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Zinc Nutrition of Tuber Crops in Ultisols of Kerala

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Abstract

Cassava, sweet potato, elephant foot yam, yams, taro, *tannia*, arrow root and coleus are the important tropical tuberous vegetables grown for their edible tubers and leaves which can meet the energy, nutritional and medicinal requirements of the consumers. Among the tropical tuber crops, cassava is most important with respect to higher biological efficiency, area under cultivation, acceptability as a secondary staple, ability to thrive under marginal soil and environmental conditions, tolerance to pests and diseases, quantity and quality of starch, and its excellent physico-chemical and biochemical properties for the preparation of value-added products. Inherently high yield potential of these crops catalyses the nutrient removal from the soil, necessitating their replenishment through external sources. Micronutrient requirements of these crops are very high; deficiency disorders, however, manifest only in extreme cases. Zinc depletion noticed under continuous cultivation of cassava over 14 years under a permanent manurial experiment made us initiate intensive studies on Zn nutrition in tropical tuber crops and we made significant accomplishments in this field. These include Zn dynamics under a long-term fertilizer management, especially with respect to reduction in cyanogen and increase in starch content of tubers; determination of the Zn status of the soils of Kerala; arriving at the Zn content in customized fertilizers developed for elephant foot yam; preparation of a Zn-enriched compost from cassava starch factory solid waste; development of low input management strategy for cassava involving soil test based application of Zn; and their respective on-farm validation trials.

Key words *:* Zinc dynamics, long-term fertilizer experiment, cyanogenic glucosides, soil test based zinc recommendation, customized fertilizers, *Thippi* compost

Introduction

Tropical tuber crops like cassava (*Manihot esculenta* Crantz), sweet potato (*Ipomoea batatas* L. Lam), yams (*Dioscorea* sp.) and Elephant foot yam (*Amorphophallus peaoniifolius*), taro (*Colocasia* sp.), tannia (*Xanthosoma* sp.) and minor tuber crops like Chinese potato (*Coleus*), arrow root (*Maranta*) and yam bean (*Pachyrrhizus*) are considered as the 'Present crops for the millennium' with respect to climate resilience, food security, quality of the tubers and soil productivity. Since these constitute staples in several countries and constitute either the primary or subsidiary food for about 1/5th of the world's population, these are also regarded as the third most important food crops for humans after cereals and grain legumes. Tuber crops have higher biological efficiency, serve as cheap source of energy, especially for the weaker sections of the population, and have ability to sustain *albeit* lower yields on poor and marginal soils even under aberrant weather conditions. These attributes make them ideal for cultivation in the less developed countries of Asia, Africa and Latin America where these are considered as a source of income and employment besides being the food-security crops. Among the tropical root and tuber crops, cassava (*Manihot esculenta* Crantz.) commonly known by the name 'Tapioca' native to South America belongs to the family Euphorbiaceae. It tops globally, nationally and regionally in terms of area and production.

Tropical tuber crops in general, and cassava in particular, respond well to the application of manures and fertilizers (Susan John et al., 2005). Due to high productivity, nutrient uptake by this group of crops *vis-à-vis* field crops is very high, leading to accelerated depletion of these nutrients from soil reserves and their replenishment through external sources like organic manures, mineral fertilizers and biofertilizers becomes vital.

Among micronutrients, zinc (Zn) has been identified to be critical with respect to tuber yield and tuber quality, especially in reducing the cyanogenic glucoside (responsible for bitterness) content of cassava tubers. Susan John et al. (2016c) reported higher uptake of major, secondary and micro nutrients by tropical tuber crops. Uptake of Zn by cassava, sweet potato, yams, elephant foot yam, taro and *Coleus* yielding 30, 18, 18-30, 33, 17 and 26 t ha^{-1} tubers was 0.81, 0.46, 0.33-0.53, 0.49, 0.65 and 0.40 kg ha^{-1}, respectively (Susan John, 2006).

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Significant crop-wise findings emanating from our intensive and sustained researches are reported below:

Cassava (*Manihot esculenta* Crantz)

Significance of Zinc Nutrition: Results from Long-term Fertilizer Experiment

Evaluation of soil fertility status of a long-term fertilizer experiment after 14 years in 1991 [experiment started in 1977 with single nutrients *viz.*, N, P, K alone or double nutrients as NP, NK, PK without any organic manure (FYM)] at CTCRI, Thiruvananthapuram showed that there was a severe drain of Zn under cassava cultivation (Kabeerathumma et al., 1993; Susan John et al., 1998). Lowest level of available Zn was obtained under P-alone treatment (0.14 mg kg^{-1}) and in treatment combinations devoid of FYM and K. At the end of 14^{th} year of cassava cultivation, available soil Zn content was reduced from initial 0.82 mg kg^{-1} in 1977 to 0.47, 0.49, 0.55 mg kg^{-1} under N-alone, P-alone and K-alone treatments. It clearly established the need for replenishing Zn in the soils under continuous cassava cultivation supplemented with major nutrients alone (Susan John et al., 2005).

Long-term Effect of Zinc Application

Realizing the alarming depletion of Zn occurring due to continuous application of major nutrients in cassava, in the second phase of the long-term fertilizer experiment (LTFE) (1991-2005), zinc treatments *viz.*, 12.5 kg zinc sulphate heptahydrate ha^{-1} alone, and 12.5 kg zinc sulphate heptahydrate plus 20 kg magnesium sulphate ha^{-1} along with package of practices (PoP) were included. The rates of application of zinc sulphate heptahydrate and magnesium sulphate had been fixed earlier at 12.5 and 20 kg ha^{-1}, respectively (Nair and Mohan Kumar, 1980; Mohan Kumar and Nair, 1985). Application of zinc sulphate alone (BR) proved to be better in terms of tuber yield, tuber quality, soil Zn status, plant Zn content and plant Zn uptake (Susan John et al., 2005). Comparison of the treatments *viz.*, T_1 - $N:P_2O_5:K_2O$ @ 125:50:125 kg ha^{-1}, T_2 - Package of practices (PoP) as $N:P_2O_5:K_2O$ @100:50:100 kg ha^{-1} and T_3 - (Blanket recommendation of Zn, BR) – PoP + 12.5 kg zinc sulphate heptahydrate ha^{-1} during the II phase on different attributes indicated that the blanket recommendation of zinc (BR) resulted in tuber yields of 33.96, 35.02 and 34.36 t ha^{-1} under the above treatments which were on par during the first 3 years when the soil Zn status was 0.35, 0.62 and 0.77 mg kg^{-1}, respectively (**Figure 1**). As the available soil Zn status increased to the adequate (>0.6 mg kg^{-1}) Zn category due to continuous application of 12.5 kg zinc sulphate ha^{-1}, no significant improvement in tuber yield was noted thereafter **(Figure 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 were significantly higher with numerical improvement in tuber Zn content **(Table 1)** (Susan John et al., 2015a).

Soil Test-based Application of Zinc

Based on the 10 years data from LTFE on Zn nutrition of cassava, and also from critical level of soil Zn, plant Zn requirements, and soil Zn status, soil-test based Zn doses were computed which have been included in the package of practices (PoP) recommendations of Kerala Agricultural University (KAU, 2011, 2016; Susan John et al., 2010; Susan John et al., 2011; Susan John et al., 2015a,b,c; Susan John et al., 2016a).

Based on the intensive experimentation it has been found that soil application of Mg as 20 kg magnesium sulphate ha^{-1} (1.62 g $plant^{-1}$) and Zn as 12.5 kg zinc sulphate heptahydrate ha^{-1} (1 g $plant^{-1}$) in small channels around the mounds within 2 months of cassava planting providing an interval of two weeks between the applications of these fertilizers is good for enhancing tuber yield and tuber quality. When these are used continuously, Zn application rates can be fixed as 12.5, 10.0, 7.5, 5.0, 2.5 kg zinc sulphate heptahydrate ha^{-1} for soils measuring <0.2, 0.2-0.3, 0.3-0.4, 0.4-0.6 and >0.6 mg kg^{-1} in available Zn, respectively (Susan John et al., 2010). Based on the results of the II phase (non-response to blanket

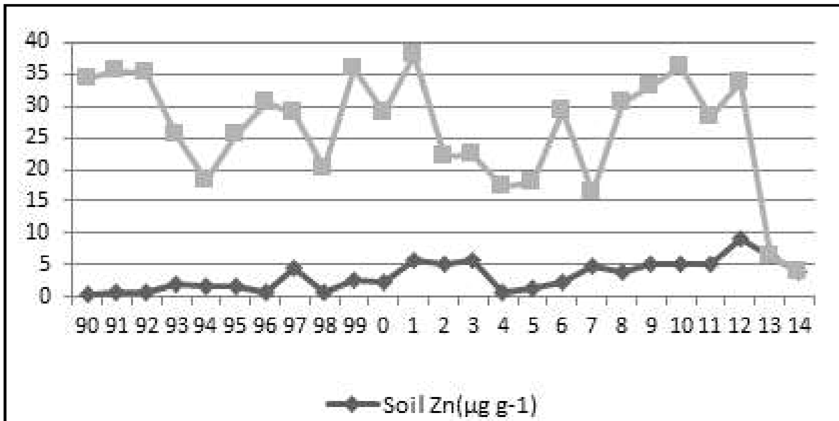


Figure 1. Relationship between tuber yield and soil Zn status over a period of 25 years

Table 1. Response of cassava to Zn nutrition over years under blanket and soil test based application (Pooled mean) (Susan John et al., 2015a)

Duration	Treatments	Tuber yield (t ha^{-1})	HCN (mg kg^{-1})	Starch (%)	Soil Zn (mg kg^{-1})	Leaf Zn (mg kg^{-1})	Stem Zn (mg kg^{-1})	Tuber Zn (mg kg^{-1})	Plant Zn uptake (g ha^{-1})
1990-2004 (BR)	T_1	28.6	54.0	23.5	1.04	62.0	27.2	23.7	520
	T_2	24.8	62.5	22.3	0.98	58.9	26.8	19.9	463
	T_3	26.2	50.9	24.0	2.57	76.9	36.6	24.4	686
	CD (P = 0.05)	2.4	NS	NS	0.88	13.5	5.13	NS	105
2005-2014 (STB)	T_1	27.9	61.1	20.9	3.67	76.0	41.5	25.2	823
	T_2	26.7	81.2	21.4	2.69	66.8	35.2	21.8	732
	T_3	24.9	46.9	23.1	4.47	78.6	45.0	29.6	754
	CD (P = 0.05)	NS	NS	1.47	0.96	NS	6.40	NS	NS
1990-2014	T_1	28.3	56.9	22.0	2.14	67.8	33.7	24.4	646
(Overall)	T_2	25.6	70.3	21.8	1.69	62.2	30.6	20.7	575
	T_3	25.6	49.3	23.4	3.36	77.6	40.4	26.6	714
	CD (P = 0.05)	1.7	15.0	1.1	0.64	9.5	3.9	4.6	88

application of Zn), Susan John et al. (2015a) resorted to soil test based application (STB) of Zn in the III phase as a maintenance dose of 2.5 kg zinc sulphate ha^{-1}. Under STB application (T_3), starch, soil Zn and stem Zn were significantly higher and the overall effect during these years vividly indicated that, though there was no significant effect on tuber yield, Zn application resulted in significant decrease in HCN and increase in starch contents of cassava tubers (T_1 and T_2 were same as in the previous phase III treatments). Moreover, leaf-, stem- and tuber-Zn and also total uptake of Zn were significantly increased **(Table 1)**. Extremely high P status (25-75 kg P_2O_5 ha^{-1}) of the experimental soil might be one of the reasons for the poor response of Zn application on tuber yield (Susan John et al., 2005).

Soil Test-based Zinc Application for Major Cassava-growing Districts of Kerala

Based on the rapid appraisal of the Zn status of the cassava growing soils of Kerala (Susan John et al. 2009), comprising of both uplands and lowlands, 7.5 kg zinc sulphate heptahydrate ha^{-1} was computed as the soil-test-based recommendation by Susan John et al. (2010) for the major nine cassava-growing districts of Kerala. Subsequently it was revised to range from 7.5 to 10 kg zinc sulphate ha^{-1} depending upon the soil Zn status (Susan John et al., 2011, 2014a).

Field Validation Trials on Soil Test-based Zinc Application

Soil test-based application of Zn was demonstrated in an area of 5 hectares in 13 locations on 18 farmers' fields in Kollam and Pathanamthitta districts of Kerala. The selected locations indicated wide variation in the Zn status which 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 0.24 to 0.85 mg kg^{-1}. Zinc requirement of cassava as well as the Zn status of these soils indicated the need to apply Zn (Howeler, 1996).

Data on tuber yield, cyanogenic glucoside content and starch content obtained from experiments conducted on farmers' fields **(Table 2)** showed the superiority of T_3 (NPK @ 82:6.3:68 kg ha^{-1} + FYM @ 6.8 t ha^{-1} + $MgSO_4$ @ 14.5 kg ha^{-1}) and T_4 (NPK @ 82:6.3:68 kg ha^{-1}+ FYM @ 6.8 t ha^{-1} + $ZnSO_4$ @ 10.50 kg ha^{-1}) where rates of Mg and Zn along with NPK and FYM had been applied based on soil test data over other treatments. Application of Zn significantly improved the quality parameters *viz.*, dry matter, starch and cyanogenic glucoside content. There was significant reduction in cyanogenic glucoside with Zn application compared to other treatments. Economics also showed the highest net income with Zn application (Rs. 45,125 ha^{-1}) as well as highest B:C ratio (1.75) (Susan John et al., 2010, 2015c).

Zinc Status of Cassava-growing Soils

As a prelude to developing soil test based micronutrient (Zn) recommendation for cassava, the Zn status of the cassava growing soils of the nine districts of Kerala *viz.*, Thiruvananthapuram,

Table 2. Tuber yield, tuber quality and economic parameters as influenced by the different treatments (Mean of 13 locations)							
Treatments	Treatment description	Tuber yield (t ha^{-1})	Tuber quality parameters			Economics	
			Dry matter (%)	Starch (%)	Cyanogenic glucosides (mg kg^{-1})	Net income (Rs ha^{-1})	B:C ratio (Rs. Re^{-1})
T_1	Farmers' practice (Mostly organic manures as FYM, ash, bone meal along with 1/4th NPK as per PoP)	28.9	35.5	21.5	56.1	5,914	1.09
T_2	Package of practices (PoP)	33.2	35.4	23.0	53.6	17,448	1.27
T_3	Soil test based NPK + FYM + Mg	38.8	37.9	24.2	37.9	37,099	1.62
T_4	Soil test based NPK + FYM + Zn	42.2	38.0	23.1	34.1	45,125	1.75
T_5	Soil test based NPK + FYM	34.6	35.3	21.2	43.6	26,871	1.45
CD (P = 0.05)		3.4	0.6	1.1	3.8	-	-

Source: Susan John et al. (2010, 2015c)

Kollam, Pathanamthitta, Alapuzha, Kottayam, Idukki Ernakulam, Palakkad and Malappuram having cassava area above 5000 hectares spread in 76 panchayats of the 45 blocks of these districts (Farm Guide, 2004) was assessed during 2003-2006. Based on the available soil Zn status, the soils were classified as per the general soil critical level of Zn as 0.6 mg kg^{-1} (Dev, 1997) into low and adequate categories and as per Howeler (1996) into very low, low, medium, high and very high categories based on the status of these nutrients in soil and the requirement of these nutrients for cassava (Susan John et al. 2009, 2011, 2014).

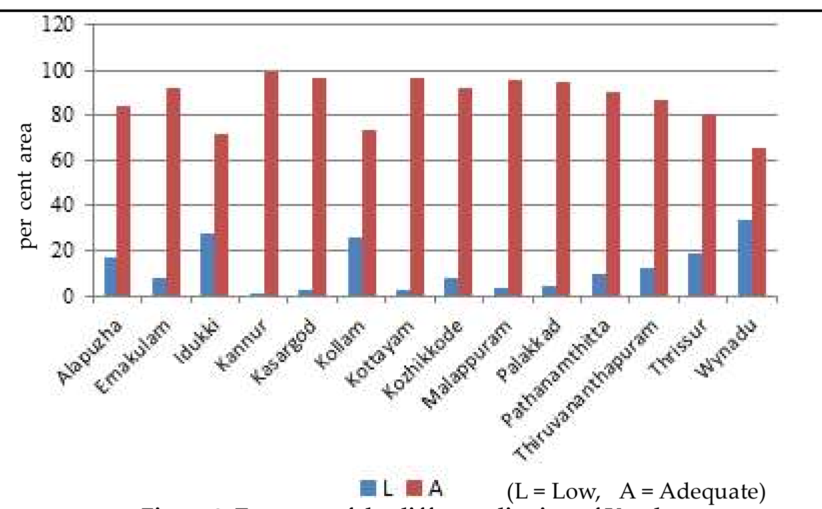
Available Zn status of the cassava-growing soils ranged from 0.62 to 2.84 mg kg^{-1} . There was not much variation in the soil Zn status of the different districts and also between the upland and lowland soils of the same district. The lowland soils of Idukki had the highest available Zn (2.84 mg kg^{-1}) and the lowland soils of Ernakulam recorded the lowest status of 0.62 mg Zn kg^{-1}. Both the upland and lowland soils were found to be sufficient in available Zn, having more than 0.6 mg Zn kg^{-1}. With respect to the specific Zn requirement for cassava, except the upland soils of Thiruvananthapuram district which were low in Zn, all others were found to be medium. In the lowland situations, the soils of Pathanamthitta, Alapuzha and Ernakulam were found to be low and others were medium (Susan John et al., 2009).

Zinc Status of Two Districts

Zinc status of the soils of Pathanamthitta and Kottayam districts was assessed. In Pathanamthitta, out of 10,591 soil samples analysed, 90% measured sufficient in available Zn with its content ranging from 1.4 to 31.6 mg kg^{-1} (mean value of 5.6 mg kg^{-1}). 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 available Zn (Geetha et al., 2013). In the preparation of a nutrient management plan for Elanthur block of Pathanamthitta district, the Zn status of the seven panchayats of the block was analysed; it varied from 2.90 to 4.30 mg kg^{-1} in these panchayats (Susan John, 2012).

Available Zinc Status of the Soils under Cassava Cultivation

Based on the analysis of 1,54,531 soil samples from 14 districts of Kerala, Zn deficiency was found to be almost negligible (except in soils of the eastern Wyanadu plateau) with 87% of the samples measuring adequate in available Zn (> 0.6 mg kg^{-1}) (KSPB, 2013; Rajasekharan et al., 2014) (**Figures 2 and 3**).



(L = Low, A = Adequate)

Figure 2. Zn status of the different districts of Kerala

Figure 3. Map showing the Zn distribution in different districts of Kerala

Sorption studies for Zinc 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 six levels of Zn *viz.* 0, 2.5, 5.0, 10, 20 and 40 µg g^{-1} in red loam (Typic Kandiustult) soils of Kerala. The soil available Zn at the above rates was 1.54, 3.60, 5, 8, 13.06 and 25 mg kg^{-1}, respectively indicating that, there is no need to apply Zn as the levels are higher than three times the soil critical level of Zn (0.6 mg g^{-1}) (Susan John and Venugopal, 2005, Susan John et al. 2007).

Zinc in Relation to Cassava Mosaic Disease

Experiments both under controlled conditions and as well as in the field were conducted to study the role of zinc in managing cassava mosaic disease (CMD). Soil application of zinc sulphate @ 1 g $plant^{-1}$ within one month of top-dressing and foliar application of 0.1% $ZnSO_4$ in alternate weeks from 3MAP (months after planting) to 6MAP under controlled conditions (*i.e.*, in lysimeter) indicated the positive effect of Zn in imparting tolerance against CMD in susceptible variety Sree Visakham. Similar 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 and Si tried, mosaic infection was least under Zn application. Tuber yield was highest for Zn application among the different nutrients tried (CTCRI, 2017). Field experiment conducted with susceptible cassava variety H 226 with Zn both soil (1 g $plant^{-1}$ as zinc sulphate) at one week after planting of setts, two-and-a- half MAP and 5 MAP and foliar (0.1% $ZnSO_4$) from one week of sprouting till 6MAP in alternate weeks during 2016-17 indicated better results with Zn as this reduced the CMD infection to 68% from 86% under absolute control. Tuber yield was 24.93 t ha^{-1} with Zn and was the second among the nutrients tried (boron being first, tuber yield: 26.68 t ha^{-1}). Tuber yield under absolute control was 21.5 t ha^{-1}, which indicates 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, 2017). Response of cassava tubers to Zn application over PoP is depicted in **Figure 4**.

Low Input Management Strategy 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^{-1} during the first year and 106:0:94:10:2.5 kg ha^{-1} during the second year along with nutrient efficient biofertilizers containing N fixer (*Bacillus cereus*), P (*B. megaterium*) and K solubilizing bacteria (*B. subtilis*) was found to be a better option for cassava. The low input management strategy with soil test based application of Zn was on par with other

Tuber yield : 5.4 kg $plant^{-1}$

Tuber yield : 4.3 kg $plant^{-1}$

Figure 4. Tuber yield under Zn in comparison to PoP

Thippi

Enriched thippi compost

Sweet potato

Figure 5. ***Thippi***

management practices where the tuber yields were 28.34, 27.53, 29.61 and 28.73 t ha^{-1} for package of practices (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 increase in cost of inputs under the above practices over the low input practice was up to 55% (Shanida Beegum, 2017; Shanida Beegum et al., 2015; Susan John et al., 2016b).

Zinc-enriched Thippi *Compost*

The cassava starch factory solid waste (*Thippi*) **(Figure 5)** with a very high C:N ratio of 82:1 and very low Zn content to the tune of 7.8 mg kg^{-1} under vermi-composting with organic materials *viz*., FYM, *Gyricidia*/cassava leaves, Mussoriephos and rock powder yielded a nutrient-rich *thippi* compost (**Figure 5**) having Zn content of 89.9 mg kg^{-1} which was 12 times higher than *thippi* and C:N ratio of 8:1 (Chithra et al., 2017; CTCRI, 2014). Effect of application of *thippi* compost for two seasons was studied in cassava. *Thippi* compost @ 3.87 t ha^{-1} along with soil test based application of NPK @78:0:48 kg ha^{-1} produced 24.66 t cassava tubers ha^{-1} and could substitute external application of 2.5 kg zinc sulphate ha^{-1} as application of zinc sulphate along with soil test based application of NPK @78:0:48 kg ha^{-1} and FYM @ 5 t ha^{-1} yielded 24.44 t ha^{-1} (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.

Effect of Soil and Foliar Application of Zinc

Effect was studied in lysimeter as well as in field. In soil application, 17 kg zinc sulphate monohydrate ha^{-1} was given within one month of topdressing of NPK fertilizers. Foliar application was done as co-application of Zn EDTA @ 250 g ha^{-1} along with NPK @ 19:19:19 kg ha^{-1} (5 kg ha^{-1}) at maximum vegetative growth stage. Both soil and foliar applications were found to be significantly superior to PoP in increasing the tuber yield to the tune of up to 15-25% (Aparna, 2017; CTCRI, 2017).

Elephant Foot Yam

Development of Customized Fertilizer Formulations

As per the *ad hoc* recommendation of KAU (2012) and based on the weighted average of the Zn status of the two agro-ecological units (AEU's), optimum Zn recommendation worked out to be 5.25 kg ha^{-1} (Anju et al., 2016). As a prelude to the development of customized fertilizer (CF) formulations for elephant foot yam (EFY) intercropped in coconut gardens of Kerala, field experiments with different levels of Zn *viz*., as 0.5, 1, 1.5 and 2 times of the optimum fixed Zn level (5.25 kg ha^{-1}) were carried out in AEU3 and AEU 9. In AEU 3, 1.5 Zn (7.88 kg Zn ha^{-1}) and in AEU 9, 0.5 Zn (2.63 kg ha^{-1}) were taken as the optimum (Anju et al. 2016). Based on the different experiments conducted, three customized fertilizer formulations containing Zn were developed for these two AEUs. The grade of Zn in the two CF formulations developed based on STCR approach for a yield target of 45 t ha^{-1} for economic fruit yield (EFY) intercropped in coconut garden was 1% for AEU 3 and 1.3% for AEU 9. In the response curve approach, the optimum Zn levels for AEU 3 and AEU 9 were 4.3 and 6.2 kg ha^{-1} respectively and the corresponding Zn grades in the CF formulations were 0.8 and 1.2% (Anju et al., 2016).

Effect of Zinc Application 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 4.00 kg plant^{-1} for soil, 3.14 kg plant^{-1} for soil + foliar and 3.77 kg plant^{-1} for foliar application along with PoP (NPK @100:50:150 kg ha^{-1}) which was 10-12% more than PoP alone (CTCRI, 2017).

Conclusions

The role of Zn in reducing the cyanogenic glucoside content (lessening the bitterness) and increasing the starch content of cassava tubers has a great social impact. Reduction in symptom expression of CMD in leaves and increase in tuber yield due to Zn application can be another socially acceptable practice as CMD is a widespread problem in cassava growing areas. Information generated on Zn status of cassava growing lowlands and uplands of Kerala, Zn status of the two districts of Kerala *viz*., Kotayam and Pathanamthitta and the weighted average Zn status of the two agro-ecological units of Kerala *viz*., AEU 3 and 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 needs to focus on studying the impact of Zn application through different modes (soil, foliar, and soil + foliar) on Zn content of the different plants as well as on bioavailable Zn status.

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