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Research Paper

Soil test-based low input nutrient-management strategy: A decade experience in cassava (*Manihot esculenta*) in Ultisols of Kerala

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ABSTRACT

The research experience under a long-term fertilizer experiment (LTFE) at ICAR–CTCRI, Thiruvananthapuram, Kerala since 1977 revealed the strong and positive response of cassava (*Manihot esculenta* Crantz) to manures and fertilizers. As a part of the LTFE, since 2005, the comparison made among 4 treatments, viz. soil test-based fertilizer recommendation (STBFR) of farmyard manure (FYM) as source of organic manure and chemical fertilizers as inorganic source, a highest dose of N : P : K @ 125 : 50 : 125 kg/ha + FYM @ 12.5 t/ha, present Package of Practices (PoP) recommendation of N : P : K @ 100 : 50 : 100 kg/ha + FYM @ 12.5 t/ha and absolute control (without any manures and fertilizers) for 10 years established the superiority of STBFR over PoP and the sustainability of cassava for continuous cultivation in the same field. The mean organic carbon, available P and K during these years was 1.106%, 99.8 and 223.7 kg/ha, respectively, and the mean FYM, N : P : K recommendation evolved was 7 t/ ha, 83.3 : 0 : 70.6 kg/ha, respectively, with complete omission of P and lower rate of N and K than PoP. Under the absolute control, during these years, the tuber yield ranged from 6.58 to 18.00 t/ha with a mean tuber yield of 14.53 t/ha. The tuber quality parameters, viz. cyanogenic glucosides (HCN) responsible for bitterness of cassava tubers and starch content were significantly influenced by treatments with STBFR giving significantly the lowest HCN and highest starch content. The cost benefit analysis indicated a benefit : cost ratio of 1.959 for STBFR at par with PoP (2.087) with a saving of 54.3 and 51% of input cost over the highest dose and PoP respectively.

Key words : Benefit : cost ratio, Cyanogenic glucosides, Input cost, Leaf dry-matter production, Long-term fertilizer experiment, Starch, Sustainability, Tuber yield

The current research focus with respect to soil-plant nutrition is an integrated nutrient-management (INM) approach combining both organic nutrient sources and mineral fertilizers for the maintenance of soil quality or soil health apart from crop yield and produce quality. As nutrients supplied by mineral fertilizers play a critical role in the global food and nutritional security perspectives, fertilizer management in a sustainable way is important to maintain the soil healthy for supporting adequate food production with minimal environmental impact. Stewart *et al*. (2005) based on several long-term soil-fertility studies in the USA, England and other tropical countries reported that, at least 50% of crop yield is attributable to commercial fertilizers. However, it is well understood that, both excess as well as low and unbalanced fertilizer application can lead to disruption of soil physico-chemical and biological properties and hence the rate processes especially mineralization affecting the soil-nutrient availability for plant uptake. One way of sustainable fertilizer management is through soil test-based nutrient management which in turn can restore the soil organic matter (SOM) level and maintain the revolving fund of soil nutrients which is made possible through the high biomass yield including the crop residues returned to the soil through balanced application of mineral fertilizers (Katyal *et al*., 2001). Wani *et al*. (2008) reported that, soil test-based nutrient-management approach may be an important entry point activity and also a mechanism to diagnose and manage soil fertility in practical agriculture. Sahrawat and Wani (2013) and Wani *et al*. (2015) established the significance of soil test-based balanced nutrient management for sustainable crop intensification and food security in the semi-arid tropics.

Tropical tuber crops, viz. cassava, sweet potato, yams, aroids, and minor tubers like coleus and arrow root play a

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significant role in the food, nutritional, employment and social security of more than 5 billion people globally. Among these crops, cassava is considered as the most important owing to its biological efficiency, ability to grow under marginal management conditions, less incidence of insect-pests and diseases, high starch content and the good physico-chemical properties of tuber starch for value-addition and the extent of area under cassava cultivation for both edible and industrial purposes other than its strong positive response to manures and fertilizers. At the ICAR-CTCRI, under a long-term fertilizer experiment (LTFE) being in progress since 1977, during the third phase, one of the treatments was a soil test-based nutrient management. The previous two phases' experience clearly indicated heavy build up of nutrients especially P and a favourable increase in soil organic carbon. Hence, this research paper compares 4 treatments of the LTFE and establishes the significance of soil test-based nutrient management as a cost-benefit approach in enhancing tuber yield, improving tuber quality and cassava as a sustainable crop for continuous cultivation.

MATERIALS AND METHODS

The third phase of the LTFE at the ICAR-Central Tuber Crops Research Institute (CTCRI), Sreekariyam, Thiruvananthapuram, Kerala, was initiated in 2005, comprising originally of 20 treatments replicated thrice in randomized block design. The variety grown was a hybrid, 'H 1687' (Sree Visakham) and the experiment was laid out in block V of the ICAR-CTCRI farm. The soil of the experimental site was sandy clay loam with *p*H 4.55, organic carbon 1.39%, available N 202.76 kg/ha, available P 120.92 kg/ha and exchangeable K 205.54 kg/ha. The data on tuber yield, tuber-quality parameters, viz. cyanogenic glucosides (Indira and Sinha, 1969), starch (Chopra and Kanwar, 1976), soil chemical properties, viz. *p*H, organic carbon, available N, P and K (Jackson, 1973) over a period of 10 years since 2005 were compiled and statistically analysed, both year-wise and pooled over 10 years, using Genstat, thirteenth edition (Ireland, 2010). From this statistical output, for the purpose of this paper, 4 treatments, viz. T_1, NPK @125 : 50 : 125 kg/ha + FYM @ 12.5 t/ha Highest Dose [(HD)][3]; T_2, NPK @ 100 : 50 : 100 kg/ha + FYM @ 12.5 t/ha [package of practices (PoP)]; T_3, Soil test-based fertilizer-cum-maurial recommendation (STBFR); and T_4, absolute control (AC) only, were taken. T_1 indicates a higher dose of N and K for cassava (@ 125 kg/ha each) over the recommended package of practices (PoP) recommendation of N : P : K @ 100 : 50 : 100 kg/ha (T_2). Soil test-based fertilizer-cum-manurial recommendation (T_3) was arrived based on the post-harvest soil status of organic carbon, available P and K following the procedure of Aiyer and Nair (1985) for major nutrients, viz. N, P, K and Susan John *et al*. (2010) for organic manure, viz. FYM. The cost effectiveness of the different treatments were compared by calculating the benefit : cost ratio and percentage saving of manure (FYM) and chemical NPK fertilizers under STBFR over PoP and saving of input costs under STBFR with respect to PoP and the highest dose in order to establish the superiority of STBFR to other practices. The sustainable yield index (SYI) as per Singh *et al*. (1990) was calculated based on the tuber yield data of the 10 years. Further, the independent and pooled analysis of the SYI also was done to confirm the sustainability of cassava for long-term cultivation in the same field.

$$YSI = \frac{Y - \sigma}{Y_{max}}$$

where Y = Average yield from the practice over years

$$\sigma = \text{Standard déviation} = \frac{\sqrt{\Sigma\,(Yi-Y)^2}}{n}$$

where Yi = Yield obtained from an individual treatment in i^{th} year (i = 1, 2, 3,….. n)

Y_{max} = Maximum yield obtained with any practice

RESULTS AND DISCUSSION

Soil test-based fertilizer-cum-manurial recommendation

The initial nutrient status, viz. organic carbon, available P and K, during 2005 before the start of the experiment and post-harvest soil status after each season was evaluated to arrive at the recommendation. During the last 10 years, the soil-test data for organic carbon, available P and K and the recommendation of FYM, N, P and K evolved are presented in Table 1.

The mean organic carbon, available P and K were 1.106%, 99.82 and 223.72 kg/ha, respectively, and incidentally the mean recommendation of FYM (Susan John *et al*., 2010), N, P and K (Aiyer and Nair, 1985) arrived were 7.0 t/ha, 83.3, 0 and 70.6 kg/ha respectively. According to Sahrawat (2006), for achieving efficient and judicious use of nutrients through fertilizer inputs, assessing the soils' inherent nutrient status is a pre-requisite. Information on the soil-fertility status is needed not only to enhance crop productivity through balanced nutrient management but also to promote judicious use of costly external inputs of nutrients and enhance the efficiency of scarce resources in developing countries like India (Sahrawat *et al.,* 2010; Chander *et al*., 2013; Wani *et al*., 2015). But Sahrawat *et al*. (2010) used the critical values of nutrients for delineating deficiency to recommend fertilizer doses to farmers by modifying the state fertilizer recommendations to meet varying soil-fertility needs. Saharawat *et al*. (2010)

and Sahrawat and Wani (2013) used soil organic carbon (SOC) as an index of available N. Soil and plant tests have long been used as tools to diagnose and manage soil-fertility problems in the intensified irrigated systems and commercial crops including fruit and vegetable crops to maximize productivity (Dahnke and Olsen, 1990; Black, 1993; Mills and Jones, 1996; Reuter and Robinson, 1997; Susan John *et al*., 2015a).

Tuber yield

The tuber yield is considered as the direct manifestation of a crop's capacity of production. The data on tuber yield over a period of 10 years under the influence of the 4 selected treatments indicated the given results (Table 2).

It was found that, the highest dose of N : P : K @ 125 : 50: 125 kg/ha was at par with the PoP recommendation (N : P: K @ 100 : 50 : 100 kg/ha) and soil test-based fertilizer recommendation during all the years except 2007, 2012 and 2014. During all the years, without P and with N to the tune of 78–91% and K to the tune of 25–106%, the tuber yield was at par with PoP where N, P and K were applied @ 100, 50 and 100 kg/ha respectively. The pooled mean over 10 years revealed that T_1 resulted in significantly higher tuber yield and it was at par with T_2. It was clearly understood that, where the supply of nutrients in the soil either as native or externally applied is adequate, crops are more likely to grow well and produce large amounts of biomass. The treatment T_3 (STBFR) under integrated nutrient management of FYM @ 7 t/ha and N : P : K @ 83 : 0 : 71 kg/ha recorded tuber yield at par with T_2 (PoP). The sustainable tuber production under soil test-based fertilizer recommendation (STBFR) can be attributed to the evolution of a sustainable soil health management system which has the capacity to give higher yields with fewer inputs. The significantly high yield realized under T_1 adheres to the report that, fertilizers are needed to produce healthy crops and sufficient biomass (Singh and Ryan, 2015).

The substantially high yield reported under treatments T_1, T_2 and T_3 can be attributed to the better fertilizer efficiency with higher soil organic matter content as the build up of soil organic carbon (SOC) (Table 1) which is remarkable under cassava because of the innate physiological mechanism of the crop to shed its leaves which in turn

Table 1. Soil-test values (organic carbon, available P and K) and the corresponding FYM and NPK recommendation during the experimental period (2005–2014)

Year	Soil-test values			Recommendation			
	OC (%)	P (kg/ha)	K (kg/ha)	FYM (t/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)
2005	0.7	56.3	145.6	10.0	91	0	94
2006	0.9	158.1	206.1	10.0	91	0	71
2007	0.9	139.9	233.0	7.5	91	0	71
2008	0.8	80.8	192.6	7.5	91	0	83
2009	0.9	56.5	267.7	7.5	91	0	60
2010	0.9	82.4	400.3	7.5	78	0	25
2011	1.0	53.9	93.5	5.0	84	0	106
2012	2.2	94.0	278.0	5.0	60	0	54
2013	1.3	130.9	288.4	5.0	78	0	48
2014	1.4	145.4	132.0	5.0	78	0	94
Mean	1.1	99.8	223.7	7.0	83.	0	71

Table 2. Tuber yield (t/ha) as influenced by the long-term fertilizer treatments over a period of 10 years

Treatment	Years										
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Pooled mean
T_1	24.32	18.53	28.05	32.03	29.23	33.11	29.79	25.10	30.84	32.85	28.38
T_2	23.80	12.62	30.97	31.02	32.57	32.13	24.70	24.90	25.17	27.62	26.55
T_3	23.55	15.85	31.07	26.16	26.24	27.12	21.32	22.87	22.57	22.27	23.90
T_4	17.02	6.58	18.00	13.98	15.93	11.03	17.28	12.14	17.93	15.17	14.53
SEm±	0.811	0.772	0.884	0.284	0.826	0.381	0.575	0.233	0.490	0.483	0.877
CD (P=0.05)	3.092	2.001	3.198	7.927	8.092	6.816	6.356	6.395	5.867	7.109	2.665

Details of treatments are given under Materials and Methods

get incorporated and forms a part of the soil organic matter. During the years, the rate of FYM, N and K as per soil test was substantially lesser with zero P except a slightly higher rate of K during 2011. The STBFR with an average N : P : K @ 83 : 0 : 71 kg/ha and FYM @ 7 t/ha (hence low input), the tuber yield, net income and benefit : cost ratio was on par with PoP where FYM @ 12.5 t/ha and N : P : K @ 100 : 50 : 100 kg/ha was applied though T_1 was significantly superior in all the above parameters. Hence, STBFR with a substantially lower dose of manures and fertilizers is not only giving an yield at par with PoP but is also superior to other treatments from the point of judicious need-based application of low quantity of external inputs. The above finding with continuous cultivation of cassava for 10 years in the same field established the superiority of soil test-based balanced nutrient management corroborating to the research outputs of Chander *et al*. (2013), Sahrawat and Wani (2013) and Wani *et al*. (2015) that, crop yield could be increased sustainably through soil test-based integrated nutrient-management practices and is an economically remunerative option for nutrient management for rainfed crops in many parts of India. Chander *et al*. (2013) realized apparent yield losses without soil test-based balanced INM to the tune of 6–62% in the current season and 3–39% in each of the next succeeding seasons. Hence it can be inferred that, continuous mining of nutrients from the soil resulting from unbalanced fertilizer practices can lead to unhealthy soils and plants, as evident from the result and therefore fertilizers should be applied in sufficient quantities and in balanced proportions.

Cassava as a sustainable crop for continuous cultivation

The sustainability of cassava for continuous cultivation in the same field was established by computing the sustainable yield index (SYI). The SYI calculated as per Singh *et al.* (1990) is presented in Table 3. It is seen that during all the years, there was significant difference among treatments for SYI with T_1 having the highest followed by T_2, T_3 and T_4, (the least). The same trend was seen for the pooled data of 10 years too. The SYI computed clearly indicated cassava as a benign crop for continuous cultivation, as there was 66–79% sustainability under nutrient management (T_1, T_2, T_3) and 40% without any external inputs (T_4), indicating the potential of cassava as the most sustainable crop for long-term cultivation in the same field with appropriate nutrient management and without any external inputs too.

The absolute control treatment without any manures and fertilizers gave the lowest tuber yield among the 4 treatments in the range of 6.5–18.00 t/ha, with a mean yield of 14.53 t/ha. This result indicates the sustainability of the crop for long-term cultivation in the same field without applying any manures and fertilizers (Susan John *et al*., 2015a, 2015b). The low or poor yield under the absolute control reflected the shortage of nutrients for yield realization as reported by Sanchez and Swaminathan (2005). It can also be noted that, under tropical condition, a crop like cassava alone can give yields (Table 2) as above without any external inputs through continuous cultivation in the same field for a decade. From the agronomical point of view, getting the above yield through continuous cultivation of cassava for 10 years without any external inputs is sustainable. However, the sustenance of the crop under continuous cultivation specifically without any manures and fertilizers can be attributed to the high leaf dry-matter (3.7–4.5 t/ha) production and high leaf nutrient content especially N (4.23–4.72%) coupled (Table 4) with the innate physiological mechanism of leaf-shedding character of the crop which in turn can nourish the soil both physically and chemically for better tuberization and tuber bulking. Moreover, cassava leaves are rich in all nutrients and the mean (10 years) content of nutrients, viz. N, P, K, Ca, Mg, Fe, Cu, Mn and Zn in cassava leaves was to the tune of 4.47, 0.45, 0.99, 0.40, 0.52, 0.035, 0.0013, 0.036 and 0.00853% respectively (Table 4). Hence the high nutrient content coupled with the high carbon content in the leaves attributed to the better soil productivity and incidentally the crop productivity.

Table 3. Sustainable-yield index (SYI) calculated for 10 years

Treatment	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Mean(T)
T_1	0.853	0.976	0.710	0.722	0.649	0.520	0.855	0.775	0.783	0.718	0.786
T_2	0.836	0.951	0.697	0.708	0.636	0.510	0.839	0.760	0.768	0.705	0.771
T_3	0.719	0.874	0.597	0.607	0.546	0.438	0.719	0.652	0.659	0.605	0.662
T_4	0.426	0.537	0.353	0.359	0.323	0.260	0.425	0.386	0.390	0.358	0.392
Mean (Y)	0.744	0.835	0.619	0.629	0.566	0.454	0.745	0.675	0.683	0.627	
SEm± (T)	0.00943	0.0129	0.0093	0.0091	0.0068	0.0057	0.0128	0.0091	0.0079	0.0072	0.0029
CD (P=0.05) (T)	0.02699	0.0369	0.0266	0.0260	0.0196	0.0163	0.0365	0.0259	0.0227	0.0205	0.0082

Details of treatments are given under Materials and Methods

Total plant dry-matter production

The total plant dry-matter production (leaf + stem + tuber) during all these years clearly indicated significant difference among the treatments. However, PoP (T_2) and STBF (T_3) were at par during all these years, but the highest NPK level (T1) was found significantly different from either T_2 or T_3 during 2007 and 2012 respectively. The pooled mean data of 10 years did not show any significant difference among T_1, T_2 and T_3 treatments and the mean total plant dry-matter yield obtained was 22.33, 22.62 and 20.39 t/ha, respectively, and the absolute control recorded a significantly lower dry matter yield of 13.73 t/ha (Table 4). Rajasekara Rao *et al*.(2010) found significantly higher dry-matter production with soil test-based balanced integrated fertilizer management over farmers' practice.

Tuber quality parameters

Balanced plant nutrition is not only important for increasing crop productivity but also critical for enhancing crop quality including grain and straw quality which has implications for human and animal nutrition. The tuber-quality attributes studied were cyanogenic glucosides (HCN) responsible for bitterness in cassava tubers and tuber starch. The effect of the 4 treatments on each of these parameters are discussed below.

Cyanogenic glucosides (HCN): The cyanogenic glucoside content of cassava tubers, estimated from fresh cassava tubers collected immediately after harvesting, indicated the sweetness/ bitterness of the tuber. Under these treatments, over these years, there was no significant effect of treatments on HCN except in 2012 and 2014. In fact, the HCN content is influenced by many factors and environmental influence is one among the major and rainfall in 1 or 2 days prior to harvesting of tubers can modify the HCN content. The mean data over these years indicated significantly the highest concentration with T_2 (PoP) and all other treatments were at par with T_3 (STBFR), recording significantly the lowest compared to all other treatments (Table 4). Sahrawat *et al*. (2008) reported increased content of N, S and Zn in the grain and straw of sorghum and maize under STBFR-based balanced nutrition.

Starch : The tuber starch estimated with the dried tuber flesh and converted on fresh-weight basis did not show any significant effect of treatments on independent year-wise analysis. However, the pooled mean over 10 years indicated significant effect of treatments with PoP (20.07%), STBFR (22.15%) and AC (20.52%) behaving at par and the highest NPK level (19.42%) showing a significant low starch content than STBFR indicating the soil test-based nutrient management as better with regards to tuber starch content (Table 4). Yadav (1993) reported that, sugar recovery was more owing to balanced and judicious application of manures and fertilizers based on soil test data in sugarcane. Saha *et al*. (2001), Usha Rani *et al*. (2009) and

Table 4. Plant dry-matter, nutrient content and quality attributes of cassava (mean over 10 years)

Treatment	LDM t/ha	TPDM t/ha	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (%)	Cu (%)	Mn (%)	Zn (%)	HCN (ppm)	Starch (%)
T_1	4.51	22.33	4.72	0.464	1.00	0.389	0.560	0.039	0.00134	0.040	0.0092	62.7	19.42
T_2	4.40	22.62	4.57	0.499	0.99	0.414	0.500	0.039	0.00125	0.035	0.0077	86.3	20.07
T_3	3.84	20.39	4.35	0.410	1.03	0.393	0.562	0.031	0.00120	0.029	0.0090	47.4	22.15
T_4	3.72	13.73	4.23	0.445	0.93	0.399	0.448	0.030	0.00136	0.041	0.0082	56.6	20.52
Mean	4.12	19.77	4.47	0.455	0.99	0.399	0.518	0.035	0.00129	0.036	0.00853	63.25	20.54
SEm±	0.264	0.982	0.080	0.024	0.041	0.019	0.043	0.004	0.00020	0.0022	0.0053	8.03	0.802
CD(P=0.05)	0.736	2.741	0.224	0.068	NS	NS	NS	NS	NS	0.00603	NS	22.40	2.240

Details of treatments are given under Materials and Methods

Table 5. Economic analysis of the long-term INM treatments under cassava (pooled mean over 10 years)

Treatment	Tuber yield (t/ha)	Input cost (₹×10^3/ha)	Cost of cultivation (₹×10^3/ha)	Gross Income (₹×10^3/ha)	Net income (₹×10^3/ha)	Benefit: cost ratio
T_1	28.4	17.9	191.9	425.7	233.9	2.22
T_2	26.6	16.7	190.8	398.2	207.4	2.09
T_3	23.9	9.2	183.1	358.5	175.4	1.96
T_4	14.5	0	174.0	217.6	43.6	1.25
SEm±	0.901	0.306	0.306	13.5	13.5	0.072
CD (P=0.05)	2.665	0.887	0.887	39.2	39.1	0.208

Details of treatments are given under Materials and Methods

Bremnan *et al*. (2010) found that, S fertilization of oilseed crops like soybean, canola and sunflower could increase dry-matter, which in turn indicate that nutrients have a role in affecting the quality of the produce.

Economic analysis of treatments

The total cost of cultivation was calculated as sum of the expenses towards farm operations, planting materials and input costs in the form of manures (FYM) and chemical fertilizers. The cost involved in farm operations from planting to harvesting was calculated as ₹173,950/ha as per the existing rates of the ICAR-CTCRI. The cost of cultivation indicated differences due to the difference in input costs in the form of manures and fertilizers. Gross income was calculated taking the average price of cassava tuber as ₹15/kg.

The economic analyses of the different treatments are presented in Table 5. Significant difference among treatments as regards to all the economic parameters were noticed. Though T_1 treatment resulted in the highest B:C ratio (2.22), it has incurred significantly the highest input (organic manure + chemical fertilizers) cost. The STBFR was at par with PoP for benefit : cost ratio. The input cost involved in STBFR with respect to T_1 and T_2 was only 54.28 and 50.98% respectively. Though T_1 indicated significantly highest gross income, it was at par with T_2. However, T_2 treatment was significantly higher over T_3. But T_4 treatment without any manures and fertilizers resulted in a gross income of ₹2 lakhs (0.2 million). The net income was at par between PoP and STBFR and PoP and the highest dose (T_1). However, it is important to note that, the absolute control also resulted in a net income of ₹43,000 further establishing the sustainability of the crop for continuous cultivation in the same field. Hence, taking into account the economic parameters, it is seen that, though T_1 treatment resulted in higher profit and benefit : cost ratio (B:C) ratio, in terms of the lesser nutrient input

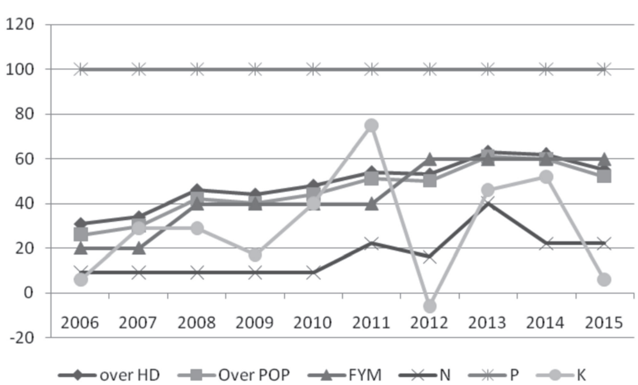

Fig. 1. Percentage saving of inputs (FYM, N, P, K) under soil, test-based fertilizer recommendation (STBFR) over package of practices (PoP) and input cost over highest dose (HD) and PoP

and hence less investment on nutrient management under STBFR, soil test-based fertilizer-cum-manurial recommendation is better from the point of view of present concept of need-based nutrient application through soil-test data. Fig. 1 indicates the percentage saving of inputs in the form of FYM and NPK fertilizers under STBFR over PoP and percentage saving of input costs under STBFR with respect to PoP and the highest dose which in turn might have improved the soil health owing to reduced use of chemical fertilizers, as no significant difference was observed in soil chemical properties even with lower rate of both fertilizers and manures (Table 1). John *et al*. (2010, 2015b) through on station and on-farm trials already had established the significance of soil test-based application of primary, secondary and micronutrients in cassava.

Establishing the superiority of STBF recommendation over PoP

The present study revealed that, soil test-based INM is a better practice in terms of tuber yield, tuber quality and benefit : cost, as evident from the comparison of 4 treatments over these 10 years taking into account other supplementary factors especially indiscriminate use of manures and fertilizers though T_1 resulted in a higher profit. The basic concept underlying integrated plant nutrient management is the maintenance and possible improvement of soil fertility and soil health for sustained crop productivity on long-term basis along with the supply of nutrients through different organic manures available at the farm level to meet the nutrient requirement of the crops to achieve a defined yield goal. Bhattacharya *et al*. (2010) under a 9-year-long-term fertilizer experiment of wheat–soybean cropping system in Alfosols of North India found that, productivity of wheat was significantly increased and soil health in terms of soil organic C was improved by combined application of organic manure and mineral fertilizers. The addition of manures and fertilizers can reduce the extent of SOM decline with cultivation. In the case of soils which are highly degraded in terms of loss of organic matter and nutrient mining, sustainable nutrient and organic matter management through integrated soil-fertility management is an accepted and proven approach (Alley and Vanlauve, 2009).

Hence, based on the 10 years data under the long-term fertilizer experiment under cassava at the ICAR-CTCRI, the following inferences could be generated. When the soil-test value of available P in the soil is high, the application of P can be skipped to maximum of 10 years. Soil test-based application of NPK without P and with lower dose of N and K did not produce any significant difference in tuber yield compared to PoP over a period of 10 years. The sustainable yield index calculated indicated, cassava as a sustainable crop for continuous cultivation in the same field with manures and fertilizers and also without any nutrient inputs as absolute control treatment also fetched a reasonably good net profit . Though the highest dose of N : P : K @ 125 : 50 : 125 kg/ha along with FYM @ 12.5 t/ha resulted in better tuber yield, net income and B:C ratio, PoP and STBFR were at par in these parameters with STBFR saving substantial quanity of chemical fertilizers and organic manures thereby the cost on nutrient inputs in addition to the quality tubers. Hence the present study confirmed need-based-nutrient management through soil test is a better option for cassava and the crop itself is one of the best sustainable crops for long-term cultivation in the same field.

As nutrients supplied by mineral fertilizers play a critical role in the world's food security and are important from both the yield and food quality perspectives, the challenge ahead is to wean agriculture away from current unsustainable practices and to manage fertilizers and soil in a sustainable way, so that not only food demands are continuously met, but soil remains healthy to support adequate food production with minimal environmental impact in future. So, there is a strong need for desired policy orientation by the respective governments to promote capacity strengthening and soil test-based INM and balanced nutrition strategies through appropriate incentives for poor small holders in India.

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