

Soil fertility and nutrient management in tropical tuber crops—An overview

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ABSTRACT

Tuber crops are the most important land-grown food crops after cereals and grain legumes. They are either the staple or subsidiary food for about one-fifth of the human population, mostly in the developing countries of the tropics. Tropical tuber crops like cassava (*Manihot esculenta* Crantz.), sweet potato [*Ipomoea batatas* (L.) Lam.], yams (*Dioscorea* spp.), aroids and minor tubers deserve special recognition owing to their higher biological efficiency (250 kcal/ha/day), ability to sustain under marginal environmental conditions, less incidence of insect-pests and diseases, high starch content (15–35%) and their excellent physico-chemical and biochemical properties in the preparation of several value-added products. Though tuber crops especially cassava grow under marginally fertile soil conditions, our experience under a long-term fertilizer experiment revealed their very high and positive response to manures and fertilizers. This review encompasses the research work undertaken in the soil fertility and nutrient management of tropical tuber crops covering aspects on nutrient uptake/ utilization, fertilizer-cum-manurial recommendations, critical nutrient concentrations, nutritional disorders, and their correction.

Key words : Cyanogenic glucosides, Elephant foot yam, Starch, Sweet potato, Taro, Tannia, Yams, Yam bean

Tuber crops play in the multifaceted needs of more than 500 million people mostly in South and South East Asia, West Africa and the Pacific Ocean Islands contributing to their food, nutritional, social and economic security. The major tropical tuber crops include cassava (*Manihot esculenta* Crantz.), sweet potato [*Ipomoea batatas* (L.) Lam.], yams (*Dioscorea* spp.), aroids like elephant foot yam [*Amorphophallus paeoniifolius* (Dennst.) Nicolson], taro [*Colocasia esculenta* (L.) Schott.] and tannia [*Xanthosoma sagittifolium* (L.) Schott.]. In addition, there are minor tubers like Chinese potato [*Plectranthus rotundifolius* (Poir.) J.K. Morton.], yam bean [(*Pachyrhizus erosus* (L.) Urban] and arrowroot [*Maranta arundinacea* (L.)]. They serve as a substitute to cereals because of their high carbohydrate and calorie contents. Currently, the status of some of these crops has been raised to a commercial scale in some countries and they have assumed greater significance, both nationally and internationally, owing to wider applicability of tuber starch for

diversified uses in the industrial sector. Though, these crops are adapted to marginal soils, application of manures and fertilizers has a profound influence in improving the yield and quality of tubers (Susan John *et al.*, 2005). In order to meet the rising demand of tuber crops in food, feed and industrial sectors, there is a need to enhance their productivity through improved agronomic management practices. The research work on standardization of the rate of application of N, P and K was initiated way back in seventies since the inception of the Central Tuber Crops Research Institute (CTCRI) under the Indian Council of Agricultural Research (ICAR) during 1963. The same standardized rates are still followed in the case of blanket recommendations. However, some new technologies have been developed in the nutrient management for the tuber crops and these are reviewed crop-wise.

CASSAVA

Cassava is the ‘king of tropical tuber crops’ and has a significant position in the global agricultural economy and trade. The productivity of cassava in Asia could attain a phenomenal increase of 22% through soil fertility management alone. Susan John (2007a) reported the total plant absorption of N, P, K, Ca, Mg, Zn, Cu, Mn and Fe by a crop of cassava producing a tuber yield of 43 t/ha as 270–310, 25–30, 250–305, 100–125, 35–50, 1–2.5, 0.07–0.3,

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1–2 and 5–7 kg/ha, respectively. The nutrient uptake and fertilizer recommendation of important tuber crops including cassava are presented in Table 1.

Soil and plant critical levels of nutrients for cassava

Howeler (1981) reported the following as optimum for cassava: soil pH 4.5–7.0, Walkley-Black organic matter 2–4%, Bray II (0.1 N HCl + 0.03 NH₄F extractable) available P 4–15 µg/g, neutral normal ammonium acetate-extractable K 0.15–0.25, Ca 1–5 and, Mg 0.4–1.0 cmol⁺/kg, Ca-phosphate-extractable available S 40–70 µg/g, 0.05 N HCl + 0.25 N H₂SO₄ extractable available Cu 0.3–1 µg/g, Mn 10–100 µg/g, Fe 10–100 µg/g, and Zn 1–5 µg/g. The youngest fully expanded leaf at 3–4 months after planting was suggested as the index leaf and the critical concentration recommended were: 5.1–5.8% N, 0.38–0.50% P, 1.42–1.88% K, 0.50–0.72% Ca, 0.24–0.29% Mg, 0.30–0.36 µg/g S, 6–10 µg/g Cu, 120–140 µg/g Fe, 50–150 µg/g Mn, and 35–37 µg/g Zn (Howeler, 1985).

NPK fertilization

In acid laterite soils of Kerala, the recommended N: P₂O₅: K₂O rate is 100:100:100 kg/ha. However, Nair *et al.* (1988) suggested the optimum dose of P as 50 kg P₂O₅/ha. Susan John *et al.* (2005) reported ground rock phosphate as a better choice of P fertilizer than super phosphate which can reduce the cost of P fertilization in low pH soils. Imas and Susan John (2013) stated K is the key nutrient for tuber productivity and quality and the first K-efficient cassava variety ‘Sree Pavithra’ performed well under low levels of K and was released in 2015. An N : P ratio of 3 : 2 (Prema *et al.*, 1975) and N : K ratio of 1:1 (Rajendran *et al.*, 1976) was found best for tuber yield, dry-matter production, protein and starch content in cassava in acid laterite soils.

Substitution of 50% of the K requirement with 50% Na through common salt (NaCl) was found beneficial on monetary terms without producing any deleterious effect on the growth and yield of the crop (Devi and Padmaja,

1999). However, Susan John *et al.* (2007b) did not find any favourable impact of substitution of Na for K in cassava.

Liming

The general lime recommendation for cassava is 2 t/ha (Mohan Kumar and Nair, 1985). However, Susan John and Venugopal (2006) found that lime had a negative effect on growth, yield and economic parameters of cassava and it does not require lime even when grown on acid soils. Njoku and Enwezor (1991) also observed that cassava being a calcifugal plant is Al tolerant and Ca efficient restricting Al toxicity by converting ionic Al to nonionic forms. Pellet *et al.* (1995) explained that differential Al tolerance of cassava was partly related to Al-induced release of citrate, phosphate and malate which can complex Al and thus it could survive under high concentrations of Al.

Secondary nutrients

Deficiency of Mg is common in Ultisols (laterite soils), especially when cassava is grown continuously in the same field. In the case of Mg, genotype sensitivity is evident and a hybrid cassava variety ‘H 1687’ was found very sensitive to Mg deficiency in these soils. Interveinal chlorosis of the lower leaves is the characteristic symptom, causing a slight reduction in the photosynthetic rate and incidentally crop yield. Soil application of MgSO₄ @ 20 kg/ha 2 months after of planting (MAP) can take care of this problem. In Mg-deficient soils, particularly in Oxisols, Ultisols and Inceptisols, use of MgO, dolomitic lime and band application of MgSO₄ are found effective. In the sandy Oxisols of Carimagua, having a Mg status of 0.06 meq/100 g soil, a significant response to Mg was recorded for an application of Mg @ 40 kg/ha. However, no significant difference was seen between different sources of Mg (Howeler, 1985). The LTFE conducted at CTCRI for 14 years since 1990 revealed that the application of MgSO₄ @ 20 kg/ha was useful in enhancing the tuber yield of

Table 1. Nutrient uptake and fertilizer recommendation of tropical tuber crops

Crop	Tuber yield (t/ha)	Uptake (kg/ha)			Farmyard manure (t/ha)	Recommended dose (kg/ha)		
		N	P	K		N	P	K
Cassava	30	180	22	160	12.5	100	50	100
Sweet potato	14	34	6	47	5.0	50	25	50
Elephant foot yam	36	122	31	176	25.0	100	50	150
Yams	25	163	24	127	10.0	80	60	80
Taro	17	119	18	157	12.5	80	25	80
Tannia	20	125	37	187	25.0	80	50	150
Coleus	26	106	13	107	10.0	60	60	100
Arrowroot	24	194	31	292	10.0	50	25	75

Source: Mohan Kumar *et al.* (2000)

cassava (Susan John *et al.*, 2005). The K-Mg, Ca-Mg antagonism and K-Ca synergism and the K : Mg and Ca : Mg ratios are more relevant than their absolute amounts in the soil (Mohan Kumar *et al.*, 1990). Results of the trials conducted at CTCRI and at the Kerala Agricultural University (KAU) with different sources and levels of S showed that application of S @ 50 kg /ha through S-containing fertilizers can significantly increase tuber yield (Mohan Kumar and Nair, 1985).

Micronutrients

The application of micronutrients, viz. Mn, Zn, Cu, B and Mo, alone and in combination in the acid laterite soils showed that cassava responded significantly to zinc sulfate (ZnSO_4), ammonium molybdate $[(\text{NH}_4)_6\text{Mo}_7\text{O}_{24}\cdot 4\text{H}_2\text{O}]$ and borax ($\text{Na}_2\text{B}_4\text{O}_7$) @ 12.5, 1.0 and 10 kg/ha, respectively, along with 100 kg/ha each of N, P_2O_5 and K_2O , which in turn increased tuber yields to the tune of 4, 2.8 and 3.1 t/ha over the control, respectively. Detailed studies conducted in the acid laterite soils of low-Zn status with varying levels of Zn as 0, 2.5 and 5 kg/ha showed that application of Zn @ 2.5 kg/ha was optimum in terms of yield and quality. At the CTCRI, application of ZnSO_4 @ 12.5 kg/ha continuously for 14 years since 1990 significantly increased tuber yield (Susan John *et al.*, 2005). Based on the data of LTFE on Mg and Zn nutrition for 10 years and field-validation trials in 13 locations of Kerala and B nutrition for 6 years, Susan John *et al.* (2010, 2015a) standardized the rate of application of Mg, Zn and B based on their soil status, tuber yield and crop requirement (Table 2).

Deficiency of Zn occurs in both acidic and saline alkaline soils in the form of interveinal chlorosis of the younger leaves reducing plant growth. Dipping the stakes in 2–4% solution of ZnSO_4 for 15 minutes before planting or foliar application of 1–2% solution of ZnSO_4 is effective in overcoming Zn deficiency. Cassava growing on saline alkaline soils especially in the Salem districts of Tamil Nadu, where the soil pH is 7.8–8.0, electrical con-

ductivity is more than 0.058 dS/m and sodium adsorption ratio is higher than 2.5% suffer due to lime-induced iron chlorosis where all the leaves become uniformly chlorotic, resulting in the reduction of plant growth and yield. Usually, this was corrected by foliar spraying of a mixture containing ferrous sulphate (1%) and zinc sulphate (1%). The B deficiency in the form of broom like appearance of the stem apex can be rectified by soil application of borax or sodium borate @ 1–2 kg/ha or by soaking the stakes for 15 minutes in 0.5–1% borax solution before planting. After the appearance of the symptom, application of borax/boric acid 0.1–0.5% along with CaNO_3 0.5% at monthly intervals till the recovery can be very effective. Application of S @ 10–20 kg/ha as elemental sulphur or gypsum or use of sulphur-containing fertilizers like ammonium sulphate, single superphosphate or potassium sulphate can rectify S deficiency. Though Mn and Cu deficiencies are rarely observed, but in case of occurrence, soil-application of MnO or MnSO_4 or foliar spray of MnSO_4 and soil application of Cu as CuSO_4 @ 2.5–3.5 kg/ha can be resorted to (Susan John *et al.*, 2006a).

Integrated nutrient management

Susan John *et al.* (2005) reported that balanced application of N, P_2O_5 , K_2O @ 100, 50 and 100 kg/ha along with FYM @ 12.5 t/ha was beneficial in increasing tuber yield. Amanullah *et al.* (2007) studied the effect of different organic manures, viz. FYM, poultry manure and composted poultry manure, on cassava nutrient uptake, yield and soil-nutrient status, and found that, poultry manure (10 t/ha) either alone or along with FYM (25 t/ha) was the best, giving slightly positive N balance. *In-situ* green manuring with cowpea (*Vigna* species), incorporation of crop residue and use of recently available organic manures like pressmud, mushroom-spent compost, sawdust compost and coir-pith compost can substitute farmyard manure for cassava production (Susan John *et al.*, 2005).

Ojeniyi *et al.* (2009) identified oil palm-bunch ash @

Table 2. Soil-test-based application of magnesium, zinc and boron for cassava in the ultisols of Kerala

Soil Mg status (meq 100/g)	Rate of application of MgSO_4 (kg/ha)	Soil-Zn status (ppm)	Rate of application of ZnSO_4 (kg/ha)	Soil-B status (ppm)	Rate of application of borax (kg/ha)
0–0.25	20	<0.2	12.5	<0.20	10.0
0.25–0.50	15	0.2–0.3	10.0	0.2–0.5	7.5
0.50–0.75	10	0.3–0.4	7.5	0.5–1.0	5.0
0.75–1.00	5.0	0.4–0.6	5.0	1–2	2.5
>1.00	2.5	>0.6	2.5	>2	0

Sources: Susan John *et al.* (2010, 2015a)

2.5–3.75 t/ha as a good source of organic manure which can enhance tuber yield. Ramanandam *et al.* (2008) under rainfed conditions of Andhra Pradesh found that application of recommended dose of N : P_2O_5 : K_2O @ 100 : 50 : 100 kg/ha along with vermicompost @ 4 t/ha and *Azospirillum* @ 5 g/plant resulted in maximum tuber yield and improvement in tuber quality. Low input-management practices comprising of green manuring with cowpea, indigenous rock phosphate (20–21% P_2O_5) and use of bio-fertilizers, namely *Azospirillum* and *Phosphobacterium*, together @ 2 kg/ha each could reduce the requirement of N and P to 50% of the recommended dose and maintain the soil-nutrient status (Suja *et al.*, 2005). Shanida Beegum *et al.* (2013) developed a low input-management strategy involving nutrient-use efficient (NUE) genotypes, viz. Acc. No. 905 and Acc. No 906, bio-fertilizers, viz. N-fixer (*Bacillus cereus*), P-solubilizer (*B. megaterium*) and K-solubilizer (*B. subtilis*) @ 5 g each per plant and soil-test-based nutrient-management practice with green manuring *in situ* with cowpea as organic manure source and soil-test-based application of N, P, K, Mg SO_4 and Zn SO_4 @ 106 : 0 : 88 : 15 : 2.5 kg/ha could save input cost up to 55% with a benefit: cost ratio of 4.43.

Howeler *et al.* (1987) reported that VAM inoculation can increase cassava tuber yield by 20–25% in low P soils and could improve P uptake. The response of cassava to mycorrhizal inoculation indicated higher uptake of P and micronutrients, viz. Cu and Zn, at lower levels of P (Potty, 1990). Susan John *et al.* (1996) studied the nutrient availability in relation to soil-microbial biomass under a long-term manurial trial and reported the significance of soil-microflora in increasing the availability of nutrients. Microbial biomass increases with organic matter addition and the biomass C, N and P ranged from 11.27 to 108.62, 3.38 to 32.58, 0.72 to 6.95 $\mu\text{g}/100\text{ g}$ soil respectively. Regression analysis showed positive relationship between organic C and biomass C but a negative relation with N and P. Susan John *et al.* (2015a) found the recommended nutrient-management practices can result in better sequestration of atmospheric CO_2 to soil organic C and hence better tuber yield.

Nutrient management and tuber quality

Two quality attributes in cassava are starch and cyanogenic glucosides. Excess N over the recommended dose increases the cyanogenic glucosides and reduces the starch content of cassava tubers. On the other hand, K, Ca and Mg improve starch content and reduce HCN content through their moderating effect on regulation of starch synthetase and linamarase enzyme responsible for starch synthesis and cyanogenic glucoside production in cassava (Susan John *et al.*, 2005). Vijayan and Aiyer (1969) found

that application of P up to 100 kg P_2O_5 /ha also enhanced the starch content and reduced HCN content. Improvement in starch content and quality parameters of starch, viz. amylose content, granule size, pasting temperature, viscosity and swelling volume, increased with the increase in high rates of K. Effect of different sources of K, viz. scheelite, syngenite and wood ash, showed that all these sources are comparable to muriate of potash (MoP) in quality aspects (Nair and Aiyer, 1986). Balanced application of N : P_2O_5 : K_2O @ 100 : 50 : 100 kg/ha along with FYM 12.5 t/ha was effective in improving the starch content and decreasing the cyanogenic glucoside content of cassava tubers (Susan John *et al.*, 2005).

Mohan Kumar and Nair (1985) reported favourable effect of lime @ 2 t/ha and S @ 50 kg/ha on the starch and cyanogenic glucoside content of cassava tubers. With an increase in the S levels, there was an increase in starch, methionine and total protein content with lowering of cyanogenic glucoside content. Among the different micronutrients applied, $ZnSO_4$ @ 12.5 kg/ha improved the quality of tubers by enhancing the starch content and lowering the cyanogenic glucoside content. Foliar application of Zn at 500 ppm through $ZnSO_4$ at 10th month stage of the crop was found effective in reducing the HCN content of cassava tubers.

New approaches in fertilizer recommendations

Major nutrients

Soil test-based fertilizer-cum-manurial recommendation: On the basis of a long-term fertilizer experiment (LTFE), omitting P and applying a lower rate of N, K_2O and FYM based on soil-available P, K and organic carbon since 2005 till 2015 under soil test-based fertilizer recommendation (STBFR) did not produce any significant difference in tuber yield compared to application of N, P_2O_5 and K_2O @ 100, 50 and 100 kg/ha along with FYM @ 12.5 t/ha as per package of practices (PoP) (Table 3) (Susan John *et al.*, 2015a). Over a period of 10 years, cultivation of cassava with continuous application of fertilizers and manures based on soil test could save N, P_2O_5 and K_2O to the tune of 17, 100, 36% with yield (23.90 t/ha) at par with PoP (26.55 t/ha). The NPK recommendation based on soil test was evolved as per Aiyer and Nair (1985) and FYM as per Susan John *et al.*, (2010).

Soil test-based fertilizer cum manurial recommendation was evolved for the 9 major cassava-growing districts of Kerala, based on organic carbon, available P (Bray I method), K, Mg (neutral normal ammonium acetate method) and Zn (DTPA method) status of the soil. These were validated under a National Horticulture Mission Project in 2 districts of Kerala (Susan John *et al.*, 2010). In situation similar to rice fallow, nutrient management for

Table 3. Soil-test-based fertilizer recommendation for cassava during 2005–2015

Year	Soil-test-values			FYM (t/ha)	Recommendation			Tuber yield (t/ha)		CD (P=0.05)
	Organic carbon (%)	P (kg/ha)	K (kg/ha)		N (kg/ha)	P (kg/ha)	K (kg/ha)	POP* (t/ha)	STBFR** (t/ha)	
2005	0.71	56.3	145.6	10.0	91	0	94	-	-	-
2006	0.90	158.1	206.1	10.0	91	0	71	23.795	23.546	3.092
2007	0.92	139.9	232.1	7.5	91	0	71	12.624	15.851	2.001
2008	0.78	80.8	192.6	7.5	91	0	83	30.965	31.065	3.198
2009	0.94	56.5	267.7	7.5	91	0	60	31.020	26.159	7.927
2010	0.93	82.4	400.3	7.5	78	0	25	32.571	26.159	8.092
2011	0.86	68.9	204.9	7.5	78	0	83	32.130	27.121	6.816
2012	1.01	53.9	93.5	5.0	84	0	106	24.700	21.320	6.356
2013	2.20	94.0	278.0	5.0	60	0	54	24.901	22.871	6.395
2014	1.30	130.9	288.4	5.0	78	0	48	25.173	22.571	5.867
2015	1.39	145.4	132.0	5.0	78	0	94	27.615	22.272	7.109
Mean	0.966	93.51	250.95	7.25	83.3	0	63.7	26.549	23.901	2.665

Source: Susan John *et al.* (2015a) PoP* – Package of practices, STBFR** – Soil test-based fertilizer recommendation

short-duration cassava based on soil-test data resulted in saving of full P, 10% N and 15% K and gave higher tuber yield (24.2 t/ha) (Suja *et al.*, 2011). Soil-health cards and soil-based nutrient management plans have been developed for the entire Kerala state.

The data on LTFE further established cassava as a sustainable crop for continuous cultivation in the same field. Over a period of 10 years, since 2005, without any manures and fertilizers (AC-absolute control), the tuber yield

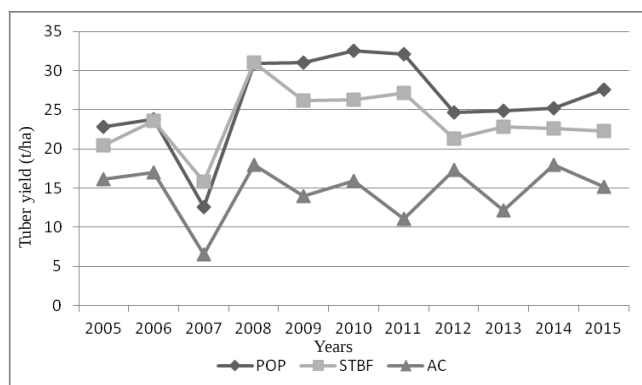


Fig. 1. Sustainable cassava tuber yield (t/ha) over a period of 10 years under package of practices, soil-test-based fertilizer recommendation and absolute control in the long-term fertilizer experiment (Source: Susan John *et al.*, 2015)

ranged from 6.583 to 17.933 t/ha, with a mean yield of 14.658 t/ha which was compared with PoP and STBFR (Fig. 1).

Site-specific nutrient management: Research efforts made at ICAR-CTCRI since 2003 resulted in the development of site-specific nutrient management (SSNM) technology by using the model ‘Quantitative Evaluation of

Fertility of Tropical Soils (QUEFT)’ for cassava. The detailed fertilizer calculation chart developed can be used to recommend dosages of N, P_2O_5 and K_2O based on yields in ‘nutrient omission plots’ at village or block level (Byju *et al.*, 2012). Leaf-colour chart (LCC) and chlorophyll meter calibrated and validated for real-time N management in cassava identified the youngest fully expanded leaf (YFEL) blade (leaf 1) had significant positive correlation to tuber yield. A LCC score of 2.65 and a SPAD value of 25 was found suitable to determine the optimal timing of N top-dressing (Byju and Anand, 2011). The NPK fertilizer recommendation maps of major cassava-growing regions by applying the techniques of remote sensing, GIS and GPS resulted in the development of a Nutrient Decision Support System (NuDSS) (Sabitha *et al.*, 2013).

SWEET POTATO

Sweet potato deserves special attention both nationally and internationally owing to its β -carotene content, especially in the orange-fleshed varieties. China is the largest producer of sweet potato globally, where the average yield is 20–25 t/ha. In India, it is grown mostly in Odisha, Uttar Pradesh, Bihar, West Bengal and NEH states. Nutrients play a significant role in the productivity and quality of tubers. From the nutraceutical point of view, the reasonably high content of antioxidants like anthocyanins and carotenoids and the storage protein sporamin in sweet potato tubers make this crop nutritionally significant for infants, invalids and tribals.

Nutrient management and tuber yield

Nair and Mohan Kumar (1984) standardized the nutrient dose as N : P_2O_5 : K_2O @ 50 : 25 : 50 kg/ha along with

FYM @ 5 t/ha. Onwudike (2010) recommended integrated application of cowdung @ 3 t/ha along with N : P₂O₅ : K₂O @ 100 : 100 : 100 kg/ha for improvement of plant growth, tuber yield and soil fertility. Laxminarayana (2013) in an Ultisol of Odisha, found that, conjunctive use of organic manures, viz. either farmyard manure @ 4 t/ha, neem-cake @ 0.5 t/ha or green manuring along with N : P₂O₅ : K₂O @ 75 : 22 : 62.5 kg/ha and lime @ 0.5 t/ha, could increase crop yields, efficiency of applied nutrients and sustained soil fertility under the sweet potato-greengram sequence. Laxminarayana and Burman (2013) reported location-specific nutrient management for sustainable production of sweet potato in saline Inceptisols of West Bengal where N and P₂O₅ @ 50 kg/ha each resulted in quality tubers and high nutrient-use efficiency. Laxminarayana and Burman (2014) studied the nutritional response of sweet potato genotypes in saline Inceptisols and found that genotypes 'Samrat', 'CIP 44-0127' and 'Pusa Safed' are tolerant to salinity, and application of full dose of N: P₂O₅ : K₂O @ 75 : 37.5 : 75 kg/ha could result in highest yields. Hamid *et al.* (2004) found that high Ca concentration can reduce the growth, yield and thickness of tuberous roots. Byju *et al.* (2007) determined B requirement of sweet potato as 1.5 kg/ha.

Yano and Takai (2005) reported that mycorrhizal association in sweet potato could reduce the toxic effects of elements causing acidity in acid soils. Byju and Ravindran (2009) reported that the present level of N (50 kg/ha) can be reduced to one-third by integrating with *Azospirillum* by dipping the vines for 15 minutes before planting and soil application of *Azospirillum* @ 10 kg/ha at the time of planting. Nedunchezhiyan *et al.* (2013) found that by increasing irrigation and nutrient levels, root and fodder yield could be increased in sweet potato grown under rice fallow. Aregheore and Tofinga (2004) found that, the type of mulch material have an influence on the crude protein, gross energy, macro and trace mineral content in the aerial parts of sweet potato, making it an ideal low-priced protein and energy source for livestock and humans. In south western Nigeria, Ukom *et al.* (2009) studied the influence of different levels of N on the bioavailability of β carotene and crude protein and found that for good nutrition and health, the N rate should be 40–80 kg/ha.

Deficiency disorders

Sullivan *et al.* (1996) listed the diagnostic criteria for identifying nutritional disorders in sweet potato including critical concentrations in leaves as 40, 4.5, 33, 19 and 11 μ g/g, respectively, for B, Cu, Fe, Mn and Zn. Deficiencies of P and K were induced under sand culture (Susan John *et al.*, 2004) with symptoms as premature senescence of older leaves with purple discolouration in the leaf lamina

and scarce tuber development in the case of P deficiency and the K deficiency resulted the margins of the leaves to turn yellow towards the mid-rib followed by necrosis and drying of the tips and margins with very poor tuber development. The deficiencies of micronutrients, viz. Fe, Mn, Cu, B, Mo and Zn, were induced under sand culture (Pillai *et al.*, 1986) and arrived at the critical foliar concentration of nutrients, viz. Mn, Zn, Cu and B as 42, 34, 2.4 and 20 μ g/g respectively. They narrated the characteristic symptoms of Zn deficiency as general chlorosis of the young leaves with narrowing of the leaf lamina, deficiency of Mn as interveinal chlorosis of the leaves of the whole plant, deficiency of Cu as wilting and drooping of mature leaves followed by chlorotic leaves having spots/patches throughout the lamina including brown streaks in the normal sized tuber flesh, Mo deficiency as reddening the veins of young leaves, Fe deficiency as pale green colour of the lamina followed by necrosis resulting in the death of terminal apex and auxiliary shoots, B deficiency as thickening of the younger leaves to a leathery consistency without any tuber formation. In the acid laterite soils of Odisha under field condition, Byju *et al.* (2007) reported tuber blister resulting in cracking of tubers is a frequent phenomenon due to B deficiency.

YAMS

The common cultivated species of yams are winged or purple yam (*Dioscorea alata* L.), white yam (*D. rotundata* Poir.) and lesser yam [*D. esculenta* (Lour.) Burkill]. Kabeerathumma *et al.* (1991) studied the absorption and utilization pattern of major nutrients (N,P,K) at different growth stages of these three species and reported the maximum utilization of N and K by *D. esculenta* and *D. rotundata* within 5–7 months after planting, (MAP), whereas the demand for P for these species was found to continue till maturity. In the case of *D. alata*, the maximum utilization of all the 3 nutrients was found to be within 5 MAP. The concentration of these nutrients in the plant parts was the highest during the early stages of growth (3–5 MAP). Kabeerathumma *et al.* (1987) standardized first fully mature leaf at 3–4 MAP as the index leaf and the critical nutrient concentration of N, P, K, Ca, Mg, Fe, Cu, Mn and Zn was arrived as 1.85–1.94, 0.16–0.20, 1.46–2.27, 0.22–0.27, 0.47–0.65%, 339–691, 390–657, 81–92 and 21–24 μ g/g respectively.

Nutrient management

Yams are highly efficient in the utilization of native and applied nutrients. The magnitude of response to fertilizers was found to vary with the species (Kabeerathumma and Mohankumar, 1994). Continuous cropping of yams may lead to severe depletion of soil essential nutrients. Suja

(2005) reported that application of coir-pith compost @ 5 t/ha along with N, P₂O₅ and K₂O @ 80, 60 and 80 kg/ha could maintain high yield (24.6 t/ha), net income (₹ 36,187/ha) and benefit: cost ratio (1.42) when white yam was intercropped in coconut garden. The rate of application of NPK for different species of yams was standardized as N, P₂O₅ and K₂O @ 80, 60 and 80 kg/ha along with 12.5 t/ha farmyard manure (FYM). Organic production technology for yams was standardized as application of FYM @ 15 t/ha, *in-situ* green manuring to get 15–20 t/ha green biomass, neem-cake @ 1 t/ha, ash @ 1.5 t/ha, *Azospirillum* @ 3 kg/ha, mycorrhiza @ 5 kg/ha and phosphobacteria @ 3 kg/ha over the conventional practice of applying FYM @ 10 t/ha and N, P₂O₅ and K₂O @ 80, 60 and 80 kg/ha (Suja *et al.*, 2015). Tchabi *et al.* (2009) reported increased yield due to arbuscular mycorrhizal colonization in yams.

Deficiency disorders

Magnesium deficiency symptoms with interveinal chlorosis of older leaves is very common in lesser yam especially when continuously grown in poor soils (Susan John *et al.*, 2006a).

ELEPHANT FOOT YAM

Elephant foot yam [*Amorphophallus paeoniifolius* (Dennst.) Nicolson] is considered as the most nutritious and medicinal tuberous vegetable grown mainly in the states of Kerala, West Bengal, Bihar, Jharkand and NEH states. Because of higher yield to the range of 30–60 t/ha, the nutrient requirement is very high. Kabeerathumma *et al.*, (1987) reported the mean uptake of N, P and K as 26.9, 4.2 and 36.6 g/plant and a crop of elephant foot yam giving a tuber yield of 43 t/ha removes 124.8 kg N, 26.1 kg P and 222.4 kg K. The N content of root, tuber and pseudostem decreases towards maturity. Among the different plant parts, leaf is the richest in N (3–5%) and pseudostem in K (4–7%) (Nair and Mohan Kumar, 1991). Kabeerathumma *et al.* (1987) standardized the index leaf of EFY as the leaf blade at 3 MAP and the critical tissue concentration was fixed as N, P, K, Ca, Mg, Fe, Cu, Mn and Zn as 4.05, 0.55, 3.82, 0.33, 0.65%, 689, 14, 238 and 121 µg/g respectively.

The ratio of Mg to Ca utilization was 1 : 2.19, indicating a higher Ca requirement especially during the active vegetative growth stage, whereas Mg utilization was higher during tuber-bulking stage, indicating the need to apply these nutrients at respective growth stages to increase the yield. Among the micronutrients, Fe, Mn, Zn and Cu are removed to the tune of 7.38, 1.78, 0.490, 0.112 kg/ha, respectively, for a tuber yield of 43 t/ha. The removal of Zn, Cu, Mn and Fe through tuber is 80, 80, 30 and 53% respectively (Kabeerathumma *et al.*, 1987).

Nutrient management

Nair and Mohan Kumar (1991) found that, EFY requires a fertilizer dose of 100, 50 and 150 kg N, P₂O₅ and K₂O/ha. Verma *et al.* (1995) reported the maximum growth, dry-matter production, tuber yield, N and K uptake with N and K₂O @ 150 kg/ha each applied in 2 splits. Ravindran and Kabeerathumma (1990) found that, vegetable cowpea can be successfully grown as an intercrop in elephant foot yam without reducing its yield, and the N, P₂O₅ and K₂O for elephant foot yam can be reduced @ 27, 20 and 33 kg/ha respectively. Suja *et al.* (2015) standardized the organic production strategy as FYM @ 36 t/ha [cowdung + neem-cake mixture in (10:1) inoculated with *Trichoderma harzianum*], green manuring with cowpea to generate 20–25 t/ha green biomass in 45–60 days, neem cake @ 1 t/ha and ash @ 3 t/ha. Anjana Devi *et al.* (2015) found that by integrating nutrient use efficient bio-fertilizers, viz. N-fixers, P- and K-solubilizers, with NPK fertilizers, N, P and K can be saved to the tune of 25, 50–75 and 25% respectively.

The impact of nutrition, viz. major, secondary and micronutrients, on delineating the acidity of tuber has not yet been explored. Patel and Mehta (1987) reported an increase in P, K and silica content in corms with FYM application, but had no effect on starch and N content. Application of N can increase the N, P, K, starch and silica content of the corms. Mukhopadhyay and Sen (1986) reported improvement in quality of corms with increasing levels of N and K.

Deficiency disorders

Symptoms of N deficiency were usually noticed in poor soils low in organic matter. Wide-spread chlorosis or yellowing of the foliage was the characteristic symptom which later results in drying and withering of the whole plant. The K deficiency was characterized by yellowing, curling inward and drying the margins and tips of the leaflets which later cause complete drying of the whole plant (Susan John *et al.*, 2006a).

TARO

Taro is an under-utilized and under-exploited tuberous vegetable of the tropics, grown by small and marginal farmers. As regards to the nutrient utilization, the peak demand for N and K is at 3 MAP and 1–2 MAP respectively (Kabeerathumma *et al.*, 1984). The peak demand for Fe and Mn is at 2–3 MAP and that for Zn and Cu was around the maturity stage. All micronutrients showed a tendency to accumulate with advancement in growth stage (Kabeerathumma *et al.*, 1985). Taro being grown in swamp conditions, Hill *et al.* (2000) studied the effect of excess Cu and the threshold was fixed as 1.2 µM, and

toxic concentration can reduce dry matter, leaf area, root length, root dry weight ratio and impaired the synthesis and accumulation of cation in leaf blade.

Nutrient management

Cattle manure or compost @ 3–4 t/ha along with N, P_2O_5 and K_2O @ 80, 60 and 80 kg/ha is recommended for most parts of India. The Package of Practices (PoP) recommendation for taro followed in Kerala is N, P_2O_5 and K_2O @ 80, 25 and 80 kg/ha along with FYM @ 10 t/ha. The organic production technology developed for taro is FYM @ 15 t/ha along with neem-cake @ 1 t/ha, green manuring *in situ* with cowpea to get a green biomass of 15–20 t/ha, ash @ 2 t/ha, bio-fertilizers (*Azospirillum*) @ 3 kg/ha, mycorrhiza @ 5 kg/ha and phosphobacteria @ 3 kg/ha (Suja *et al.*, 2015)

Nutritional disorders

Sullivan *et al.* (1996) arrived at the diagnostic criteria for nutritional disorders due to major, secondary and micronutrients and described the visible symptoms of both deficiency and toxicity along with the critical tissue concentration as N, P, K, Ca, Mg, Fe, Cu, Mn and Zn as 3.67, 0.36, 2.43, 0.75, 0.52%, 56, 17, 675 and 48 µg/g respectively.

TANNIA

Tannia or new cocoyam requires a well-drained, nutrient-rich soil, preferably with pH ranging from 5.5 to 6.5, with mean soil temperature of more than 20°C for their optimum growth. Tannia realizes 60% of maximum yield in soils with 50% Al^{3+} saturation of the soil cation-exchange capacity. High yields of tannia can be obtained at about pH 4.8 with 20% exchangeable Al^{3+} . Total nutrient uptake by tannia is 125, 15, 156, 48 and 25 kg/ha for N, P, K, Mg and Ca respectively. The leaf lamina of well-fertilized tannia plant contained 3.2% N, 0.25% P, 2.3% K and 1.3% Ca (Chandler *et al.*, 1982). Kabeerathumma *et al.* (1987) identified the third or fourth leaf at 4 MAP as the index leaf and the critical nutrient concentrations of N, P, K, Ca and Mg as 3.2, 0.5, 2.3, 0.9 and 1.3% respectively.

Susan John *et al.* (2013) evolved an integrated nutrient management strategy for tannia with N: P_2O_5 : K_2O @ 80 : 50 : 150 kg/ha along with FYM @ 25 t/ha and dolomite @ 1 t/ha. However, N and K @ 60 and 125 kg/ha resulted in the highest yield and net returns under intercropping in coconut. Susan John and Suja (2012) developed the optimum nutrient rate and nutritional constraints in tuber crops growing in Ultisols of India with special emphasis on tannia. Subsoil acidity in strongly acid soils with a pH of 4–5 was found as the most important problem limiting

tannia production for which dolomite was identified as the best soil ameliorant (Susan John *et al.*, 2013).

Nutrient disorders

In the acid laterite soils, the crop does not grow well due to the occurrence of a multi-nutrient disorder involving K, Ca and Mg induced by subsoil acidity causing complete devastation of the crop at 5 MAP (Susan John *et al.*, 2006a; Ramesh *et al.*, 2007). Dolomite @ 1 t/ha was identified as a suitable liming material to rectify the problem (Susan John *et al.*, 2013)

ARROWROOT

Arrowroot is a heavy feeder, usually thrives well in fertile acid sandy-loam soils with partial shade. Maheswarappa *et al.* (2000) and Veena (2000) reported the highest uptake of N and K with high level of fertilization when arrowroot was intercropped in coconut garden. Suja *et al.* (2006) reported N, P_2O_5 and K_2O @ 50, 25 and 75 kg/ha to obtain better yield (23.29 t/ha) and high nutrient uptake. Jayakumari and Potty (2008) found the potential of arbuscular mycorrhizal fungal inoculation in transforming more roots to tubers.

YAM BEAN

Mondal and Sen (2006) reported that, the seed yield can be increased by fertilizing yam bean with N, P_2O_5 and K_2O @ 50, 25 and 50 kg/ha. The nutrient requirement for yam bean was standardized for the whole of India as FYM or compost @ 15–20 t/ha along with N : P_2O_5 : K_2O @ 80 : 40 : 80 kg/ha.

CHINESE POTATO

A fertile, well-drained sandy loam to alluvial soil, rich in organic matter is ideal for this crop. The best soil pH for good growth and tuber production is 6.6–7.0. FYM @ 4.5 t/ha along with wood ash @ 1.1–2.2 t/ha and a fertilizer dose of N, P_2O_5 and K_2O @ 80, 60 and 80 kg/ha was suggested. The recommended dose is N, P_2O_5 and K_2O @ 60, 60 and 100 kg/ha along with FYM @ 10 t/ha (Mohan Kumar *et al.*, 2000).

CONCLUSION

Tuber crops in general are regarded as the ‘Treasures in the soil’ in view of their very high yield potential which in turn is hidden inside the soil. Taking into account the potentialities of tropical tuber crops under the present scenario of global environmental change, tuber crops can be regarded as the ‘Future crop for the millennium’. One of the reasons for realizing the highest productivity of cassava in India is the adoption of better nutrient-management practices, as the research work over these years

clearly indicated the very high and positive response of these crops to fertilizers and manures. This review on the soil fertility and nutrient management of tropical tuber crops can definitely be a good repository of valuable information, as it encompasses important aspects of crop nutrition affecting growth, yield and quality of all tropical tuber crops. Tropical tuber crops being high nutrient demanding, proper integrated management of the crop through the different approaches as described above comprising of major, secondary and micronutrients can definitely help in achieving the yield potential.

As regards to the future thrust areas of research in nutrition of tropical tuber crops, the inherent physiological mechanism of cassava plant to shed its leaves especially during drought resulting in better carbon sequestration (conversion of atmospheric CO₂ to soil organic C) needs to be exploited in the management of nutrient resources as the organic manure requirement can be partly met through the soil organic carbon build up. As cassava is identified as a climate resilient crop with better carbon sequestering potential, other tuber crops can also be studied for their efficiency to sequester atmospheric CO₂ to soil organic carbon with a view for reducing the organic manure application.

Though extensive studies were conducted on the primary, secondary and micronutrient nutrition of cassava, limited research information is available on secondary and micronutrient nutrition of other tuber crops like yams, aroids and minor tubers. Hence, research intensification on basic, strategic and applied aspects of secondary and micronutrient nutrition of these groups of crops need to be focussed.

As tuber crops in general are grown by resource-poor farmers, as in the case of low input-management strategy developed for cassava involving nutrient-use efficient genotypes (NUE), efforts may be initiated to screen the available elite germplasm collection of other tuber crops to identify better efficient genotypes to reduce over dependence on chemical fertilizers. Since the present nutrient management strategy involve the development of nutrient formulations containing primary, secondary and micronutrients based on soil and crop requirement, research works have already been initiated to develop customized fertilizer formulations for different tuber crops suited to different agro climatic situations both under sole cropping and intercropping situations.

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