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Utilization of Resources as a Component of Integrated Nutrient Management Strategy in Tropical Tuber Crops

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Abstract

Tropical tuber crops like cassava, sweet potato and elephant foot yam have served as major/subsidiary food for a major section of the global human population since time immemorial. Because of the higher biological efficiency, manifested in terms of high tuber yields, response of these crops to application of fertilizers and manures is high. Though tuber crops are grown on marginal soils, our experience has shown that the farmers' income can be enhanced substantially through proper utilization of different natural as well as applied resources under integrated nutrient management (INM) practice. Natural resources managed in this strategy include soil, planting material and crop residues; whereas applied resources involve organic manures, chemical fertilizers and biofertilizers. This paper describes a detailed account of the ways in which these resources have been managed efficiently leading to the higher benefit : cost ratio. The low input management technology developed at the ICAR-CTCRI, Thiruvananthapuram by combining the natural as well as applied resources like nutrient use efficient (NUE) planting material; cost-effective organic manure source like green manuring *in situ* with cowpea; soil test based application of fertilizers including major, secondary and micro nutrients; and use of effective biofertilizers not only effected up to 55% saving in the fertilizer inputs but also raised the farm income with benefit : cost (B:C) ratio up to 4.4:1.

Key words: Nutrient use efficiency (NUE), planting material, sustainability, carbon sequestration, customized fertilizers, *thippi*, soil quality, crop residues

Introduction

As per Cambridge dictionary, resource is a useful or valuable possession or quality of a country, organization, or person. Air, water, food, plants, animals, minerals, metals and everything else that exists in nature and has utility to mankind is a 'resource'. There are three types of economic resources which are also referred to as factors of production; these are land (including all natural resources), labour (including all human resources), and capital (including all economic resources). In crop production, natural resources namely, soil, planting material or residue of the crop influence the crop yields and sustain soil health. Soil resource, in addition to supplying nutrients for plant growth, provides beneficial microbes which help in cycling nutrients to plant-assimilable forms. Usually the applied resources are chemical fertilizers, organic manures and bio-fertilizers. Effective utilization of all these resources leads to the enhanced productivity.

Sustained research efforts were made at ICAR-CTCRI for enhancing income of the farmers growing tropical food crops like cassava, sweet potato and elephant foot yam through judicious use of natural resources like soil (nutrients, microbes), planting material (crop/variety), crop residues (leaves, stem, solid waste from cassava starch factory) and applied resources like chemical fertilizers, organic manures and bio-fertilizers. This article presents, collates and discusses the work done at ICAR-CTCRI which led to the development of integrated plant nutrition supply system for these crops.

Soil as a Natural Resource for Tropical Tuber Crops

Soil is a prime source of nutrients for plant growth. Tropical tuber crops are mainly grown in Ultisols (laterites), Alfisols (red soils) and Entisols (coastal sandy loam). Laterites are poor in organic matter, and low in available nitrogen (N), available phosphorus (P) and available potassium (K) with pH range of 4.0-5.5. Red soils are loamy in texture; low in organic matter, available N and available P; and medium in available K with pH varying from 5.0 to 7.0. Sandy loam soils are low in organic matter and plant nutrients. Hence, in general tuber crops growing soils are poor in native fertility, low in cation exchange capacity (CEC) and high in P fixing capacity. As regards to the fertility status, tuber crops growing soils of Kerala are acidic with medium soil organic carbon (SOC); high in available P; low to medium in available K; low in calcium (Ca) and magnesium (Mg) content; sufficient in a available sulphur (S), iron (Fe), copper (Cu), manganese (Mn) and zinc (Zn); and very

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low in available boron (B) content. Extensive use of Factomphos (NPKS @20:20:0:13) by farmers which is manufactured in Kerala and comparatively the low P requirement of these crops over N and K coupled with the immobile nature of the nutrients can be attributed to the very high build-up of available P and sufficiency of S in these soils (Rajasekharan et al., 2013).

Resource Management in Tropical Tuber Crops under INM Practice

Natural Resources

Natural resources are further classified as soil/ nutrients, planting materials and crop residues. Management of each resource is described below:

Soil/Nutrient Management

In case of soil nutrient management under INM, the best approach is the soil test based (STB) application of manures and fertilizers including major, secondary and micro nutrients. In case of major nutrients *viz*., N, P and K, procedure suggested by Aiyer and Nair (1985) was followed. Cassava crop under a longterm fertilizer experiment was initiated in 1977; present team of researchers introduced the following changes. Because of high P build up, application of P fertilizers was omitted and the rates of application of N and K fertilizers were also reduced. Experiment has been monitored regularly since then. Data over 13 years (from 2005 to 2017) revealed that the N, P, K rate on the soil test basis (STB) was only 82:0:73 kg ha^{-1}, where the recommended package of practices (PoP) envisaged the application of 100:50:100 kg N: P_2O_5: K_2O ha^{-1}. Correspondingly, the mean tuber yield data over these years under PoP and STB was 25.03 and 22.95 t ha^{-1}, respectively which was statistically on par (Susan John et al., 2015, 2018, 2019b). Application of secondary (Mg) and micro (Zn and B) nutrients for cassava under LTFE was made as per Susan John et al. (2010b). Blanket recommendation of Mg, Zn and B practiced from 2005 till 2011 was 20 kg $MgSO_4$, 12.5 kg $ZnSO_4$ and 10 kg borax ha^{-1}, respectively. Mean soil test data for six years since 2012 in the case of Mg, Zn and B was 0.55 ceq kg^{-1}, 5.07 mg kg^{-1} and 0.91 mg kg^{-1}, respectively. Based on these soil test values, the mean rates of application of $MgSO_4$, $ZnSO_4$ and borax were 10, 2.5 and 4.2 kg ha^{-1}, respectively.

The mean tuber yield data over seven years under the blanket recommendation of Mg, Zn and B was 24.76, 25.08 and 24.81 t ha^{-1}, respectively. It was on par with that under PoP (26.30 t ha^{-1}). However, with soil test based application of these nutrients since 2013 for six years significantly higher yield was obtained in case of Mg (27.27 t ha^{-1}). In other treatments *viz*., Zn (24.66 t ha^{-1}) and B (23.37 t ha^{-1}), yield was on par with PoP (22.39 t ha^{-1}). This directly points to the fact that the response of the crop to the applied nutrient occurs only if the available status of that nutrient in the soil is below the critical level of deficiency. In this case, soil was deficient only in Mg and hence the yield response (Susan John et al., 2019b). Application of Zn over PoP caused increase in tuber yield, reduction in the cyanogenic glucoside content and enhancement in the starch content (**Table 1**).

Soil test based application of Mg and Zn was tested in the field at 13 locations spread over 3 districts of Kerala during 2005-07 under a State Horticulture Mission Project with five treatments (**Table 2**). Data on B:C ratio revealed that the application of Zn and Mg was superior to PoP and FP in terms of significantly higher tuber yield, lower cyanogenic glucoside content and higher starch content (**Table 2**) (Susan John et al., 2019b).

Planting Material (Crop/ Variety)

It became evident from the study in cassava initiated in 2006 to screen K-efficient genotypes initially and then N-efficient and NPK-efficient genotypes that the nutrient use efficient (NUE) genotypes play a significant role in reducing the use of chemical fertilizers. Out of the six genotypes *viz*., Aniyoor, W-19, H 1687, CR 43-8, 7 III E3-5 and 6-6 which were screened for physiological efficiency coupled with almost all favourable attributes to designate them as acceptable by farmers, Aniyoor was released with

Table 1. Effect of Zn application on tuber yield and quality of cassava

Practices	Period	Treatment	Tuber yield (t ha^{-1})	Cyanogenic glucosides (mg kg^{-1})	Starch (%)
Blanket	2006-12	PoP	24.82	62.50	22.28
		PoP+Zn	26.16	50.90	23.96
STBF	2013-18	PoP	24.46	62.55	20.60
		PoP+Zn	26.74	54.56	22.66
Mean		PoP	24.64	62.53	21.44
		PoP+Zn	26.45	52.73	23.31

Source: Susan John et al. (2019a, b)

Table 2. Soil test based application of secondary and micro nutrients on cassava under field trial at 13 locations

Treatment description	Tuber yield (t ha^{-1})	Tuber quality parameters			Economics	
		Dry matter (%)	Starch (%)	Cyanogenic glucosides mh kg^{-1}	Net income (Rs. ha^{-1})	B: C ratio (Rs. Re^{-1})
Farmers practice (FP)	28.95	35.53	21.48	56.16	5,914	1.09
Package of Practices (PoP)	33.18	35.41	22.96	53.58	17,448	1.27
Soil test based NPK+ FYM+ Mg	38.84	37.88	24.20	37.89	37,099	1.62
Soil test based NPK + FYM+ Zn	42.19	38.03	23.08	34.08	45,125	1.75
Soil test based NPK+FYM	34.63	35.28	21.16	43.62	26,871	1.45
CD (P = 0.05)	3.35	0.60	1.19	3.75	-	-

Figure 1. 'Sree Pavithra' the first K efficient variety in cassava

name 'Sree Pavithra' during 2015. It can yield even without application of K or with half the recommended dose of K owing to the innate potential of this genotype to scavenge and use the nutrients fixed in the lower layers through its unique root architecture **(Figure 1)**. Leaf area index also plays a crucial role.

Later these six genotypes were tested for their N efficiency. Cultivars W-19 and CR 43-8 were found to be yielding satisfactorily without N application and at lower levels of applied N (**Figure 2**). Again three other genotypes *viz.*, CI-905, CI-906 and 7 III E3-5 later screened as physiologically efficient were tested for their NPK efficiency for three years and it was found that the NPK application rate can be reduced to 25% by using these NPK efficient genotypes, thereby saving 75% on chemical NPK fertilizers. All these genotypes after field validation trials at 24 locations of Kerala was well accepted by farmers due to its good cooking quality and ideal plant architecture. As shown in **Figure 3**, genotypes

Figure 2. Tubers of N-efficient and NPK-efficient cassava genotypes

Figure 3. β carotene rich tubers of NUE genotypes (CI-905, CI-906)

Thippi Thippi compost

Figure 4. A view of the Thippi and its compost

CI-905 and CI-906 have good β-carotene content (Susan John et al., 2016, 2019b).

Sustainability of Cassava for Continuous Cultivation

Cassava is considered as a benign crop for continuous cultivation. Even without any manures and fertilizers (absolute control), the mean tuber yield during 2006-2018 was 14.33 t ha^{-1}. Sustainable yield index (SYI) worked out over these years was 0.74 and 0.39, respectively under PoP and absolute control (Susan John et al., 2018, 2019b). Higher SYI can be attributed to the C sequestration potential of the crop as well the comparatively high nutrient content in the leaves. High leaf dry matter production (to the tune of 2.5-5 t ha^{-1}) is indicative of the higher amount of CO_2 absorbed from the atmosphere through photosynthesis, causing reduction in the atmospheric CO_2 content. Because of the inherent leaf shedding nature of cassava, the atmospheric CO_2 converted to leaf carbon through photosynthesis will add to the soil and form a part of the soil organic carbon. Based on the data over 20 years since 1992 on leaf dry matter production, initial and final soil organic carbon and as per the theoretical calculations suggested by Singh et al., (2007), Jian (2004) and Ramakrishna et al. (2006), the organic carbon build up was 0.34 and 0.31%, respectively under PoP and absolute control (Susan John et al., 2019b). Elemental analysis of the cassava leaves showed that the average N, P, K, Ca, Mg, Fe, Cu, Mn and Zn content in the shed leaves was 4.41%, 0.28%, 1.25%, 0.21%, 0.32%, 160 mg kg^{-1}, 8 mg kg^{-1}, 154 mg kg^{-1} and 64 mg kg^{-1}, respectively. Since the shed leaves are rich in nutrients, their incorporation in the soil would improve the nutrient status of the soil, especially N. Comparatively higher yields and SYI under absolute control indicate that cassava is a sustainable benign crop for long-term cultivation under limited resource availability (Susan John et al., 2019b).

Crop Residues

In industrial belts of cassava cultivation like Tamil Nadu, after the extraction of starch, the solid waste (*thippi*) is found piled up in the starch factory premises and acts as a pollutant affecting the normal life of people, especially during rainy season. An attempt was made to convert *thippi* to an organic manure through vermi-composting and further recycling and using it in cassava cultivation both as an organic manure source, and also substitute to chemical fertilizers including secondary and micro nutrients. Results indicated a B:C ratio of 2.55 with thippi compost alone and 2.52 with FYM alone. Green manuring *in situ* with cowpea, crop residue, vermi compost, coir pith compost, and *thippi* compost along with soil test based (STB) application of manures and fertilizers yielded a B:C ratio of 2.62, 2.41, 1.55, 1.67 and 1.96, respectively. In the case of substitution of chemical fertilizers with *thippi* compost, 50% recommended dose of NPK as per soil test gave a B:C ratio of 1.95 which was on par with *thippi* compost along with full recommended dose of NPK as per soil test (1.96). In the case of substitution of Mg and Zn with *thippi* compost, the B:C ratio with Mg along with STB, Zn along with STB, and *thippi* compost along with STB was 2.71, 2.37, and 1.96, respectively (Chithra, 2017; Chithra et al., 2017; Susan John et al., 2019b).

Applied/ Purchasable Resources

These include organic manures, chemical fertilizers and biofertilizers.

Organic Manures

Different organic manures were tried for cassava in long-term fertilizer experiments during 1990-2005 as substitute for FYM. These included green manuring *in situ* with cowpea, half the recommended dose of FYM and crop residue along with recommended PoP, ash along with crop residue, ash along with FYM without NPK fertilizers. It was found that over these years, green manuring *in situ* with cowpea (21.40 t ha^{-1}), crop residue alongwith recommended PoP (23.12 t ha^{-1}), and half the recommended dose of FYM along with PoP (23.82 t ha^{-1}) yielded on par with full doze of FYM along with PoP (26.02 t ha^{-1}). Ash along with FYM and ash along with crop residue gave significantly lower yields of 16.67 and 14.48 t ha^{-1}, respectively. Later from 2006 till 2018, FYM was compared with organic manures like green manuring *in situ* with cowpea, coir pith compost and vermi compost along with PoP and half the recommended dose of NPK along with vermi-compost and coir pith compost and ash, crop residue, coir pith compost and vermi-compost together without NPK fertilizers. Mean data over these years indicated that the full dose of FYM (25.16 t ha^{-1}) was on par with green manuring *in situ* with cowpea (24.42 t ha^{-1}), coir pith compost (24.27 t ha^{-1}) and vermicompost (25.61 t ha^{-1}). Tuber yield was significantly low in the treatments receiving organics along with half the recommended dose of NPK (20.54 t ha^{-1}) and organics alone (17.72 t ha^{-1}) (Susan John et al., 2018, 2019b).

Chemical Fertilizers

In tuber crops, the major approaches used for applying chemical fertilizers include blanket recommendation based on fertilizer level experiments; soil test based INM practices as per the nutrient status of the soil taking care of the major, secondary and micro nutrient status; yield maximization through systematic approach in fertilizer use where the initial nutrient status of the soil, sorption characteristics of the soil and critical level of each nutrients are considered for arriving at the nutrient recommendation. Soil test crop response (STCR) approach takes into account the soil status as well as crop requirement for certain yield target, nutrient omission and nutrient level experiments focussed on arriving at the plant nutrient requirement based on the innate nutrient supplying capacity of the soil including nutrient use efficiency of the applied fertilizers. In this regard, the latest approach is customized fertilizer formulation specific to crops and soils/ agroecological units.

Customized fertilizer formulations were developed for elephant foot yam under intercropping in coconut gardens of Kerala for the major tuber crops growing soils *viz*., AEU3 and AEU 9. Grades of the customized fertilizer (CF) were arrived at based on the crop nutrient requirement, nutrient uptake, total soil nutrient availability, per cent contribution from soil, fertilizer nutrient to be applied and fertilizer use efficiency (Susan John et al., 2019b). Four grades of CF were developed based on soil test crop response approach for a yield target of 45 t ha^{-1} and response curve (RC) approach (**Table 3**). Component fertilizers for arriving at the grades mentioned above were mixed, ground and granulated such that each fertilizer granule had the same nutrient composition.

Out of the four CFs developed for AEU 3 and AEU 9, based on STCR and RC approaches, three were tried at one site in AEU 3 and two sites in AEU 9 at two different rates *viz*., 500 and 625 kg ha^{-1} during the first year. At all the three sites, all the three CFs at 625 kg ha^{-1} produced significantly high yield (**Table 4**).

Table 3. Grades /composition of the customized fertilizer (CF) mixtures developed for the two AEU's

AEU's	Approach	Customized fertilizer (CF) grade	Nutrient content (%)					
			N	P_2O_5	K_2O	Mg	Zn	B
AEU 3	STCR*	CF1	8	11	21	3.5	1	0.3
AEU 3	RC**	Not selected for field trial	6	3	30	3.5	1	0.3
AEU 9	STCR*	CF2	7	12	24	3.5	1.25	0.4
AEU 9	RC**	CF3	7	3	25	4.0	1.25	0.4

* STCR: Soil Test Crop Response **RC: Response curve

Table 4. Economic parameters under the field experiment (I year)

Treat-ment	Treatment description	Total cost of fertilizers and manures (Rs. ha^{-1})	Total cost of cultivation (Rs. ha^{-1})	Tuber yield (t ha^{-1})		Gross income (Rs. ha^{-1})		Net income (Rs. ha^{-1})		B:C ratio (Rs. Re^{-1})	
				AEU 3	AEU 9	AEU 3	AEU 9	AEU 3	AEU 9	AEU 3	AEU 9
T_1	500 kg CF1 ha^{-1}	40,803	3,69,053	14.25	33.84	4,27,511	10,15,320	58,457	10,15,319	1.16	2.75
T_2	500 kg CF2 ha^{-1}	41,745	3,69,995	13.39	38.22	4,01,718	11,46,669	31,723	11,46,668	1.09	3.10
T_3	500 kg CF3 ha^{-1}	39,212	3,67,462	15.45	38.96	4,63,395	11,68,695	95,933	11,68,694	1.26	3.18
T_4	625 kg CF1 ha^{-1}	44,138	3,72,388	19.03	39.12	5,70,777	11,73,568	1,98,389	11,73,566	1.53	3.15
T_5	625 kg CF2 ha^{-1}	44,158	3,81,218	18.13	44.84	5,43,810	13,45,160	1,62,591	13,45,158	1.43	3.53
T_6	625 kg CF3 ha^{-1}	42,885	3,70,364	20.22	44.41	6,06,497	13,32,151	2,36,133	13,32,150	1.64	3.60
T_7	Package of practices (PoP)	26,451	3,54,701	15.24	30.73	4,57,099	9,21,766	1,02,398	9,21,765	1.29	2.60
T_8	Farmers' practice	41,215	3,69,465	16.21	29.32	4,86,270	879467	116805	879465	1.32	2.38

Table 5. Economic parameters under the field experiment (II year)

Treatment	Treatment description	Total cost of manures and fertilizers (Rs. ha^{-1})	Total cost of cultivation (Rs. ha^{-1})	Tuber yield (t ha^{-1})	Gross income (Rs. ha^{-1})	Net income (Rs. ha^{-1})	B:C ratio (Rs. Re^{-1})
T_1	FP	41,215	3.69.465	51.65	15,49,350	12,21,100	4.19
T_2	PoP	26,451	3.54.701	47.36	14,20,800	10,92,550	4.01
T_3	625 kg CF1 ha^{-1}	44,138	3.72.388	58.71	17,61,240	14,32,990	4.73
T_4	625 kg CF2 ha^{-1}	44,158	3.72.408	67.56	20,26,830	16,98,580	5.44
T_5	625 kg CF3 ha^{-1}	42,885	3.71.135	62.62	18,78,690	15,50,440	5.06

In the ensuing year, three CFs @ 625 kg ha^{-1} were tested in the five major elephant foot yam growing districts of Kerala *viz.*, Thiruvananthapuram, Kollam, Pathanamthitta, Kottayam and Ernakulam. Formulation CF2 emerged as the best in terms of tuber yield, gross income, net income and B:C ratio (**Table 5**). Highest soil quality index (SQI) was recorded under farmers' practice, but it was statistically at par with CF1 and CF2 (**Figure 5**) (Anju, 2019, Anju et al., 2018; Susan John et al., 2019b).

Biofertilizers

In tropical tuber crops like sweet potato and elephant foot yam, biofertilizers containing N fixers, P and K solubilizers were included independently and together as microbial consortium under INM to study the extent of substitution of chemical fertilizer nutrients *viz.*, N, P and K. In sweet potato, two P solubilizers viz., *Enterobacter* spp. and *Pantoea agglomerans* were tried along with full N and K doses at different levels of P viz., 0, 25, 50, 75 and 100%. It was found that, *Enterobacter* could substitute chemical fertilizer P up to 25%. The N fixer *Acaligenes feacalis* was tried again in sweet potato at different levels of N and this could substitute up to 25% of chemical N (Susan John et al., 2010b).

In elephant foot yam, independent use of the N fixer (*Bacillus cereus)*, P solubilizer (*Bacillus megaterium*) and K solubilizer (*Bacillus subtilis*) and conjoint application of these three as microbial consortia could substitute fertilizer N, P and K independently and NPK together to the tune of 50, 100, 50 and 25%, respectively (Anjana Devi, 2014; Anjana Devi et al., 2015).

Low Input Management Strategy in Cassava

This was evolved by putting together all the different nutrient management components discussed earlier independently *viz.*, nutrient use efficient (NUE) genotypes, low cost organic manure source, soil test based application of manures and fertilizers, and nutrient use efficient microbes. Nutrient use efficient genotypes *viz.*, CI-905 and CI-906 under INM involving green manuring *in situ* with cowpea as the organic manure source, soil test based application of N: P: K: $MgSO_4$: $ZnSO_4$ @ 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 N fixer (*Bacillus cereus)*, P solubilizer (*Bacillus megaterium*) and K solubilizer (*Bacillus subtilis*) could save P, K, Mg and Zn to the extent of 100, 11.5, 62.5 and 80.0% with total reduction in an input cost of 55%. Tuber yield of 33.68 and 34.72 t ha^{-1} was realised with CI-905 with CI-906 genotypes with B:C ratio as 4.43 and 4.57, respectively (Shanida Beegum, 2016; Susan John et al., 2019b).

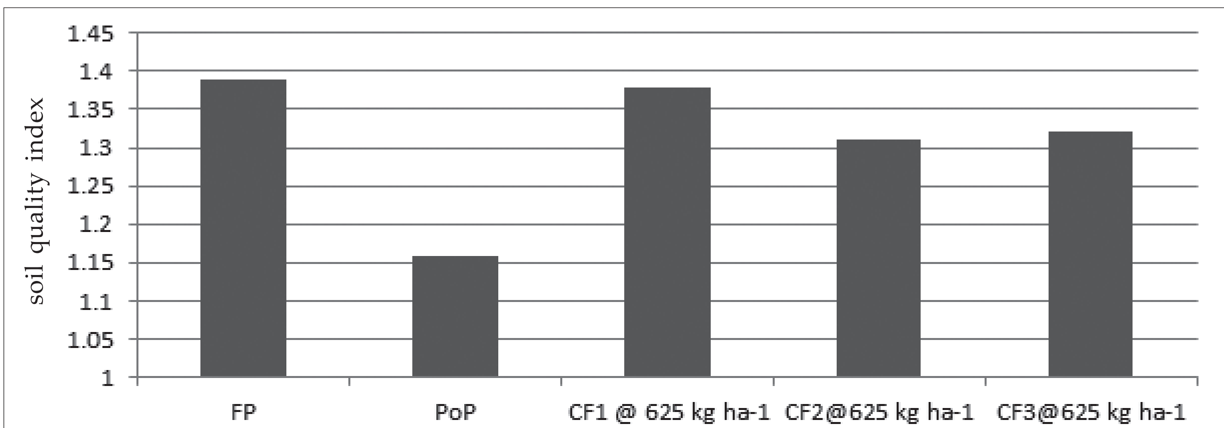

Figure 4. Effect of treatments on soil quality indices

Future Line of Research

This research work is being pursued for rationalization of the existing PoP recommendation (major, secondary and micro nutrients) for cassava for the major cassava growing areas *viz.*, AEU3 (Onattukara sandy soil) and AEU 9 (South central laterite) based on soil status and plant requirement, development of an integrated plant nutrition package comprising of major, secondary and micro nutrients for sweet potato and elephant foot yam (both soil & foliar) in Ultisols. Studies confirm the possibility of using polysulphate as fertilizer containing K, Ca, Mg and S as a good soil ameliorant for tuber crops growing in tropics soils as these are deficient in these nutrients and all these nutrients are significant for tropical crops**.**

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