilizer prices, and constraints on the availability of fertilizers as well as the hazardous effect of underuse or overuse of fertilizers on environmental health, especially soil health, we attempted to create a manure and fertilizer recommendation for the major cassava-growing soils of Kerala after evaluating the fertility status of these soils and to convince the farmers of the significance of soil-test-based fertilizer recommendation (STBFR) over the existing blanket recommendation.

Materials and Methods

To evolve the fertilizer recommendation based on soil and plant test data, the different methodologies and activities undertaken were as follows.

Evaluation of the Nutrient Status of the Soil

The fertilizer and manure recommendations based on soil test and plant tissue analysis data were based on the evaluation of the status of organic carbon, available phosphorus (P), potassium (K), magnesium (Mg), and zinc (Zn) of the soils of the major cassava-growing districts.

Rapid Appraisal of the Nutrient Status of Cassava-Growing Soils of Kerala. Indian Council of Agricultural Research (ICAR) and Central Tuber Crops Research Institute (CTCRI) conducted a random survey to evaluate the nutrient status of the major cassava-growing soils of Kerala to develop fertilizer and manure recommendations based on soil data. Hence, districts having more than 5000 ha of cassava cultivation as per the statistics available at that time were selected for the study. In consultation with the principal agricultural officers of each selected district, the major blocks growing cassava were identified, and the main panchayats in each block where cassava is a main crop were identified with the help of the assistant directors of agriculture of each selected block. 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.

Evaluation of the Nutrient Status of the Soils Growing Cassava and Nutrient Concentrations in Cassava Plants. ICAR-CTCRI, in collaboration with the Kerala State Land Use Board (KSLUB), evaluated the soil fertility status of the nine major cassava-growing districts of Kerala. Soil samples were collected at a depth of 0–20 cm from the identified farmers' fields by KSLUB. Similarly, plant samples were also collected from index leaf tissues, taken as the youngest fully expanded leaf (YFEL) at 3–4 months after planting (MAP).

Long-Term Fertilizer Experiment at CTCRI. Under the Long-Term Fertilizer Experiment (LTFE), initiated at ICAR-CTCRI during 1977, one of the treatments during the third phase, which started in 2004, included soil-test-based fertilizer recommendation (STBFR), wherein soil samples were collected from the respective plots at a depth of 0–20 cm.

The collected soil samples from the different locations and experimental plots after proper processing were analyzed for pH using potentiometry in a 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 molybdenum blue method in Bray 1 extract (Bray and Kurtz 1945) respectively. Available potassium (K), calcium (Ca), and magnesium (Mg) were determined with neutral normal ammonium acetate extraction and direct reading in flame photometer (Hanway and Heidal 1952). Available sulfur (S) was determined by calcium chloride ($CaCl_2$) extraction followed by turbidimetric estimation (Tabatai 1982). Micronutrients [iron (Fe), copper (Cu), manganese (Mn), and zinc (Zn)] were determined by diethylene triamine pentaacetic acid (DTPA) extraction (Lindsay and Norvell 1978) followed by atomic absorption spectrophotometry (AAS) (Analyst 100). The nutrient contents, N, P, K, Ca, Mg, Fe, Cu, Mn, and Zn, in the index leaf tissues were determined by diacid digestion followed by standard procedures (Piper 1970).

Criteria for Categorization of the Soil Based on Soil and Plant Test Data

The soil samples collected were categorized based on different approaches.

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

Computation of Soil Nutrient Index

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

$$\mathrm{SN1} = \frac{(\mathrm{Nl} \times 1) + (\mathrm{Nm} \times 2) + (\mathrm{Nh} \times 3)}{\mathrm{Nt}}$$

Nl, Nm, Nh, and Nt are the number of samples in low, medium, and high fertility classes and total number of samples respectively. Based on the SNI computed, organic carbon and available N, P, and K were rated as low (<1.67), medium (1.67–2.33), and high (>2.33).

Table 1
General rating of soils based on nutrient status

Nutrient	Low	Medium	High	Sufficient	Deficient	Reference
Organic carbon (%)	<0.5	0.5–0.75	>0.75	—	—	Dev (1997)
Available P (kg ha^{-1})	<10	10–25	>25	—	—	Dev (1997)
Available K (kg ha^{-1})	<110	110–280	>280	—	—	Dev (1997)
Exchangeable Ca (meq 100 g^{-1})	—	—	—	≥1.5	<1.5	Dev (1997)
Exchangeable Mg (meq 100 g^{-1})	—	—	—	≥1.0	<1.0	Dev (1997)
Available Fe (µg g^{-1})	—	—	—	4–6	<4.0	Motsara (2002)
Available Cu (µg g^{-1})	—	—	—	≥0.2	<0.2	Motsara (2002)
Available Mn (µg g^{-1})	—	—	—	≥3.00	<3.00	Motsara (2002)
Available Zn (µg g^{-1})	—	—	—	≥0.6	<0.6	Motsara (2002)

Classification Based on Soil Nutritional Requirement of Cassava. According to Howeler (1996), the soils are classified based on the soil nutritional requirement for cassava (Table 2).

Classification Based on Plant Nutritional Requirement of Cassava. The nutrient content in the index leaves (YFEL at 3–4 MAP) was taken as the criteria to evaluate the nutritional status of the plant as per Howeler (1996) and is given in Table 3.

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	<3.5	3.5–4.5	4.5–7	7–8	>8
Organic matter (%)	<1.0	1.0–2.0	2.0–4.0	>4.0	—
P (µg g^{-1})	<2	2–4	4–15	>15	—
K (meq 100 g^{-1})	<0.10	0.10–0.15	0.15–0.25	>0.25	—
Ca (meq 100 g^{-1})	<0.25	0.25–1.0	1.0–5.0	>5.0	—
Mg (meq 100 g^{-1})	<0.2	0.2–0.4	0.4–1.0	>1.0	—
S (µg g^{-1})	<20	20–40	40–70	>70	—
Cu (µg g^{-1})	<0.1	0.1–0.3	0.3–1.0	1–5	>5
Mn (µg g^{-1})	<5	5–10	10–100	100–250	>250
Fe (µg g^{-1})	<1	1–10	10–100	>100	—
Zn (µg g^{-1})	<0.5	0.5–1.0	1.0–5.0	5–50	>50

Table 3
Nutrient concentrations in YFEL blades of cassava at 3–4 MAP

	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	—
Cu (μg g^{-1})	<1.5	1.5–4.8	4.8–6.0	6.0–10	10–15	>15
Fe (μg g^{-1})	<100	100–110	110–120	120–140	140–200	>200
Mn (μg g^{-1})	<30	30–40	40–50	50–150	150–250	>250
Zn (μg g^{-1})	< 25	25–32	32–35	35–57	57–120	>120

Evolution of Fertilizer Recommendation Based on Soil Test and Plant Tissue Analysis

Major Nutrients. The blanket recommendation for cassava is NPK at 100:50:100 kg ha^{-1} + FYM @12.5 t ha^{-1}. In the case of fertilizer recommendation 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.

Organic Manure (FYM), Secondary Nutrient (Mg), and Micronutrient (Zn) Recommendation Based on Soil Test Data. At ICAR-CTCRI, based on the research work carried out under LTFE since 1990, the rate of application of Mg and Zn as $MgSO_4$

Table 4
Soil fertility classes and N, P, and K recommendation for each class as percent of general recommendations

Soil fertility class	Organic carbon (clayey/ loamy soil) (%)	Recommendation of N as percent of general recommendation (%)	Available P (kg ha^{-1})	Exchangeable K (kg ha^{-1})	Recommendation of P and K as percent of general 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

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^{-1})	Soil status of Mg (meq 100 g^{-1})	Rate of application of $MgSO_4$ (kg ha^{-1})	Soil status of Zn (μg g^{-1})	Rate of application of $ZnSO_4$ (kg ha^{-1})
<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

(magnesium sulfate) and $ZnSO_4$ (zinc sulfate) and organic manure as farmyard manure (FYM) were standardized based on the data of tuber yield, soil nutrient status, plant nutrient content, critical levels, and nutritional requirements (Susan John et al. 2010), given in Table 5.

Field Validation of the Soil-Test-Based Fertilizer Recommendation

The validation and demonstration of soil-test-based fertilizer recommendation was undertaken through a State Horticulture Mission (SHM) project during 2007–2009 in thirteen locations of the two selected districts of Kerala (Kollam and Pathanamthitta), involving seventeen farmers and an area of 5.28 ha. Soil samples collected before laying out the trial from these locations were analyzed for organic carbon and 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). The validation trial consisted of five treatments as follows:

T1: Farmer's practice
T2: Package of practices (POP) recommendation for cassava (NPK @ 100:50:100 kg ha^{-1} + FYM @ 12.5 t ha^{-1})
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

Observations on tuber yield, tuber quality parameters [viz., cyanogenic glucosides (Indira and Sinha 1969) and starch (Chopra and Kanwar 1976)], and dry matter were estimated. The economics of STBFR with and without the application of Mg and Zn was also computed by calculating parameters such as gross cost, gross income, net income, and benefit–cost (BC) ratio.

Results and Discussion

The results obtained under the different activities on nutrient evaluation, assessment of the overall 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 under the on-station trial at ICAR-CTCRI and field validation trial in different farmers' fields are briefly discussed.

Evaluation of the Nutrient Status of Cassava-Growing Soils of Kerala

The evaluation of the nutritional status of cassava-growing soils of Kerala was undertaken by both ICAR- CTCRI and ICAR-CTCRI in collaboration with KSLUB in the nine major cassava-growing districts of Kerala. The rapid appraisal of the nutrient status of nine major cassava-growing districts conducted by CTCRI indicated wide variation in all the soil chemical characteristics including primary, secondary, and micronutrient status though there was not much difference between the garden and wetland soils of the same district. Both garden and wetland 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 the 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).

As per the general rating, the evaluation of the nutrient status of the soils collected by ICAR-CTCRI under the rapid appraisal indicated the following results. The soil organic carbon status of the different districts ranged from low to high with a mean high status for the state; the available N status was low to medium in the different districts with a mean low status for the state; and the available P was high in 90–95 percent of the surveyed area, indicating a very high content for the state as a whole. As regards to exchangeable K, the soils of the different districts ranged from low to high with a mean medium status for the state as a whole (Susan John, Ravindran, and Manikantan Nair 2009a). The exchangeable Ca content of the surveyed districts ranged from 0.518 to 2.058 $cmol^{+}\ kg^{-1}$ with a mean value of 1.123 $cmol^{+}\ kg^{-1}$. However, in 75 percent of the appraised districts based on the general soil critical level, the status was not sufficient. As regards to the exchangeable Mg status, the content ranged from 0.233–1.956 $cmol^{+}\ kg^{-1}$ with a mean value of 0.901 $cmol^{+}\ kg^{-1}$. The status was sufficient in 50 percent of the surveyed districts as per the general critical level of 1 $cmol^{+}\ kg^{-1}$ fixed for Indian soils. In the case of micronutrients (viz., Fe, Cu, Mn, and Zn), as per the general critical level, they were sufficient in 100% of the surveyed districts (Susan John, Ravindran, and Manikantan Nair 2009b).

In the case of the soil samples collected by KSLUB in collaboration with ICAR-CTCRI, the general rating indicated that the nine districts belonged to moderately acidic class (4.5–5.5) with organic carbon ranging from medium to high in 90 percent of the districts. The available N status of all the nine districts was low, but P was 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 for a few districts where it was high (about 0.35–0.62 meq 100 g^{-1}). The exchangeable Ca status in all the districts was sufficient, having status above the critical level of 1.5 meq 100 g^{-1} soil. The available Mg status of all these districts was low, with status below the critical level of 1.00 meq 100 g^{-1} soil. The S status also was found high in all these districts and was well above the critical level of 5 ppm fixed for Indian soils. The micronutrient status of the soils of all these districts was satisfactory, with status well above their respective critical levels (Table 6).

Based on the soil nutrient index (SNI) computed, the cassava-growing soils of Kerala were 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 to 3.00, with a mean value of 2.02, indicating 56 percent of the surveyed area was high, 33 percent was medium, and 11 percent was low. The SNI computed for available N was in the range of 1–2 for the uplands and lowlands of the different districts, with 72 percent of the surveyed area

Table 6
Nutrient status of cassava-growing soils of Kerala

District	pH	OC (%)	N (kg ha^{-1})	P (kg ha^{-1})	K (meq 100 g^{-1})	Ca (meq 100 g^{-1})	Mg (meq 100 g^{-1})	S (ppm)	Fe (ppm)	Cu (ppm)	Mn (ppm)	Zn (ppm)
Trivandrum	4.57	0.93	266.3	35.3	0.24	1.24	0.38	7.65	57.89	3.77	9.24	1.16
Kollam	5.26	1.42	114.5	58.3	0.15	1.52	0.42	8.22	70.07	2.65	5.66	1.04
Kottayam	5.24	1.49	209.8	41.5	0.39	2.79	0.53	9.09	37.59	3.70	10.59	2.16
Pathanamthitta	4.51	1.23	225.6	30.0	0.21	1.01	0.39	6.75	49.85	5.07	14.72	1.04
Alapuzha	5.00	0.55	194.7	92.3	0.29	0.98	0. 80	6.59	56.31	0.99	4.78	0.90
Ernakulam	4.49	1.50	244.8	67.5	0.13	1.66	0.44	20.16	70.85	3.63	11.88	0.95
Thrissur	5.09	0.66	137.4	65.5	0.35	1.87	0.76	8.88	46.13	4.38	30.58	1.23
Kozhikode	5.20	0.40	51.5	93.9	0.15	2.00	0.42	5.65	25.34	1.38	16.59	2.34
Malappuram	5.65	1.68	206.1	65.5	0.62	2.95	0.84	8.88	48.36	3.30	17.94	2.73
Mean	5.001	1.094	183.4	61.08	0.279	1.780	0.551	9.097	51.376	3.207	13.553	1.504

belonging to the low category and 28 percent area to 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 percent of the surveyed area under the high category and 39 percent under the medium category. The exchangeable K indicated an SNI value of 1–3 for the different districts, with a mean value of 2.12, where 11, 50, and 39 percent of the surveyed area were under low, medium, and high classes respectively (Susan John, Ravindran., and Manikantan Nair 2009a). In the case of all these nutrients, the high status was encountered mainly in the high ranges of Kerala, such as in the districts of Kottayam, Idukki, Palakkad, and Pathanamthitta, which in turn can be attributed to the previous cropping history with rubber plantations and its leaf shedding might have contributed to the high nutrient status, which might have favored cassava growth and productivity (Joseph, Karthikakuttyamma, and Mathew 1990; Karthikakuttyamma et al. 1991). Because cassava requires soils rich in organic matter with high contents of basic cations for both yield and quality, the soils of Kottayam, Idukki, Palakkad, and Pathanamthitta were found to be the best for growing cassava (Susan John, Ravindran, and Manikantan Nair 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 were categorized based on the soil and plant nutritional requirements for cassava as suggested by Howeler (1996), and the details are presented in Tables 6 and 7.

As per the soil nutritional requirements suggested by Howeler (1996), the soils of these nine districts were categorized from very low to high with respect to all chemical characteristics. In all these districts, the soils were medium in soil reaction with organic carbon status ranging from very low to medium and available P as high. In the case of available K, the status ranged from low to high and exchangeable Ca was medium in all districts except in three districts, where it was low. The exchangeable Mg status also was seen medium in all the districts except in two districts where it was low. Among the secondary nutrients, the S status of these soils was found to be very low in all districts except in one where it was low. As regards to the general micronutrient status, Fe was medium, Cu was high, Mn was very low to medium, and Zn was low to medium. As regards to the overall status of these nutrients for Kerala, the soil pH and available Ca, Mg, Fe, Mn, and Zn were medium; organic carbon was low; P, K, and Cu were high; and S was very low.

As per the evaluation made following the classification made by Howeler (1996), in general, N, Ca, and S were deficient; P, K, Mg, Cu, and Zn were sufficient; and Fe and Mn were toxic.

Soil Test and Plant Tissue Analysis Fertilizer Recommendations for the Major Cassava Growing Districts of Kerala

The usefulness of soil test data as a guide in evolving fertilizer recommendation has been suggested by many researchers (Goswami, Bapat, and Pathak 1971), but Baker (2008) was of the opinion that because 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 recommendation for these districts for cassava comprising organic manure and N, P, K, Mg, and Zn as per the procedure indicated earlier, given in Table 8.

Compared to the POP recommendation for cassava (FYM at 12.5 t ha^{-1} along with NPK at 100:50:100 kg ha^{-1}, Mg at 3.2 kg ha^{-1}, and Zn at 2.5 kg ha^{-1}), as per STBFR, the

Table 7

Evaluation of plant nutrient status based on plant nutrient requirement for cassava (nutrient content in the YFEL at 3- to 4-month stage of cassava)

District	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (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	4.113	0.428	1.997	0.655	0.318	0.096	14.804	56.399	298.787	379.185

Table 8
Fertilizer recommendation based on soil test and plant tissue analysis

District	Organic manure ($t\ ha^{-1}$)	N ($kg\ ha^{-1}$)	P ($kg\ ha^{-1}$)	K ($kg\ ha^{-1}$)	$ZnSO_4$ ($kg\ ha^{-1}$)	$MgSO_4$ ($kg\ ha^{-1}$)
Trivandrum	12.0	107	25.0	79	5.0	5.7
Kollam	10.5	125	26.0	104	6.25	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

organic manure requirement was 12 t ha^{-1}, the N requirement was slightly greater (118 kg ha^{-1}), and the P, K, Mg, and Zn requirements were less compared to the blanket 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 low inherent status of N in these soils as evidenced from the results of samples collected from the nine districts both under ICAR-CTCRI and also in collaboration with KSLUB (Table 6) as well as the low N content noticed in the index leaf tissues. The medium to high available P status in 90 percent of the surveyed districts suggested the possibility of reducing the application of P as evidenced from Table 8. This is in conformity with the reports of Nambiar (1994) and Singh, Singh, and Bhardwaj (1998) that there are instances in many fertilizer trials where the buildup 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 in a lesser rate of application of K.

Though the Ca status of these soils is deficient in more than 50 percent of the surveyed districts and the response of cassava to lime application was not encouraging because 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^{-1} as the general range of soil Mg, which necessitates its external 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, about 4–12 kg ha^{-1} in the of the general recommended dose of $MgSO_4$ at 20 kg ha^{-1}. As far as cassava is concerned, it absorbs Mg from the soil to the tune of 25–35 kg ha^{-1} (Susan John, Ravindran, and James 2005), causing depletion of native Mg.

In the case of Zn application, based on the results from LTFE, the blanket dose of $ZnSO_4$ recommended is 12.5 kg ha^{-1} (Susan John, Ravindran, and James 2005). The Zn status in the lowland and upland soils of the districts surveyed showed that these soils are sufficient with respect to the soil critical level of 0.6 µg g^{-1} as fixed by Dev (1997). Hence, because of the innate Zn status of the soil, there is no need for its application. However, taking into account the Zn uptake by cassava (1–2 kg ha^{-1}) (Susan John, Ravindran, and James 2005) and the additional yield gain as well as tuber quality improvement, the required rates of Zn application were calculated (Table 8). According to Howeler (1996), Zn has to be applied through external sources when the soil Zn status ranges from 0.5 to 5.0 µg g^{-1}. In this case, based on both soil Zn status and plant Zn content, the rate of application of $ZnSO_4$ ranged from 3 to 9 kg ha^{-1}. In a full-fledged fertilizer recommendation module comprising organic manure and major, secondary, and micronutrients, the significance of secondary and micronutrients was highlighted by Portch and Stauffer (2005) who showed that incomplete analyses ignoring micro- and secondary nutrients leads to fertilizer recommendations that cause poor yield.

Comparison of STBFR with POP

At ICAR-CTCRI under the LTFE, STBFR for organic manure, N, P, and K was included as one of the treatments since 2004 based on the procedure followed in Kerala (Aiyer and Nair 1985). During all these years, as the organic carbon content of the soil was high (>0.5 percent), the recommendation for FYM was less to the tune of 7.5–10 t ha^{-1} with an overall mean value of 8 t ha^{-1}. In the case of N and K, the STBFR was less during all these years compared to POP to the tune of 92 and 67 kg ha^{-1} (overall mean) respectively. During these years, as the available P status of the soil was found very high, application was avoided (Table 9).

As regards to the comparison made on tuber yield with respect to POP, STBFR, and absolute control (AC), it is seen that during all these years, with 100% savings in P fertilizer, 3–9 percent savings in N, 6–75 percent savings in K fertilizer, and 25 percent savings in organic manure, the tuber yield was on par with POP, indicating the need to rationalize the fertilizer recommendation for cassava based on soil nutrient status. There are several reports revealing the significance of balanced fertilizer application including FYM in maintaining the tuber yield and its quality (Asokan et al. 1988; Susan John et al. 1998).

The nutrient buildup with respect to POP and STBFR in the cases of organic carbon, N, P, and K is depicted in Figures 1–4, and there is slight to drastic decline in the statuses of all these nutrients except available N during the 2 years.

The remarkable observation was that, because of no application of P during these years, the buildup of P was reduced to a great extent, and the case of exchangeable K was similar. The results obtained under this experiment for the last 6 years support the views of Tiwari and Sharma (2007) from a LTFE that soil-test-based fertilization is required under India's intensive cropping system.

Validation and Popularization Trial for STBFR in Cassava

In this demonstration trial, the organic manure and fertilizer recommendations evolved based on the initial nutrient status of the soil on organic carbon and available P, K, Mg, and Zn. The locations and nutrient statuses of these sites including the recommendations are presented in Table 10.

In general, the organic carbon and P statuses of these locations were very high, whereas the K, Mg, and Zn statuses of these locations were low, indicating a recommendation of a comparatively lower dose of organic manure and N (6 t ha^{-1} and 80 kg ha^{-1} respectively) and P (7 kg ha^{-1}) only. Compared to the statuses of major nutrients, the contents of secondary nutrient (Mg) and micronutrient (Zn) were very low in these locations (well below their critical levels of 1 meq 100 g^{-1} and 0.6 ppm for Mg and Zn

Table 9
Comparison of STBF with POP under the long-term fertilizer experiment

	Soil-test value			Fertilizer and manure recommendation				Tuber yield			
Year	OC (%)	P (kg ha^{-1})	K (kg ha^{-1})	Organic manure (t ha^{-1})	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	POP (t ha^{-1})	STBF (t ha^{-1})	AC (t ha^{-1})	CD (0.05)
2004–05	0.706	56.34	145.60	10	97	0	94	22.810	20.407	16.193	2.515
2005–06	0.897	158.07	206.08	7.5	91	0	71	23.795	23.546	17.015	3.092
2006–07	0.915	139.94	232.96	7.5	91	0	71	12.624	15.851	6.583	2.001
2007–08	0.778	80.79	192.64	7.5	91	0	83	30.965	31.065	17.999	3.198
2008–09	0.939	56.47	267.48	7.5	91	0	60	31.020	26.160	13.080	7.927
2009–10	0.931	82.46	400.32	7.5	91	0	25	29.230	26.240	15.930	8.092
Mean	0.861	95.678	240.847	8.0	92	0	67	25.074	23.878	14.467	4.471

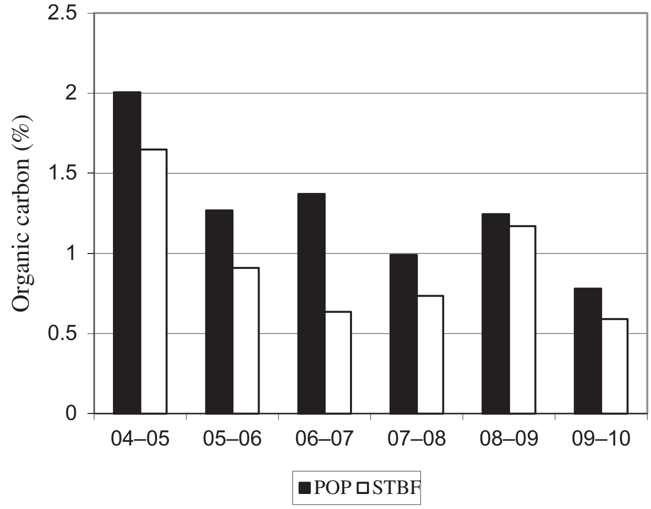

Figure 1. Organic carbon status over years in the selected treatments.

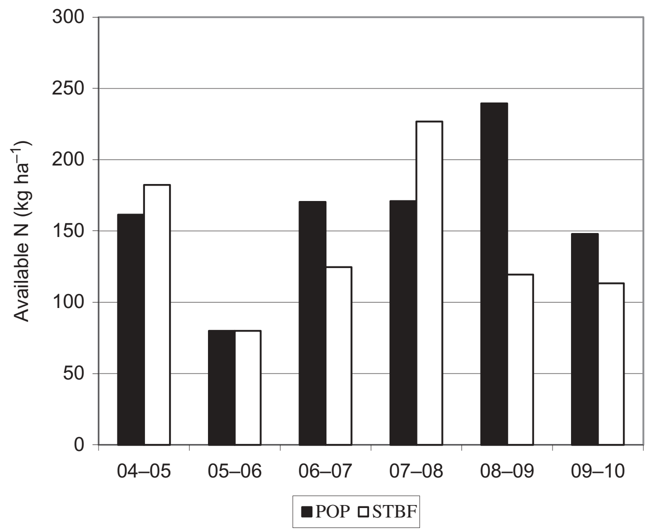

Figure 2. Available N status over years in the selected treatments.

respectively), and all these locations need application of 2.5–20 and 2.5–12.5 kg ha^{-1} $MgSO_4$ and $ZnSO_4$ respectively.

The effects of these treatments on cassava tuber yield, tuber quality parameters (viz., dry matter, starch, and cyanogenic glucosides), and economic parameters (viz., gross income, gross cost, net income, and BC ratio) were also studied.

In the case of cassava tuber yield, soil-test-based application of organic manure and N, P, K, and Zn (T3) as FYM at 6 t ha^{-1} and N, P, K, and $ZnSO_4$ at 80:7:70:7 kg ha^{-1} resulted in the greatest tuber yield of 42.19 t ha^{-1}, which was on par with soil-test-based

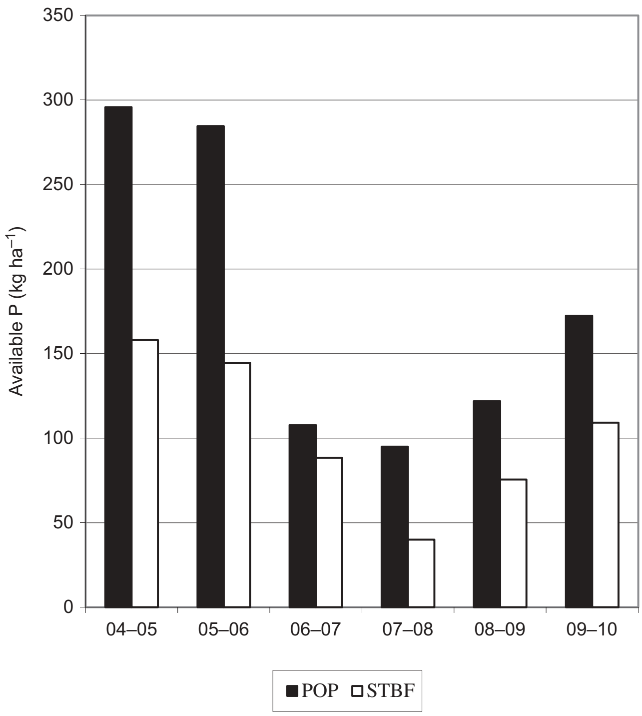

Figure 3. Available P status over years in the selected treatments.

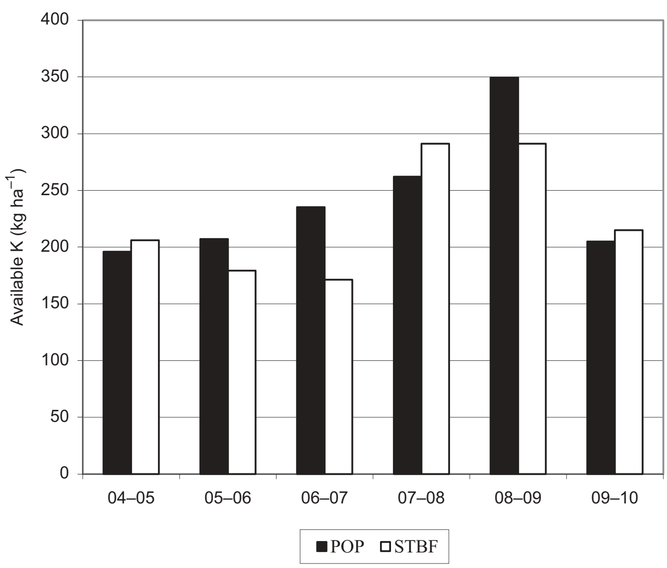

Figure 4. Available K status over years in the selected treatments.

Table 10

Nutrient status of selected locations and soil-test-based fertilizer recommendation

Sl. No.	Locations	Nutrient status					Soil-test-based fertilizer recommendation					
I	Kollam	OC (%)	P (kg ha^{-1})	K (kg ha^{-1})	Mg (meq 100 g^{-1})	Zn (ppm)	FYM (t ha^{-1})	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Mg (kg ha^{-1})	Zn (kg ha^{-1})
1.	Sakthikulangara	0.46	58.91	191.15	0.662	0.659	12.5	91	0	83	10	2.5
2.	Chadayamangalam	1.92	24.94	212.80	0.617	0.235	5	63	24	71	10	10
3.	Kadakkal	1.02	216.18	349.44	0.350	0.568	5	84	0	37	15	5
4.	Anchal	1.29	133.35	439.04	0.292	0.369	5	78	0	25	15	7.5
5.	Ezhukone	2.40	39.25	78.40	0.478	0.851	5	54	0	106	15	2.5
6.	Kalayapuram	1.18	203.19	268.80	0.198	0.239	5	84	0	60	20	10
7.	Panaveli	1.14	110.15	185.92	0.356	0.547	5	84	0	83	15	5
8.	Pallickal	1.08	123.68	145.39	0.257	0.189	5	84	0	83	15	12.5
II.	Pathanamthitta											
9.	Adoor	1.44	83.05	206.08	2.21	0.248	5	78	0	71	2.5	10
10.	Thumpamon	1.02	27.47	199.36	0.506	0.259	5	84	24	71	10	10
11.	Thumpamon	1.08	51.17	190.40	0.342	0.578	5	84	0	83	15	5
12.	Elanthur	1.56	200.35	306.88	0.494	0.368	5	71	0	48	15	7.5
13.	Adoor	0.72	12.58	165.76	0.198	0.857	10	97	47	83	20	2.5
	Mean	1.255	98.79	226.11	0.535	0.459	6	80	7	70	13.65	7.0

application of organic manure and fertilizer application along with Mg as $MgSO_4$ at 13.65 kg ha^{-1} (T4). Soil-test-based application of FYM at 6 t ha^{-1}along with NPK at 80:7:70 kg ha^{-1} resulted in a yield of 34.63 t ha^{-1}, which in turn was on par with POP where FYM at 12.5 t ha^{-1} was applied along with NPK at 100:50:100 kg ha^{-1} (33.18 t ha^{-1}). Among the five treatments, farmers' practice registered the lowest tuber yield of 28.95 t ha^{-1} wherein mostly organic manures in the form of FYM, bone meal, and ash along with chemical fertilizers such as factomphos and muriate of potash were applied in comparatively larger quantity to the tune of 125:100:150 kg ha^{-1}. Kamaraj et al. (2008) reported an yield increase of 23–34 percent in cassava through application of major, secondary, and micronutrients based on soil test data in two villages of Tamil Nadu. Moreover, balanced nutrient application in pulses–green gram–black gram with the required quantity of micronutrients along with macronutrients was found to be an effective proposition for getting greater grain yield of these crops in red and lateritic soils (Bhattacharya et al. 2004) and in rainfed rice in West Bengal (Mukhopadhyay et al. 2008) and sugarcane in Uttar Pradesh (Singh et al. 2008). According to Sharma and Biswas (2007), the investments on the macronutrients alone will not give the desired results unless the micronutrient deficiencies are corrected. Ghosh, Chatterjee, and Sanyal (2008) from West Bengal also reported the significance of soil-test-based nutrient management in 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 high crop yields, net returns, and relative agronomic efficiencies.

As regards to the quality attributes, tuber dry-matter content was greatest with Zn application, which in turn was on par with Mg. In the case of the other three treatments, they were on par with respect to dry-matter production. Starch content in the tuber was greatest with Mg (23.081 percent), which in turn was on par with POP (22.957 percent). The effect of all other treatments was similar with respect to starch yield. Application of Zn resulted in the lowest cyanogenic glucoside content of 34.077 ppm, followed by Mg (37.885 ppm). In the case of STBFR (T5), compared to POP and farmers' practice, which in turn was on par with respect to cyanogenic glucosides, the content was significantly lower (43.615 ppm). This is in agreement with the reports by Yadav (1993) that sugar recovery was more due to balanced and judicious application of manures and fertilizers based on soil test data in sugarcane.

The economic parameters (viz., gross income, gross cost, net income, and BC ratio) computed indicated the greatest gross income, net income, and BC ratio with T4 followed by T3. Treatment T5, with a lower level of organic manure and NPK than POP, registered a greater BC ratio of 1.45 compared to 1.27 in the case of T2 (POP) (Susan John, Suja, and Ravindran 2011). All these parameters thus clearly pointed out the need for recasting and rationalizing the present POP and blanket fertilizer recommendation to need-based application following soil test and plant analytical data (Table 11).

Nutrient Management Plan for Agroecosystems of Kerala

The Department of Agriculture, government of Kerala, in collaboration with fourteen agricultural governmental institutions involving twenty-seven soil-testing laboratories, are involved in developing a soil-based nutrient management plan for twenty-three agroecological zones of Kerala. Under this program, analysis of around

Table 11
Influence of soil-based nutrient management on yield, quality, and economic parameters of cassava

		Quality			Economic parameters			
Treatment	Yield (t ha^{-1})	Dry matter (%)	Starch (%)	Cyanogenic glucosides (μg g^{-1})	Gross income (Rs ha^{-1})	Gross cost (Rs ha^{-1})	Net income (Rs ha^{-1})	BC ratio
T1	28.95	35.532	21.477	56.115	72,365	66,451	5,914	1.09
T2	33.18	35.412	22.957	53.577	89,960	65,512	17,448	1.27
T3	38.84	37.880	23.081	37.885	97,110	60,011	37,099	1.62
T4	42.19	38.031	21.156	34.077	1,05,468	60,343	45,125	1.75
T5	34.63	35.276	21.156	43.615	86,563	59,692	26,871	1.45

CD (0.05) 4.21 0.601 1.108 3.75

1.50 lakh soil samples out of a total of 2.25 lakh soil samples collected indicated the deficiency of only secondary nutrients (viz., Ca and Mg) and micronutrients (viz., B). The very high level of organic carbon, P, S and other micronutrients (viz., Fe, Cu, Mn, and Zn) was reflected in their respective recommendations, indicating the need either to reduce their dose or to avoid its use. The nutrient-management plan being prepared for the different panchayats, blocks, and districts very vividly revealed the need to rationalize the existing fertilizer recommendation based on soil and plant tests. 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 trial 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 to minimize the cost of cultivation as well as to maintain soil health.

Conclusions

As cassava is a high-input requiring crop managed by resource-poor farmers of the developing and developed countries through low inputs, rather than adopting a blanket recommendation, soil-test- and plant-tissue-based fertilizer recommendations and application were worthy from the point of view of tuber productivity, soil productivity, and factor productivity. The research experience of analyzing the essential soil and plant nutrients required for cassava production, evolution of soil-test-based fertilizer recommendations, and the experience of six continuous years of practice on soil-test-based fertilizer recommendations and the extension strategy for validation and popularization to farmers clearly revealed the immediate need to change recommendations to those based on soil and plant tests. This research as well as extension experiences showed that by resorting to soil- and plant-based nutrient recommendation, the rate of application can be minimized, which in turn can avoid the present practice of indiscriminate use of chemical fertilizers, thus improving both soil health and human health and giving greater monetary returns. In this context, especially in the case of low-value crops such as cassava, the farmers need to be educated on the superiority of the soil-test-based fertilizer and manure recommendation over the present practice of blanket recommendation.

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