Indian Journal of Agronomy **64** (1): 1—10 (March 2019)

Review/Overview Article

Zinc nutrition in tropical tuber crops: A review

K. SUSAN JOHN[1], P.S. ANJU[2], G. SUJA[3] JEENA MATHEW[4] AND Y.S. SHIVAY[5]

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

Received : December 2017; Revised accepted : February 2019

ABSTRACT

Tropical tuber crops are known for their biological efficiency, climate, soil and pest resilience, quantity and quality starch for the preparation of several industrial value added products. Their inherent yield potential results in the uptake of substantial quantum of nutrients from the soil necessitating their replenishment through external sources. In addition to the major and secondary nutrients, the micronutrient requirement of these groups of crops are very high though deficiency disorders are manifested in extreme cases. Depletion of Zn noticed under continuous cultivation of cassava (*Manihot esculenta* Crantz) over 14 years under a permanent manurial experiment resulted in the initiation of Zn-nutrition studies in tropical tuber crops. Extensive studies conducted in the Zn-nutrition of tropical tuber crops especially cassava, sweet potato [*Ipomoea batatas* (L.) Lam] and elephant foot yam [*Amorphophallus paeoniifolius* (Dennst.) Nicolson] including Zn content in the different plant parts of other tuber crops over the growth period, Zn status of the soils of the State, Zn in value-added fertilizers developed for elephant foot yam and enriched manure prepared from cassava starch factory solid waste, sorption characteristics of Zn, significance of the low-input management strategy involving soil test-based application of Zn for cassava and results of the on-farm trials conducted in some of the above studies are reviewed in this paper.

Key words : Cassava, *Coleus*, Elephant foot yam, Soil test-based Zn recommendation, Sorption characteristics of Zn, Sweet potato, Taro, Weighted average of Zn, Yams

Tropical tuber crops like, cassava, sweet potato, yams (*Dioscorea* sp.) and aroids, viz. elephant foot yam, taro [*Colocasia esculenta* (L.) Schott.], tannia [*Xanthosoma sagittifolium* (L.) Schott], and minor tuber crops like *Coleus* sp., arrowroot (*Maranta arundinacea* L.) and yam bean [*Pachyrhizus erosus* (L.) Urb.] are considered as the 'Present crop for the millennium' with respect to climate resilience, food security, quality of the tubers and soil productivity. These crops are regarded as the third most important food crops of mankind after cereals and grain legumes, since they have their own role as a staple in several countries and constitute either the primary or subsidiary food for about one-fifth of the world population. These crops are strong with respect to their higher biological efficiency, supply of low-priced source of energy especially for the weaker sections of the population and ability to yield in poor and marginal soils and weather conditions. These attributes make these crops ideal for cultivation in the less-developed countries of Asia, Africa and Latin America where these are now being increasingly valued as a source of income and employment besides being food security crops. Among the tropical root and tuber crops, cassava, commonly known by the name tapioca, native to South America belonging to the family Euphorbiaceae occupies the first position in terms of area and production globally.

Tropical tuber crops and cassava in particular respond well to the application of manures and fertilizers (Susan John and Venugopal, 2005). It is already understood that, owing to high productivity of these group of crops compared to field crops, the nutrient uptake is very high implying to the substantial quantity of nutrient removal from the soil. This of course relates to the need for replenishment through organic or inorganic sources of nutrients.

Among the micronutrients, zinc (Zn) is found as one of the important nutrients for these crops with respect to tuber yield, tuber quality, especially in reducing the cyanogenic glucoside content of cassava tubers responsible for bitterness. These special attributes related to Zn is associated with its role as a constituent of enzymes involved in photosynthesis, root respiration, oxidation and translocation and transport of Zn in plants. Susan John *et al.*

[1]**Corresponding author Email:** susanctcri@gmail.com

[1]Principal Scientist (Soil Science), [2]Research Scholar, [3]Project Assistant, Division of Crop Production; [4]Scientist (Soil Science), ICAR-Central Plantation Crops Research Institute, Kayamkulam, Alapuzha, Kerala 690 533; [5]Principal Scientist & Ex-Professor (Agronomy), ICAR-Indian Agricultural Research Institute, New Delhi 110 012

(2016c) reported the primary, secondary and micronutrient uptake of tropical tuber crops as high. Uptake of Zn in cassava, sweet potato, yams, elephant foot yam, taro and *Coleus* for tuber yields to the tune of 30, 18, 18–30, 33, 17 and 26 t/ha, respectively, was found as 0.81, 0.46, 0.33–0.53, 0.49, 0.65 and 0.40 kg/ha (Susan John, 2006b).

CASSAVA

The awareness on the need to replenish Zn arouse from the observation of the Zn status of the soil under a permanent manurial experiment at the Central Tuber Crops Research Institute (CTCRI) where-in after 14 years of continuous cultivation of cassava since 1977 with single nutrient, viz. N, P, K alone or double nutrients as NP, NK, PK without any organic manure (FYM) resulted in a severe drain of micronutrients, especially, Zn (Kabeerathumma *et al*., 1993; Susan John *et al*., 1998). The lowest level of available Zn was seen with P alone treatment (0.14 µg/g) and in treatment combinations devoid of FYM and K. From an initial soil Zn status of 0.82 µg/g, at the end of the 14^{th} year, the soil Zn content was reduced to 0.47, 0.49, 0.55 µg/g in the case of N alone, P alone and K alone treatments, respectively, compared with absolute control recording a Zn content of 0.22 µg/g, revealing the need to replenish Zn when cassava is grown continuously in the same field with major nutrients alone (Susan John *et al*., 2005). This information was the first step in initiating Zn nutrition studies in cassava followed by other crops.

Response to micronutrients including zinc

Micronutrient deficiencies are not very frequently reported for cassava, though it appears that, the Zn requirement for cassava is particularly high. In acid laterite soils, Nair and Kumar (1980) studied the effect of nutrients, viz. Mn, Zn, Cu, B and Mo, on tuber yield and tuber quality and found that, application of Zn as $ZnSO_4$ @ 12.5 kg/ ha along with NPK @100 kg/ha each resulted in tuber yield, starch (fresh-weight basis) and HCN content to the tune of 29.4 t/ha, 29.6% and 90.3 µg/g compared to 25.4 t/ha, 27.6% and 119.6 µg/g under control, showing 16 and 7% increase in tuber yield and starch and 24.5% decrease in HCN content owing to Zn application (Nair and Mohan Kumar, 1980).

Standardization of the rate of application of Zn

In the laterite soils of Kerala with a low Zn status of 0.35 µg/g, trials were undertaken with 3 levels of Zn as 0, 2.5 and 5.0 kg/ha and the tuber yield, starch percentage and HCN under these levels were 23.4, 26.4, 26.5 t/ha and 24.9, 25.3 and 26.7% and 52, 41.6 and 38.1 µg/g, respectively (Mohan Kumar and Nair,1985), indicating that, application of Zn at optimum level can improve both tuber yield and tuber quality by reducing the cyanogenic glucoside content and increasing the starch content; and hence, recommended the application of Zn @ 2.5 kg/ha (as $ZnSO_4.7H_2O$ @ 12.5 kg/ha) along with recommended package of practices (PoP: NPK @ 100:50:100 kg/ha + farm yard manure (FYM) @ 12.5 t/ha).

Effect of continuous application of Zinc

Understanding the depletion of Zn due to continuous application of major nutrients in cassava, in the second phase of the long-term fertilizer experiment (LTFE) (1991–2005), Zn as $ZnSO_4.7\ H_2O$ @ 12.5 kg/ha alone and together with $MgSO_4$ @ 20 kg/ha along with PoP was included as treatments. Independent application of Zn is better in terms of tuber yield, tuber quality, soil Zn status, plant Zn content and plant Zn uptake (Susan John *et al*., 2005). A comparison of the treatments, viz. T_1, N : P_2O_5 : K_2O @ 125 : 50 : 125 kg/ha; T_2, package of practices (PoP) as N : P_2O_5 : K_2O @ 100 : 50 : 100 kg/ha; T_3, blanket recommendation of Zn, (BR) – PoP + $ZnSO_4$ @ 12.5 kg/ha during the II phase on different attributes indicated the BR resulted in tuber yields as 33.96, 35.02 and 34.36 t/ha under the above treatments which were at par during the first 3 years when the soil Zn status was 0.35, 0.62 and 0.77 µg/g, respectively (Fig. 1). As the soil Zn status increased high (> 0.6 µg/g) due to continuous application of $ZnSO_4$ @ 12.5 kg/ha, no significant improvement in tuber yield was noted afterwards (Fig.1). Though no significant effect of Zn application was noticed with BR on tuber quality attributes, soil Zn, leaf Zn, stem Zn and total plant uptake of Zn was significantly higher with numerical improvement in tuber Zn (Table 1) (Susan John *et al*., 2015a).

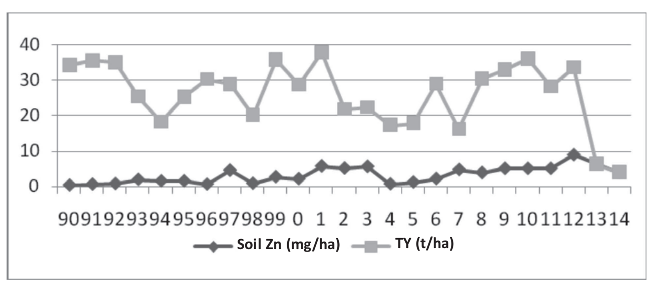

Fig. 1. Relationship between tuber yield and soil zinc status over a period of 25 years

Soil test-based application of Zn

Based on the data of 10 years under LTFE on Zn nutrition of cassava, the Zn dose to be applied was arrived based on soil Zn status, soil critical level of Zn and plant requirement of Zn and included in the package of practices (PoP) recommendation of the Kerala Agricultural University (KAU, 2011, 2016; Susan John *et al*., 2010, 2011, 2015a, 2015b, 2015c, 2016a).

The recommendation is read as: Soil application of Mg as $MgSO_4$ @ 20 kg/ha (1.62 g/plant) and Zn as $ZnSO_4$.$7H_2O$ @ 12.5 kg/ha (1 g/plant) in small channels around the mounds within 2 months of planting cassava providing an interval of two weeks between the applications of these fertilizers is good for enhancing tuber yield and tuber quality. When they are used continuously, the application rates of Zn can be fixed based on their status in the soil as <0.2, 0.2–0.3, 0.3–0.4, 0.4–0.6 and > 0.6 µg/g as 12.5, 10, 7.5, 5.0, 2.5 kg $ZnSO_4.7H_2O$/ha (Susan John *et al*., 2016c).

Based on the results of the II phase (non response to blanket application of Zn), resorted to soil test-based application (STB) of Zn in the III phase as a maintenance dose of $ZnSO_4$ @ 2.5 kg/ha. Under STB application (T_3), starch, soil Zn and stem Zn were significantly higher and the overall effect during these years vividly indicates that, though there was no significant effect on tuber yield, Zn application can result in significant reduction in HCN and enhancement in starch content of cassava tubers (T_1 and T_2 are as in the previous II phase treatments). Moreover, leaf, stem and tuber Zn including total uptake of Zn were significantly increased (Table 1). The extremely high P status (25–75 kg P_2O_5/ha) of the soil of the experimental site might be one of the reasons for the poor response of Zn application on tuber yield (Susan John *et al*., 2005).

Soil test-based application of Zn was demonstrated in an area of 5 ha in 13 locations of 18 farmers fields in Kollam and Pathanamthitta districts of Kerala. The selected locations indicated wide variation in the Zn status and was attributed to the diverse cropping pattern, variation in the type and quantum of manures and fertilizers applied and the type of crops grown by farmers prior to soil sampling. The Zn status of the locations was very low to low with values ranging from 0.235 to 0.851 meq/100 g. The Zn requirement of cassava as well as the Zn status of these soils indicated the need to apply Zn in these soils as per the methodology suggested by Howeler (1996).

As per the soil test-based Zn recommendation evolved, based on the Zn status of the lowlands and uplands of the major 9 cassava-growing districts of Kerala, the Zn recommendation was arrived as $ZnSO_4.7H_2O$ @ 7.5 kg/ha. However, it ranged from 7.5 to 10 kg/ha $ZnSO_4.7H_2O$ (Susan John *et al*., 2011, 2014b). But application of Zn containing salts are definitely needed both for improvement of the status of these nutrients in the soil as well as for increasing yield and quality of the tuber. The tuber yield, cyanogenic glucoside content and starch content realized in the different farmers' field following the fertilizer and manurial recommendation as shown in Table 2. The tuber yield data in Table 2 clearly indicated the superiority of T_3 (NPK @ 82 : 6.3 : 68 kg/ha + FYM @ 6.8 t/ha + Mg SO_4 @ 14.5 kg/ha) and T_4 (NPK @ 82 : 6.3 : 68 kg/ha + FYM @ 6.8 t/ha + $ZnSO_4$ @ 10.50 kg/ha) where Mg and Zn, respectively along with NPK and FYM was applied based on soil test data over other treatments.

Moreover, application of Zn improved the quality parameters, viz. dry-matter, starch and cyanogenic glucoside content, as significant effect of treatments were noticed in

Table 1. Response of cassava to zinc nutrition over years under blanket and soil test-based application (pooled mean)

Duration	Treatment	Tuber yield (t/ha)	HCN (µg/g)	Starch (%) (F.w. basis)	Soil Zn (µg/g)	Leaf Zn (µg/g)	Stem Zn (µg/g)	Tuber Zn (µg/g)	Plant Zn uptake (g/ha)
1990–2004 (BR)	T_1	28.56	54.0	23.51	1.04	62.0	27.2	23.7	520
	T_2	24.82	62.5	22.28	0.98	58.9	26.8	19.9	463
	T_3	26.16	50.9	23.96	2.57	76.9	36.6	24.4	686
	SEm±	0.616	1.322	0.579	0.067	2.312	1.101	0.987	23.65
	CD (P=0.05)	2.443	NS	NS	0.883	13.47	5.13	NS	105.3
2005–2014 (STB)	T_1	27.87	61.1	20.93	3.67	76.0	41.5	25.2	823
	T_2	26.68	81.2	21.42	2.69	66.8	35.2	21.8	732
	T_3	24.89	46.9	23.08	4.47	78.6	45.0	29.6	754
	SEm±	0.722	1.409	0.698	0.053	3.124	1.345	0.784	18.95
	CD (P=0.05)	NS	NS	1.473	0.959	NS	6.40	NS	NS
1990–2014 (Overall)	T_1	28.27	56.93	21.96	2.14	67.8	33.69	24.35	646
	T_2	25.59	70.30	21.76	1.69	62.2	30.59	20.71	575
	T_3	25.63	49.25	23.43	3.36	77.6	40.41	26.62	714
	SEm±	0.853	1.648	0.345	0.061	2.908	1.674	0.698	21.23
	CD (P=0.05)	1.740	15.032	1.110	0.636	9.45	3.921	4.632	88.4

BR, Blanket recommendation; STB, soil test-based application; T_1, N : P_2O_5 : K_2O @ 125 : 50 : 125 kg/ha; T_2, PoP N : P_2O_5 : K_2O @ 100 : 50 : 100 kg/ha; T_3, blanket recommendation of Zn – PoP + $ZnSO_4$ @ 12.5 kg/ha

Table 2. Tuber yield, quality and economic parameters as influenced by the different treatments (mean of 13 locations)

Treatment	Tuber yield (t/ha)	Tuber quality parameters			Economics	
		Dry matter (%)	Starch (%) F.w. basis	Cyanogenic glucosides (µg/g)	Net income (₹/ha)	Benefit: cost ratio
T_1, Farmers practice	28.94	35.53	21.47	56.11	5,914	1.09
T_2, Package of practices (PoP)	33.18	35.41	22.95	53.57	17,448	1.27
T_3, Soil test-based NPK + FYM + Mg	38.84	37.88	24.19	37.88	37,099	1.62
T_4, Soil test-based NPK + FYM + Zn	42.18	38.03	23.08	34.07	45,125	1.75
T_5, Soil test-based NPK + FYM	34.62	35.27	21.15	43.61	26,871	1.45
SEm±	1.345	1.987	2.453	3.987	–	–
CD (P=0.05)	3.348	0.601	1.108	3.751	–	–

these parameters. There is significant reduction in cyanogenic glucoside with Zn application compared to the other treatments. The economics also showed the highest net income with Zn application (₹45,125/ha) as well as highest benefit: cost ratio (1.75) (Susan John *et al*., 2010, 2015c).

Diagnosis of Zn disorders in cassava under continuous cropping and its management

Cassava is found exceptionally susceptible to Zn deficiency and its continuous monoculture definitely leads to Zn deficiency (Susan John *et al*., 2005). In the permanent manurial experiment, well-developed Zn deficiency symptoms were seen as reduction in the number of leaf lobes and widening the angle of the lobes in young leaves under N and NP treatments at about 7–8 months stage of the crop. The senescence of affected leaves was much faster and finally the stem appeared very thin with very few rudimentary leaves at the top (Kabeerathumma *et al*., 1993; Susan John *et al*., 1998). Zinc deficiency causes a characteristic interveinal chlorosis of the younger leaves. Small white or light yellow chlorotic patches develop between the veins and then, successive leaves produced become smaller and more chlorotic. The leaf lobes become narrow, light green to white with the margins cupped upwards. Leaf tips turn necrotic under severe conditions. The basal lobes often tend to point away from the stem. Since the growing point is most affected, Zn deficiency drastically reduces the plant growth and yield.

It might be due to the depletion of soil-available Zn and Zn-P antagonism as reported by Nair *et al*. (1988). At higher levels of P, the concentration of Zn goes below the normal limit of 35 µg/g in youngest fully expanded leaf (YFEL) which in turn was the index leaf. The Zn deficiency can be ameliorated by application of $ZnSO_4.7H_2O$ @ 12.5 kg/ha. Dipping the stakes in 2–4% solution of $ZnSO_4.7H_2O$ for 15 minutes before planting or foliar application of 1–2% solution of $ZnSO_4.7H_2O$ is effective (Susan John *et al*., 2006a).

Critical nutrient concentration of Zn in soil and plant for cassava

The critical Zn content in soil for cassava cultivation as per Howeler (1983) was fixed as < 0.5, 0.5–1.0, 1–5, 5–50, > 50 µg/g as very low, low, medium, high and very high, respectively. According to Asher *et al.* (1980), the youngest fully expanded leaf (YFEL) petiole or leaf blade at 3–4 months stage is the best indicator of the nutritional status of the plant (index leaf) and the critical Zn content was fixed as < 25, 30–60 and > µg/g as the deficiency, sufficiency range and toxicity levels for Zn in cassava plant.

Zinc status of cassava-growing soils of Kerala

A rapid appraisal of the nutrient status of cassava-growing soils of Kerala was undertaken during 2003–06 in which the Zn status along with other soil chemical parameters of both lowlands and uplands of the 9 major cassava-growing districts of Kerala was determined.

As a prelude to developing soil test-based micronutrient (Zn) recommendation for cassava, the Zn status of the cassava growing soils of the 9 districts of Kerala, viz. Thiruvananthapuram, Kollam, Pathanamthitta, Alapuzha, Kottayam, Idukki. Ernakulam, Palakkad and Malappuram having cassava area above 5,000 ha spread in 76 panchayats of the 45 blocks of these districts according to the statistics available in Farm Guide (2004) were analysed. Based on the soil Zn status, the soils were classified as per the general soil critical level of Zn as 0.6 µg/g (Dev, 1997) into sufficient and as per Howeler (1996) into very low, low, medium, high and very high based on the status of these nutrients in soil and the requirement of these nutrients for cassava (Susan John *et al*., 2011, 2014a).

The Zn status of the cassava-growing soils of Kerala ranged from 0.619 to 2.836 µg/g. There was not much variation in the soil Zn status of the different districts and also between the upland and lowland soils of the same district. The lowland soils of Idukki had the highest available Zn (2.836 µg/g) and the lowland soils of Ernakulam gave the lowest status of 0.619 µg/g. Both the upland and lowland soils were found sufficient in Zn as per the soil critical level. With respect to the specific Zn requirement for cassava, except the upland soils of Thiruvananthapuram district which was low in Zn, all others were found medium. In the lowland situation, the soils of Pathanamthitta, Alapuzha and Ernakulam were found low and others were medium (Susan John *et al*., 2009; Susan John *et al*., 2014c).

Moreover, the Zn status of the soils of 2 districts of Kerala, viz. Pathanamthitta and Kottayam, were assessed based on the analysis of 21,953 soil samples. In Pathanamthitta, based on the analysis of 10,591 soil samples, 90% of the samples were found sufficient in Zn with the content ranged from 1.4 to 31.6 µg/g with a mean value of 5.6 µg/g. All the 56 panchayats of the district were high in available Zn (Susan John *et al*., 2012a, 2013). In Kottayam district, 95% of the samples out of the 11,605 samples analysed were adequate in Zn (Geetha *et al*., 2013). In the preparation of a nutrient-management plan for 1 block (Elanthur) of Pathanamthitta district, the Zn status of the 7 panchayats of the block was analysed and the Zn status of the panchayats under the block ranged from 2.90 to 4.30 µg/g which in turn was sufficient (Susan John, 2012b).

Based on the analytical results of around 1,54,531 soil samples of the 14 districts of Kerala, Zn deficiency was found negligible (except in soils of the eastern Wyanadu plateau) with 87% of the samples adequate in Zn (KSPB, 2013, Rajasekharan *et al*., 2014) (Figs. 2 and 3).

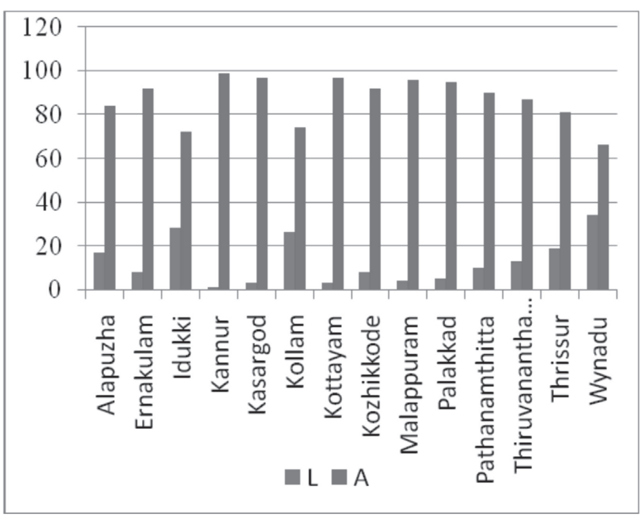

Fig. 2. Zinc status of the different districts of Kerala (%)

As a prelude to developing customized fertilizer mixtures for EFY and best management practices (BMP) in cassava and EFY, the weighted average of the Zn status of 2 agro ecological units (AEU) of Kerala, viz. AEU 3 and AEU 9, comprising 43 panchayats of the 2 districts viz., Alappuzha and Kollam, and 161 panchayats spread over Thiruvananthapuram, Kollam, Alappuzha, Pathanamthitta, Kottayam and Ernakulam districts in AEU 9 was arrived as 3.74 and 5.3 µg/g respectively (Anju *et al*., 2016).

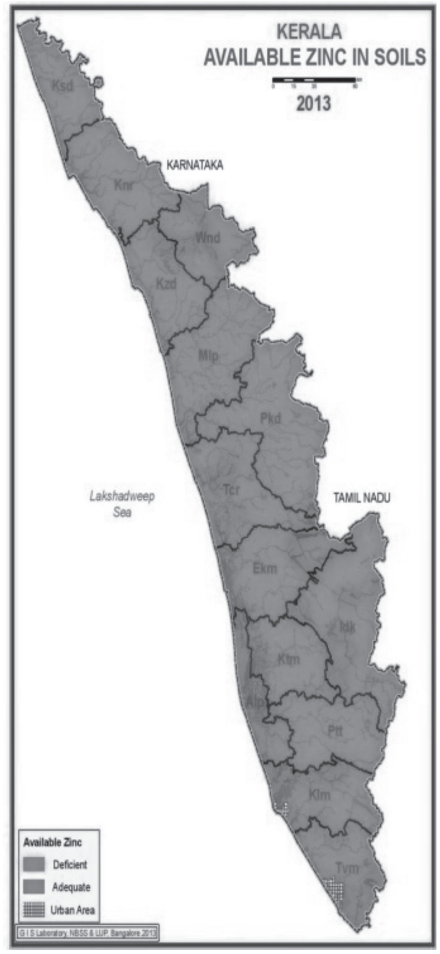

Fig. 3. Map showing the zinc distribution in different districts of Kerala

Sorption studies for Zn under the concept of 'Systematic approach in fertilizer use for cassava

In order to arrive at the optimum treatment to realize the maximum yield in cassava, under the concept of Maximum Yield Research (MYR) with the principle of 'Systematic approach in fertilizer use', nutrient sorption studies were conducted for Zn with 6 different levels of Zn as 0, 2.5, 5.0, 10, 20, 40 µg/g in a Typic Kandiustult of Kerala. The soil-available Zn at the above rates were 1.54, 3.60, 5, 8, 13.06 and 25 µg/g, respectively, indicating that there is no need to apply Zn as the levels are higher than 3 times the soil critical level of Zn (0.6 µg/g) (Susan John *et al*., 2005, 2007).

Zinc in relation to cassava mosaic disease

Zn was also tried as one of the nutrients to manage cassava mosaic disease (CMD) where the experiments were conducted both under controlled condition and in field. Soil ($ZnSO_4$ @ 1 g/plant within 1 month of top dressing) and foliar application of Zn (as 0.1% $ZnSO_4$) in alternate weeks from 3 MAP to 6 MAP under controlled condition (in lysimeter) indicated nutrients, viz. Zn, is having effect on tolerance to CMD in the most-susceptible variety Sree Visakham. The same trend was observed in the qPCR analysis of virus load in the treated plants at different durations with Zn giving the best results. Among the nutrients, viz. Ca, Mg, K, Cu, Zn, B, Mn, Si tried, the better response with respect to mosaic infection was least for Zn application. The tuber yield was the highest for Zn application among the different nutrients tried (CTCRI, 2017c).

Field experiment conducted with the most susceptible cassava variety 'H 226' using Zn both with soil application @ 1 g/plant as $ZnSO_4$ at 1 week after planting of setts, 2 1/2 months after planting (MAP) and 5 MAP and foliar @ 0.1% $ZnSO_4$ from 1 week of sprouting till 6 MAP in alternate weeks during 2016–17 indicated better results with Zn in reducing the infection to 68% from 86% under absolute control. Tuber yield was 24.93 t/ha with Zn and was the second among the nutrients tried (boron being first, tuber yield: 26.68 t/ha) and the absolute control gave an yield of 21.5 t/ha, indicating 16% increase in tuber yield with Zn application. In the field experiment, the second least infection was for Zn (65%) after Si (61.7%) (CTCRI, 2017c).

Low-input management strategy involving soil test-based application of Zn for cassava

The low-input management strategy involving nutrient-efficient genotypes, viz. Acc. No. 905 and Acc. No. 906 coupled with integrated nutrient-management practice involving green manuring *in-situ* with cowpea as source of organic manure and soil test based application of N, P, K, $MgSO_4$ and $ZnSO_4$ @ 106 : 0 : 83 : 20 : 2.5 kg/ha during the first year and 106 : 0 : 94 : 10 : 2.5 kg/ha during the second year along with nutrient efficient biofertilizers containing N fixer (*B. cereus*), P (*B. megaterium*) and K-solubilizing bacteria (*B. subtilis*) was found as a better option for cassava. The low-input management strategy with soil test-based application of Zn was at par with other management practices where the tuber yield under the management practices were 28.34, 27.53, 29.61 and 28.73 t/ha for PoP, soil test-based NPK + FYM, PoP + biofertilizers and low-input management strategy. The low input practice could save P, K, Mg and Zn to the tune of 100, 11.5, 62.5 and 80%, respectively, and the percentage increase in cost of inputs under the above practices over the low input practice varied significantly up to 55% with a benefit: cost ratio of 4.41 (Shanida Beegum *et al*., 2015; Susan John *et al*., 2016b; Shanida Beegum, 2017).

Zinc-enriched thippi compost

The cassava starch factory solid waste (thippi) with a very high C: N ratio of 82 : 1 and very low Zn content to tune of 7.8 μg/g under vermi-composting with organic materials, viz. FYM, *Gliricidia*/cassava leaves, Mussoriphos and rock powder resulted in a nutrient-rich thippi compost having Zn content of 89.93 μg/g which was 12 times than thippi and C : N ratio of 8:1. (Chithra *et al*., 2017; CTCRI, 2014). In cassava, the effect of application of thippi compost for 2 seasons was studied and found thippi compost @ 3.87 t/ha along with soil test-based application of N: P : K @ 78 : 0 : 48 kg/ha (24.662 t/ha) can substitute external application of Zn fertilizer to the tune of $ZnSO_4.7H_2O$ @ 2.5 kg/ha along with soil test-based application of NPK @ 78 : 0 : 48 kg/ha and FYM @ 5 t/ha (24.436 t/ha) (Chithra *et al*., 2016).

SWEET POTATO

Sweet potato is a hardy and nutritious staple crop, grown throughout the humid tropical and subtropical regions of the world. The edible roots (tubers) are formed by secondary thickening of the upper part of some feeder roots.

Index leaf and critical nutrient concentration

The youngest fully expanded leaf (YFEL) at 1 month after planting is taken as the index leaf and the critical concentration of Zn in this leaf tissue is reported as 11 μg/g (Sullivan *et al.,* 1997).

Zinc deficiency symptoms and its management

At CTCRI, Pillai *et al*. (1986) conducted sand culture experiment under controlled condition to simulate deficiency symptoms of Zn wherein omission of Zn resulted in thickened but not distorted leaves with serious plant growth limitation including shortening of internodes. General chlorosis of the young leaves, with narrowing of the leaf lamina is common. Initially, yellow spots appear on young leaves, which later change to interveinal chlorosis and finally end with complete bleaching of the young leaves. The tubers of Zn-deficient plants are of normal shape and well developed, but a brown discolouration can be seen on the flesh. Almost the same symptom was noticed under field condition too. Over control (40.8 μg/g), the Zn content in the Zn omitted plant tissues were 33.6 μg/g which in turn helped in the diagnosis of Zn deficiencies under field conditions. Zn-deficiency is usually managed through dipping the cuttings in 2–4% $ZnSO_4.7H_2O$ for 15 minutes before planting and foliar spraying of 1–2% $ZnSO_4.7H_2O$ solution (Susan John *et al*., 2006a).

Effect of soil and foliar application of Zn on sweet potato tuber yield

The effect of soil and foliar application of Zn was studied in lysimeter as well as in field. For soil application, $ZnSO_4.7H_2O$ @ 17 kg/ha was given within 1 month of top-dressing of NPK fertilizers. Foliar application was done as co-application of Zn-EDTA @ 250 g/ha along with N : P : K @ 19 : 19 : 19 kg/ha (5 kg/ha) at maximum vegetative growth stage. Over PoP, both soil and foliar applications were found effective in enhancing the tuber yield to the tune of up to 15–25% (Aparna, 2017; CTCRI, 2017b).

YAMS

Zinc content in different plant part of yams

A study was was conducted by Kabeerathumma *et al.* (1987) on the Zn content in the leaf, vine, root and tuber of the different *Dioscorea* sp., viz. µg/g purple yam (*D. alata* L.), white yam [*Dioscorea rotundata* (Poir.)] and lesser yam (*D. esculenta* (Lour.) Burkill] during the 3, 5, 7 and 9 months after planting (MAP) revealed a steady decline in Zn content of root and tuber with maturity of the crop. A slight reduction in Zn content of leaf and vine was noticed in the case of *D. esculenta* and *D. cayensis* subsp. *rotundata* at 7 MAP. An increasing tendency in the Zn content of plant parts was observed at harvest stage. The low concentration of Zn during the active vegetative growth may be due to dilution effect, while the build up may be due to senescence and consequent transfer of Zn from aged leaves to growing parts. Zn content in the tubers of *D. esculenta, D. alata* and D *rotundata* were 29, 29, 30 µg/g, respectively. Zn uptake was the highest in *D. esculenta* (0.531 kg/ha), followed by *D. rotundata* (0.456 kg/ha) and *D. alata* (0.327 kg/ha). The tuber uptake of Zn was determined as *D. rotundata* (0.286 kg/ha), D. *esculenta* (0.278 kg/ha) and *D. alata* (0.134 kg/ha).

ELEPHANT FOOT YAM

Zinc content in different plant parts

Kabeerathumma *et al.* (1987) studied the Zn content in leaf, pseudostem, tuber and root portions of elephant foot yam (EFY) at 3, 5, 7 and 9 MAP and reported that, the Zn content of the different plant parts decreased with maturity which indicated that active uptake of Zn was in the early stages of growth. Zn content in the EFY tuber was 60 µg/g. Zn removal through the entire crops was 0.49 kg/ha and through the crop residue was 0.085 kg/ha.

Development of CF formulations for EFY containing Zn under intercropping in coconut for AEU 3 and AEU 9

As per the Adhoc recommendation of KAU (2012) and based on the weighted average of the Zn status of the 2 AEU's, the optimum Zn recommendation was arrived as 5.25 kg/ha (Anju *et al.*, 2016). As a prelude to the development of customized fertilizer (CF) formulations for EFY intercropped in coconut gardens of Kerala, to arrive at the optimum rate of Zn application and the quantity of fertilizer Zn to be added in the CF formulations, Zn level experiments with different levels of Zn as 0.5 Zn, 1 Zn, 1.5 Zn, 2 Zn times that of optimum fixed were carried out in AEU3 and AEU 9. In AEU 3, 1.5 Zn as Zn @ 7.88 kg/ ha and in AEU 9, Zn @ 2.63 kg/ha (0.5 Zn) has been taken as the optimum (Anju *et al.*, 2016). Three customized fertilizer formulations containing Zn too were developed for 2 AEU's of Kerala based on the different experiments conducted. The grade of Zn in the 2 CF formulations developed based on STCR approach for an yield target of 45 t/ha for EFY intercropped in coconut garden was 1% for AEU 3 and 1.3% for AEU 9. In the response curve approach, the optimum Zn level for AEU 3 and 9 were 4.3 and 6.2 kg/ha, respectively, and the Zn grades in the CF formulations were 0.8 and 1.2% for AEU 3 and 9 respectively (Anju *et al.*, 2016).

Effect of soil and foliar application of Zn on tuber yield

The effect of soil and foliar application of Zn was studied with the same treatments given for sweet potato under controlled condition and in field and the yield data of the first season indicated a tuber yield of 3.998 kg/plant for soil, 3.135 kg/plant for soil + foliar and 3.765 kg/plant for foliar application along with PoP (NPK @ 100 : 50 : 150 kg/ha) which was 10–12% more than PoP alone (CTCRI, 2017a).

TARO

Zn content in different plant parts of taro (Colocasia) and Zn uptake

Kabeerathumma *et al.* (1987) studied the percentage removal of Zn by the different plant parts, viz. leaf, petiole, root and tuber of taro at 30, 60, 90, 120 and 150 DAP (harvest). Zn content in the plant showed a tendency to increase with increase in the age of the crop and peak concentration was observed at 150 DAP. Zn content was maximum in root and leaves had the least Zn content. Taro tuber contained 107 µg/g of Zn. The percentage removal of Zn declined with maturity in all plant parts except tuber which showed an increasing trend. The percentage removal of Zn progressively increased with maturity and the maximum was observed between 120–150 days after planting (DAP). The Zn uptake was determined as 647 g/ha.

CHINESE POTATO

Zn content in different plant parts of Chinese potato

(Coleus) and Zn uptake

Kabeerathumma *et al*. (1987) studied the Zn content in the leaf, vine, root and tuber of *Coleus* and shown that, the Zn content of the leaf decrease with maturity and was higher than that of vine and root during the first 2 months after planting (MAP). Zn content of the stem and root did not show any significant change with maturity. Zn content of the tuber was slightly lower at tuber-initiation phase and the increase noticed at 3 MAP was maintained up to harvesting. The tuber has 31 μg/g Zn and the Zn uptake was calculated as 397 g/ha.

The role of Zn in reducing the cyanogenic glucoside content and increasing the starch content of cassava tubers is having good social impact in using Zn, especially in bitter cassava varieties with high cyanogenic glucosides and hence the technology/ practice can be a socially acceptable information. The reduction in symptom expression of cassava mosaic disease (CMD) in leaves and increase in tuber yield owing to Zn application can be a socially acceptable practice as CMD is a widespread problem everywhere, where cassava is grown. Hence, if it can be practically feasible, social acceptance of the technology is expected in using Zn for managing CMD. The information generated on Zn status of cassava-growing lowland, uplands of Kerala, Zn status of the 2 districts of Kerala, viz. Kotayam and Pathanamthitta, and other districts of Kerala and Kerala in general and the weighted average of the Zn status of the 2 agro-ecological units of Kerala, viz. AEU 3 and AEU 9, is academically an important input for students, planners and policy-makers for reference and implementing more Zn centric research and extension activities related to crop and soil productivity. However, future research need to be oriented in studying the impact of Zn application through different modes as soil, foliar and soil along with foliar on Zn content of the different plants and incidentally on the bio-available Zn. As chemical fortification of Zn is more profitable, easy and can be achieved in a short time frame, this can be an urgent need of the hour especially as tuber crops form a staple for the nutritionally vulnerable folk of the country.

REFERENCES

Anju, P.S., Susan John, K., Subhendu Bhadraray., Suja, G., Jeena Mathew., Nair, K.M., Sunitha, S. and Veena, S.S. 2016. Development of protocol for custom mixed fertilizers for elephant foot yam under intercropping in coconut gardens of the two agro-ecological units of Kerala. *Journal of Root Crops* **42**(2): 66–74.

Aparna, S. 2017. Secondary and micronutrients on soil health and plant growth under sweet potato. *MSc. Thesis submitted to Mahatma Gandhi University, Kerala* pp. 89

Asher, C.J., Edwards, D.G. and Howeler, R.H. 1980. *Nutritional Disorders of Cassava (Manihot esculenta* Crantz*)*, University of Queens land, St. Lucia, Australia, pp. 48.

Chithra, S., Susan John, K. and Sreekumar, J. 2016. Low cost traditional cassava starch factory solid waste (Thippi) composting: A possible strategy for organic nutrient management and economic security for tribal farmers. *Journal of Root Crops* **42**(2): 52–58**.**

Chithra, S., Susan John, K., Manikantan Nair, M. and Sreekumar, J. 2017. Management of cassava factory solid waste (Thippi) through composting to a nutrient-rich organic manure. *Communications in Soil Science and Plant Analysis* **48**(6): 595–607.

CTCRI. 2014. A nutritious thippi compost organic manure from cassava starch factory solid waste. *CTCRI Newsletter* **29**(4): 6.

CTCRI, 2017a. *ICAR-Central Tuber Crops Research Institute*, *Annual Report,* CTCRI, pp. 46.

CTCRI, 2017b. *ICAR-Central Tuber Crops Research Institute*, *Annual Report,* CTCRI, pp. 47

CTCRI, 2017c. *ICAR-Central Tuber Crops Research Institute*, *Annual Report,* CTCRI, pp. 62.

Farm Guide. 2004. *Area under crops, 2001–02*. Farm Information Bureau, Government of Kerala. p. 16.

Dev, G. 1997. Soil fertility evaluation for balanced fertilization. *Fertiliser News* **42**(4): 3–34.

Geetha, K., Susan John, K., Dhanyamol, K., Praveena, N., Radhika, T.A., Manikantan Nair, M., Jibi Joseph, Sherin Paul and Anuroopa, S. 2013. Soil fertility: Kottayam district. (In) *Soil Fertility Assessment and Information Management for Enhancing Crop Productivity in Kerala*. Rajasekharan, P., Nair, K.M., Rajasree, G., Suresh Kumar P. and Narayanan Kutty, M.C. (Eds), Kerala State Planning Board, Thiruvananthapuram, Kerala. pp. 284–304.

Howeler, R.H. 1983. Analisis del tejidovegetalen el diagnostico de problems nutritionales de algunas cultivos tropicals. Centro International de Agricultura Tropicale (CIAT) ISBN 84-89206-35-X, Cali, Colombia.

Howeler, R.H. 1996. Diagnosis of nutritional disorders and soil fertility management of cassava. (In) *Tropical Tuber Crops: Problems, Prospects and Future Strategies,* pp. 181–193. Kurup, G.T., Palaniswami, M.S, Potty, V.P., Padmaja, G., Kabeerathumma, S. and Pillai, S.V. (Eds) Oxford & IBH Publishing Co Pvt., Ltd, New Delhi.

Kabeerathumma, S., Mohan Kumar, C.R., Nair, G.M. and Nair, P.G. 1993. Effect of continuous cropping of cassava with organics and inorganics on the secondary and micronutrient elements status of an acid Ultisol. *Journal of Indian Society of Soil Science* **41**(4): 710–713.

Kabeerathumma,S., Mohan Kumar, B. and Nair, P.G. 1987. *Nutrient Uptake and their Utilization by Yams, Aroids and Coleus*. Technical Bulletin Series, No.10, Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, pp. 34

KAU. 2011. *Package of Practices (PoP) Recommendations*: *Crops* (14th Ed.). Directorate of Extension, Kerala Agricultural University, (KAU), Thrissur, pp. 58.

KAU. 2016. *Package of Practices (PoP) Recommendations*: *Crops* (15th Ed.). Directorate of Extension, Kerala Agricultural University, (KAU), Thrissur, pp. 65.

KAU, 2012. *Adhoc Recommendation for Management of Secondary and Micronutrients in Kerala*, KAU, Thrissur.

KSPB, 2013. *Soil fertility assessment and information management* *for enhancing crop productivity in Kerala*. Rajasekharan, P., Nair, K.M., Rajasree, G., Suresh Kumar, P. and Narayanan Kutty M.C (Eds.), Kerala State Planning Board, Thiruvananthapuram, Kerala, pp. 514.

Mohan Kumar, B. and Nair, P.G. 1985. *Lime, sulphur and zinc in cassava production*. Technical Bulletin Series, No. 2, Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, pp. 15.

Nair, P.G. and Mohan Kumar, B. 1980. Response of cassava to micronutrient application in acid laterite soils. (In) *National Seminar on Tuber Crops Production Technology*, Coimbatore, India, pp. 81–83.

Nair, P.G., Mohan Kumar, B., Prabhakar, M. and Kabeerathumma, S. 1988. Response of cassava to graded doses of phosphorus in acid laterite soils of high and low P status. *Journal of Root Crops* **14** (2): 1–9.

Pillai, N.G., Mohan Kumar, B., Kabeerathumma,S. and Nair, P.G. 1986. Deficiency symptoms of micronutrients in sweet potato (*Ipomoea batatas* L.). *Journal of Root Crops* **12**(2): 91–95.

Rajasekharan, P., Nair, K.M., Susan John, K., Suresh Kumar, P., Narayanan Kutty, M.C. and Ajith, R.N. 2014. Soil fertility related constraints to crop production in Kerala. *Indian Journal of Fertilisers* **10**(11): 56–62.

Shanida Beegum, S.U., Susan John, K., Sheela, M.N. and Sreekumar, J. 2015. Low cost cassava production strategy through nutrient use efficient genotypes integrated with low input management. *Journal of Root Crops* **41**(2): 42–48.

Shanida Beegum, S.U. 2017. Low input management strategy in cassava: Implications of rhizosphere dynamics and carbon sequestration under changing global environment. Ph.D Thesis, Kerala University, pp. 226.

Sullivan, J.N., Asher, C.J. and Blamey, F.P.C. 1997. *Nutrient Disorders of Sweet Potato*. Australian Centre for International Agricultural Research Monograph No. 4B, p. 136.

Susan John, K., Mohan Kumar, C.R., Ravindran, C.S. and Prabhakar, M. 1998. Long term effect of manures and fertilizers on cassava production and soil productivity in an acid Ultisol. (In) *Proceedings of the National Workshop on Long term Soil Fertility Management through Integrated Plant Nutrient Supply.* Swarup, A., Reddy, D.D. and Prasad, R.N. (Eds.). Indian Institute of Soil Science, Bhopal, India, pp. 318–325.

Susan John, K., Ravindran, C.S. and James George. 2005. *Long term fertilizer experiments-Three decades experience in cassava*. Technical Bulletin, Series No. 45, Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, p. 89.

Susan John, K. and Venugopal, V.K. 2005. Optimizing the nutritional status of a Typic Kandiustult of Kerala, India using sorption study. *Communications in Soil Science and Plant Analysis* **36**(7 and 8): 2,329–2,342.

Susan John, K. Suja, G., Edison, S. and Ravindran, C.S. 2006. Nutritional Disorders in Tropical Tuber Crops. Technical Bulletin Series No. 48, Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, p. 74.

Susan John, K. 2006. Plant nutrition requirements of yams, aroids and minor tuber crops. (In) *Quality Planting Material Production in Tropical Tuber Crops*, Central Tuber Crops Research Institute, Sreekariyam, Thiruvananthapuram, Kerala, India, pp. 114–124.

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

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

Susan John, K., Ravindran, C.S. and Manikantan Nair, M. 2009. Secondary and micronutrient status of cassava growing soils of Kerala. *Journal of Root Crops* **35**(2): 175–181.

Susan John, K., Ravindran, C.S., Suja, G., Prathapan, K., Naskar, S.K. and James George. 2011. Response of cassava to zinc: Two decades experience in an Ultisol of Kerala, India. (In) *Extended Abstracts, 3rd International Zinc Symposium*, Hyderabad, India, 10–14 October 2011, pp. 27–28.

Susan John, K., Bharathan, R., Manikantan Nair, M. and Suja, G. 2012. Soil based nutrient management plan for Pathanamthitta district of Kerala state. *Journal of Root Crops* **38**(1): 32–41.

Susan John K. 2012. Nutrient management plan for Elanthur block of Pathanamthitta district. A joint publication of Department of Agriculture, Government of Kerala, Kerala State Planning Board and Central Tuber Crops Research Institute, p. 30.

Susan John, K., Manikantan Nair, M., Sherin Paul, Anuroopa, S., Geetha, K., Dhanyamol, K., Praveena, N. and Radhika, T.A. 2013. Soil Fertility: Pathanamthitta district. (In) *Soil Fertility assessment and information management for enhancing crop productivity in Kerala*. Rajasekharan, P., Nair, K.M., Rajasree, G., Suresh Kumar, P. and Narayanan Kutty M.C. (Eds.), Kerala State Planning Board, Thiruvananthapuram, Kerala, pp. 377–399.

Susan John, K., Ravi, V., Shanida Beegum, S.U., Ravindran, C.S., Manikantan Nair, M. and James George. 2014a. Recommended nutrient management practices in the carbon sequestration potential of cassava (Two decades experience from a long term fertilizer experiment). *Indian Journal of Fertilisers* **10**(4): 28–33.

Susan John, K., Shanida Beegum, S.U. and Ravi, V. 2014b. Management of the wastelands by exploiting the carbon sequestration potential and climatic resilience of cassava. *Journal of Root Crops* **40**(2): 28–32.

Susan John, K., Ravindran, C.S., Manikantan Nair, M. and James George 2014c. Soil test based fertilizer cum manurial recommendation for cassava growing soils of Kerala. *Technical Bulletin Series, No. 58*, Central Tuber Crops Research Institute, Sreekariyam, Thiruvananthapuram, Kerala, India, p. 44.

Susan John, K., Ravindran, C.S. James George, Shanida Beegum, S.U. and Manikantan Nair, M. 2015a. Zn nutrition in cassava (*Manihot esculenta* Crantz): Experience from 25 years of continuous cultivation in an Ultisol of Kerala, India. (In) *Catalogue of Abstracts of the 4th International Zinc Symposium, Improving Crop Production and Human Health,* Sao Paulo, Brazil, 15–17 October 2015. pp. 48–49.

Susan John, K., Ravindran, C.S., James George, Shanida Beegum, S.U. and Manikantan Nair, M. 2015b. Zn Nutrition in cassava (*Manihot esculenta* Crantz): Experience from 25 years of continuous application in an Ultisol of Kerala, India. *CTCRI Newsletter* **32**(4): 8.

Susan John, K., Ravindran, C.S. and James George 2015c. Soil test and plant analysis as diagnostic tools for fertilizer recommendation for cassava in an Ultisol of Kerala, India. *Communications in Soil Science and Plant Analysis* **46**(13): 1,607–1,627.

Susan John, K., Ravindran, C.S., Naskar, S.K., Suja, G., Prathapan, K. and James George. 2016a. Sustainable cassava production and soil based nutrient management: Experience from a long term fertilizer experiment and field validation trial in an Ultisol of Kerala, India. (In) *Proceedings of the 9th Regional cassava workshop,* Nanning, China, pp. 217–233.

Susan John, K., Shanida Beegum, S.U., Sheela, M.N. and Suja, G. 2016b. Nutrient efficient genotypes in cassava: scope to substitute for chemical fertilizers and in C sequestration. *Acta Horticultura* 118. ISHS. 2016. DOI 10.17660 / Acta Hortic. 2016.1118.29. XXIX- Proc. Int. Symp. on Root and Tuber Crops: Sustaining Lives and Livelihoods into the Future, Schultheis, J.R. (Ed.), pp. 193–200.

Susan John, K., James George, Shanida Beegum, S.U. and Shivay, Y.S. 2016c. Soil fertility and nutrient management of tropical tuber crops-An overview. *Indian Journal of Agronomy* **61**(3): 263–273.