



# Soil-Plant Nutrition of Sweet Potato and Minor Tuber Crops: A Review

K. Susan John

Central Tuber Crops Research Institute, Sreekariyam, Thiruvananthapuram 695 017, Kerala, India  
Corresponding author: K. Susan John, e-mail: susanctcri@gmail.com

Received: 2 December 2011; Accepted: 27 December 2011

## Abstract

Among the tropical tuber crops, sweet potato is the most nutritious in terms of macro and micronutrients contained in both the tubers and the green leaves. Owing to these good quality traits, it is valued as a secondary staple in many underdeveloped and developing countries viz., China, Africa, South America, South East Asia, Oceania etc., Nutrient management is one of the important topics that is intensively researched as it directly contributes to higher productivity and produce quality. Research on soil-plant nutrition undertaken in different sweet potato growing countries, the various soil factors influencing yield as well as quality of tubers, nutrient requirement, crop response to nutrients, nutrient management strategies, index leaf, critical nutrient concentration, nutritional disorders etc., are reviewed in this paper. Minor tuber crops like arrowroot, Chinese potato, yam bean etc., are also important from the nutraceutical point of view, but yet to be explored to unravel the potential of these crops for various medicinal uses. The available literature on minor tuber crops that indicate their positive response to manures and fertilizers are also discussed.

**Key words:** Sweet potato, Chinese potato, arrowroot, yam bean, nutrient uptake, nutrient recommendation, major, secondary, micronutrients, critical level, index leaf, tuber yield, tuber quality, nutritional disorders

## Introduction

Sweet potato (*Ipomoea batatas* L. Lam.) belonging to the family convolvulaceae is an important tuberous root crop having tremendous potential for utilization in food, feed and industrial sectors, especially for the production of starch, flour, glucose and alcohol. They are good sources of vitamin C, B2, B6 and E as well as dietary fibre, K, Cu, Mn and Fe. The high nutrient content coupled with its anti-carcinogenic and cardio-vascular disease preventing properties has gained recognition for the crop as a health food. They are widely grown in the tropics and warm temperate regions of the world. In developing countries, it is ranked fifth in economic value, sixth in dry matter production, seventh in energy production and ninth in protein production (Lobenstein, 2009). In India, it is the third most important tuber crop after potato and cassava. Globally, India occupies twelfth, eighth and fifth rank in area, production and

productivity respectively. It is cultivated predominantly as a rainfed crop in Eastern India, especially in Orissa, West Bengal, Uttar Pradesh, Bihar and Jharkhand, accounting for 77% of area and 82% of production (Edison et al., 2009).

Minor tuber crops like arrowroot, Chinese potato and yam bean are important due to their nutraceutical properties. However, these are neglected and require more research attention to exploit their yield potential.

It is understood that there is a wide gap between potential yield and the yield obtained under actual field situations for all these tuber crops. Among the different factors contributing to this yield gap, soil-plant nutrition is worthy of mention as soil fertility management and proper nutrition of these crops can result in large yield gains. This review deals with the soil-plant nutrition of sweet potato and minor tuber crops in relation to growth and productivity.

## I. Sweet potato

### Soil requirement

Sweet potato can be grown in a wide range of soils and climate (Jansson and Ramon, 1991). According to Bouwkamp (1985), sweet potato can be grown on a wide range of soil types but sandy or sandy loam soils having good porosity and aeration with reasonably high organic matter content and permeable sub soil are ideal. They are sensitive to saline and alkaline conditions. Adequate drainage is essential for their good growth. Heavy clays or soils very rich in humus generally result in good growth of shoots and leaves but normally result in low yields and poor quality tubers. Sweet potato is an acid tolerant crop and yields are usually high in soils with a pH of 5.5 to 6.5. Agricultural lime should be applied @ 1.25-2.50 t ha<sup>-1</sup> to soils with pH below 5.5 to effectively raise the pH to acceptable levels. In USA, application of lime was found to increase tuber yields in acid soils. Maximum yields were obtained at a pH range of 6.5-7.5 in silt loam (Watts and Cooper, 1943) and 6-7 in fine sandy loam soils (Bouwkamp, 1985).

### Nutrient requirement

Sweet potato removes considerable amount of nutrients from the soil. Sreelatha et al. (1999) reported that on an average, it removed 12.36 kg N, 1.01 kg P<sub>2</sub>O<sub>5</sub> and 10.72 kg K<sub>2</sub>O ha<sup>-1</sup> to produce 1 tonne of tuber. Mohankumar and Nair (1990) indicated that as the dry matter production of this crop per unit area per unit time was fairly high, the nutrient uptake was high and it was estimated that to produce an average yield of 18 t ha<sup>-1</sup>, the crop removed approximately 41 kg N, 13 kg P, 68 kg K, 22 kg Ca and 18 kg Mg.

### Response to nutrients

#### Major nutrients

##### *Nitrogen (N)*

Sweet potato generally responds to small doses of N application. Excessive N application results in profuse leaf production at the expense of root yield. N deficiency is usually noticed in sandy soils and soils low in organic matter content. Sweet potato responded to N application up to 100 kg ha<sup>-1</sup>. In one of the earlier trials conducted at Central Tuber Crops Research Institute (CTCRI) (Mandal et al., 1971), significant yield increases were

obtained up to 100 kg N ha<sup>-1</sup>. However, studies conducted at Kerala, Tamil Nadu and Maharashtra indicated that N @ 50 kg ha<sup>-1</sup> was sufficient for sweet potato production (Nair and Sadanandan, 1973; Muthuswami et al., 1981; Rajaput et al., 1981). Trials conducted at Coimbatore, Tamil Nadu revealed that application of 80 kg N, 50% as basal and 50% as foliar in the form of 2% urea at 30, 60 and 90 days after planting (DAP) regulated foliage growth and increased the tuber yield over full basal dressing and 50% basal + 50% top dressing at 30 DAP (Shanmugavelu et al., 1973). Similar observation was also made by Alexander et al. (1976) with the application of 75 kg N, 50% as basal and 50% as foliar at 35 DAP. Advantage of split application of N at planting and 30 days later in moderating top growth during tuber development period and thus achieving best result have been suggested by Morita (1967). On the other hand, delayed N application was unfavourable for tuber formation in sweet potato grown in sandy loam soils (Morita, 1970). It is a common experience that the plants utilize only 40-50% of applied N in the form of urea and the rest of the N is lost through leaching, volatilization and denitrification. Such low efficiency of utilization can be improved by modifying the urea to release N in a regulated fashion throughout the growing season (Nair, 2000). Different techniques of coating urea can improve N use efficiency in the Indian farming system. Preliminary trials conducted at CTCRI (1997) indicated that the dose of N could be reduced to 37.5 kg by coating urea with cow dung and inserting into the soil as cow dung ball urea at the time of planting.

##### *Phosphorus (P)*

Phosphorus deficiency and response to P application are most common in acid soils, especially in laterite and red soils such as Oxisols, Ultisols and Inceptisols, which contain high levels of Fe and Al. At CTCRI, Kabeerathumma et al. (1986) reported that rock phosphate was equally effective as single super phosphate in direct effect, but was superior in residual effect. Since the crop does not require very large quantities of P for root development, a P<sub>2</sub>O<sub>5</sub> dose of 25-50 kg ha<sup>-1</sup> was considered optimum.

##### *Potassium (K)*

Potassium plays a major role in the translocation of photosynthates from the leaves to the roots and

accelerates the process by contributing to the rapid cambial activity in the tuberous roots in which starch is stored. When K was applied, the activity of the enzyme, starch synthetase increased and when it was lacking, the enzyme activity became extremely low (Murata and Akazava, 1968). Deficiency of K is normally expected in sandy soils. Tsune and Fujise (1968) found that the photosynthetic activity of sweet potato leaves could be maintained by high level of K. Differential response to applied K has been reported from various parts of India. Soils high in available K status do not respond to added levels of K by significantly improving the tuber yield (Muthuswami et al., 1981). They also observed that between the two sources of K, schoenite had similar effect on the yield and starch content of sweet potato as that of muriate of potash. Based on the analyses of several experiments, Bao et al. (1985) concluded that K fertilization was very effective in sweet potato. On an average, applying 70 kg potash ha<sup>-1</sup> increased the tuber yield by 3.7 t ha<sup>-1</sup>. They also observed that K fertilizer increased the yield of sweet potato by increasing the number of tubers and the ratio of large to small tubers.

#### **Secondary nutrients (Ca, Mg and S)**

Calcium plays a major role in the water regulation of the plant, while Mg is a constituent of chlorophyll and is therefore essential for photosynthesis. Sulphur is a basic component of various aminoacids and is required for protein synthesis. The deficiency of these nutrients is generally encountered in highly leached acid soils.

Application of CaO @ 200 kg ha<sup>-1</sup> was found to be beneficial in increasing the yield and quality of sweet potato tubers in acid laterite soils of Kerala (Nair and Mohankumar, 1984). Chew et al. (1982) also reported remarkable increase in tuber and vine dry matter yield of sweet potato grown in a Malaysian acid peat soil (pH 3.5 to 3.7) by liming. Hamid et al. (2004) found that high Ca concentration reduced the growth, yield and thickness of tuberous roots of sweet potato.

In acid peat of Malaysia, Yong (1971) observed increased tuber yield due to application of MgCO<sub>3</sub> @ 5 t ha<sup>-1</sup>. Moreno (1982) observed that sweet potato removed large quantities of Mg from the soil and stated that additional Mg was needed when K was used, to obtain a proper balance with applied N. At CTCRI, Maini et al. (1973) observed that application of 1000 ppm Mg

increased the protein content of sweet potato tubers. Navarro and Padda (1983) reported that tuber yield increased due to the application of S in the islands of Puerto- Rico.

#### **Micronutrients**

Sweet potato responds favorably to the application of Zn. Zinc is regarded as the third most important limiting nutrient element in crop production after N and P (Gupta, 1995). It was further reported that, Zn was essential for several enzyme systems and its deficiency retarded photosynthesis and N metabolism in plants. Appreciable increase in sweet potato yield by basal as well as foliar application of Zn was reported by George and Mittra (1996) in the trials conducted at Kharagpur in West Bengal.

Boron is one of the essential micronutrients required for the normal growth and development of plants. Boron is needed for the development and differentiation of tissues particularly growing tips, phloem and xylem (Sakal and Singh, 1995). It also plays an important role in sugar translocation. A combined application of ethrel (500 ppm) as vine dip and soil application of K<sub>2</sub>O @ 90-120 kg ha<sup>-1</sup> along with foliar application of boric acid @ 700 g ha<sup>-1</sup> significantly increased the yield and quality of sweet potato tubers in Tripura. Maini et al. (1973) reported an increase in the protein content of tubers and enhancement in flowering due to the application of 10 ppm boron. Application of borax @ 10 kg ha<sup>-1</sup> as basal dressing or foliar spray (0.2 %) of boric acid has been recommended for overcoming the deficiency (Sakal and Singh, 1995). Byju et al. (2007) determined the B requirement of sweet potato based on B uptake as 1.5 kg ha<sup>-1</sup> borax.

Dagupta et al. (2006), in an attempt to develop elite genotypes tolerant to salt stress, studied the physiological response of orange-fleshed sweet potato to varying concentrations of NaCl and found decreased peroxidase and increased catalase activity under NaCl stress.

### **Nutrient management practices in different countries**

#### **India**

As sweet potato removes substantial quantities of nutrients from the soil, application of considerable amount of organic manure at planting is recommended

to maintain soil productivity. Sweet potato grown in fertile soils do not require dressings of organic manure, while soils low in organic matter content have to be supplied with organic manures at 5 or 10 t ha<sup>-1</sup> to ensure proper development of tubers. Studies conducted at CTCRI indicated that balanced application of nutrients was essential for the optimum growth and yield of sweet potato and conjoint application of farmyard manure (FYM) @ 5 t ha<sup>-1</sup> along with NPK @ 50:25:50 kg ha<sup>-1</sup> was sufficient to take care of the nutrient requirement of the crop to a great extent resulting in higher tuber yields (Ravindran and Bala Nambisan, 1987). Full dose of P and K and half dose of N as basal application and the remaining half N at 30 days after planting was recommended.

Nair and Mohankumar (1984) studied the impact of lime along with NPK on soil chemical properties, nutrient uptake, yield and quality and found that NPK@ 75:50:75 along with lime @ 2 t ha<sup>-1</sup> was beneficial for improving the above parameters. Laxminarayana et al. (2008a, 2008b, 2011) reported that continuous integrated nutrient management practices involving liming material, organic, inorganic (major, secondary and micronutrients) and biofertilizers improved the soil fertility, yield, nutrient uptake and quality in an Ultisol under sweet potato-moong sequence. Nutrient recommendations for sweet potato in different states of India are given in Table 1.

Table 1. Nutrient recommendations for different states of India

States	FYM ( t ha <sup>-1</sup> )	NPK ( kg ha <sup>-1</sup> )
Bihar, West Bengal and Assam	10	40-60: 40: 40-60
Andhra Pradesh	-	60: 60: 60
Karnataka	-	60: 60: 90
Kerala	5	50:25:50

Source: Palaniswami and Shirly Raichal Anil (2006)

Sreelatha et al. (1999) developed equations for fertilizer recommendations to obtain targeted yields from soils with different test values based on data of tuber yield, nutrient uptake and soil test values. The fertilizer adjustment equations for varying levels of soil available

N for maximum tuber yield ( t ha<sup>-1</sup>) of sweet potato in laterite soil was derived as  $FN = 1.58T - 0.7812 SN$ , where FN is the fertilizer N ( kg ha<sup>-1</sup>) and SN is the soil available N ( kg ha<sup>-1</sup>) and T is the targeted yield. For economic tuber production, the equation becomes  $FN = 1.5087T - 0.7812SN - R$ , where R is the ratio of cost of 1kg fertilizer N to the price of 1 kg tuber. Similarly for P and K, the fertilizer adjustment equations for varying levels of P and K becomes  $FP_2O_5 = 0.300T - 0.0619 SP$  and  $FK_2O = 1.700T - 1.348SK$ , where SP and SK are soil available P and K respectively and T is the targeted yield.

#### South East Asia

In Vietnam, compost consisting of animal manure and crop residues was commonly applied together with inorganic fertilizers (Campilan, 2009). Usually inorganic fertilizers were applied in excessive doses resulting in inefficient nutrient management (Van de Fliert et al., 2001). In Indonesia, over application of inorganic N fertilizers were common without much profitability (Braun et al., 1997).

#### China

In China, both basal as well as top dressing were practiced for realizing high yield with good quality tubers in sweet potato. Basal dressing was usually done with organic manures which accounted for 80% of the total annual fertilizer use @ 37- 75 t ha<sup>-1</sup>. Top dressing was usually done, if necessary, depending upon the growth and yield. It was presumed that top dressing during middle and later stages of tuber development was generally needed for the production of high yield and good quality tubers. At later stage, a mixture of 0.5% urea, 2-3% calcium super phosphate and 0.2% potassium di hydrogen phosphate was applied to the crops, 2-3 times, once in every 7 days @ 1.125-1.5 t ha<sup>-1</sup>. For producing a tuber yield of 37-52.5 t ha<sup>-1</sup>, total usage of fertilizers including basal and top application should be N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O @ 188, 150, 450-600 kg ha<sup>-1</sup> respectively (Zhang et al., 2009)

#### United States of America (USA)

From USA, it was reported that proper fertilization based on soil and tissue analysis was critical to realize maximum yield potential in the crop. Bouwkamp (1985) reported that without supplemental nutrients from fertilizers and or compost, deficiency symptoms could occur. Fertilizers



containing NPK are applied annually to commercial fields. In the South East part of USA, N was applied before transplanting or as a side dress application, 25-30 days after planting @ 35-80 lbs acre<sup>-1</sup> depending on soil type and cultivar. Application of P and K were @ 90-120 and 120-220 lbs acre<sup>-1</sup> respectively. Minor elements like Ca, Mg, B and Zn were also applied as soil amendments or as foliar applications when needed. Application of N was usually split, with half being applied as pre-planting and half during the growing season through drip irrigation system. Liquid formulations as urea, ammonium nitrate and calcium ammonium nitrate were the most common. Application of P and K were usually based on soil testing and expected yields. It is perceived that, if the P and K test values were greater than 250 and 150 ppm respectively, no response to applied P and K fertilizers was usually expected (Smith et al., 2009).

#### **South America**

In Brazil, organic manures were mostly used; on an average animal manure @ 25 t ha<sup>-1</sup> was applied. Usually chemical fertilizers were applied after soil fertility evaluation. In loam soils, borax @ 5-10 kg ha<sup>-1</sup> was recommended. When organic manures were used, the N dose would be reduced to half of the recommendation and it is reported that high yields were usually obtained with 200 kg ha<sup>-1</sup> of NPK fertilizer mixture 5:20:10. In Peru, fertilizer application was usually done based on the soil physico-chemical characteristics and the recommendation followed was NPK @ 80:40:120 kg ha<sup>-1</sup> with organic manure or animal manure applied @ 12-30 t ha<sup>-1</sup> during land preparation/planting. In Paraguay, cattle manure was applied @ 10 t ha<sup>-1</sup> without the use of any chemical fertilizers. In Uruguay, the use of both organic as well as chemical fertilizers was scarce or nil. But fertilizer solution along with irrigation water was applied at transplanting to enhance root development and growth (Fuentes and Chujoy, 2009).

#### **Sub Saharan Africa (SSA)**

In different regions of SSA, purchased fertilizer and chemical use was minimal and the use of organic manure varies depending on household livestock assets and presence of other crops that are valued higher than sweet potato. In Tanzania, only 5% of the household used inorganic fertilizers but when intercropped with other

crops like maize, cassava, beans and pigeon pea, fertilizers were applied and hence sweet potato took advantage of residual fertilizer applied to these crops (Low et al., 2009).

#### **West Africa**

Fertilizers were not usually applied though it was known that organic manures and fertilizers increased yield as well as quality of tubers. If fertilized, it was done during first weeding at 4-5 weeks after planting (WAP). Usually, commercial farmers monitored the NPK levels in sweet potato fields for fertilizer application. Rendle and Kang (1977) found that a P content of 0.22% in the petiole of index leaves at 9 WAP indicated that it was not limiting. Levels of N should be low to avoid vigorous shoot growth than tuber production. Organic manures were usually applied before supplementing fertilizers. They have the presumption that wise fertilization was needed for enhancing storability, taste of end products and getting high cost:benefit ratio. An NPK fertilizer mixture rate of 125-700 kg ha<sup>-1</sup> or 27-54 kg N, 72-120 kg P, 72-120 kg K were generally applied to satisfy any local soil nutrient shortages after soil test to precisely make up for nutrient deficiency. Onwudike (2010) reported that integrated application of cow dung @ 3 t ha<sup>-1</sup> along with NPK @ 100 kg ha<sup>-1</sup> improved plant growth, tuber yield and soil fertility. As most of the West African farmers could not afford soil tests, they graded the soil into low, medium and high using soil kits to prescribe fertilizer rates (Akoroda, 2009). The soil test values to guide fertilizer recommendation and the critical level of nutrients in the index leaf tissues of sweet potato which were used as criteria for nutrient recommendation to farmers are presented in Tables 2 and 3 respectively.

#### **Israel**

Before planting, compost and PK fertilizers were applied. Nitrogen was applied during the growing period. In sandy soils, top dressing of N @ 80-120 kg ha<sup>-1</sup> was practiced (Lobenstein et al., 2009).

#### **Oceania**

Bourke (1977) studied the influence of N and K fertilizers on the growth of sweet potato in Papua New Guinea. In Papua New Guinea (PNG), soil fertility was usually maintained by natural fallows and if inadequate, fertility was commonly enhanced by growing green

Table 2. Soil test values (STV) to guide fertilizer recommendation (R) for sweet potato in Nigeria

Soil test variable	Low STV	R rate of the respective nutrient (kg ha <sup>-1</sup> )	Medium STV	R rate of the respective nutrient (kg ha <sup>-1</sup> )	High STV	R rate of the respective nutrient (kg ha <sup>-1</sup> )
Total NO <sub>3</sub> -N (%)	<0.10	90	0.10-0.15	45	>0.15	20
Brays P I (mg kg <sup>-1</sup> )	<10	50	10-20	25	>20	0
Brays P II (mg kg <sup>-1</sup> )	<15	50	15-25	25	>25	0
Exchangeable K (cmol kg <sup>-1</sup> )	<0.15	90	0.15-0.25	48	>0.25	0
Available Zn (mg kg <sup>-1</sup> )	<1.0	-	1-5	-	>5.0	-
Organic C (g kg <sup>-1</sup> )	20	-	20-30	-	>30.0	-

Source: FFD (2002); Chude et al. (2004)

manure crops and planting N fixing trees like *Casuarina oligodon* or by rotating with groundnut crop. Generally, inorganic fertilizers were not applied. However, occasionally farmers applied small quantities of coffee pulp, fire ash or chicken manure. In New Zealand, green or winter cover crops were incorporated into the soil prior to planting followed by inorganic fertilizers, especially K (Bourke, 2009).

Table 3. Critical levels in the index leaf\* tissues of sweet potato and nutrient removal (NR)

Nutrients	Adequate nutrient range (%)	NR for tuber yield of 12 t ha <sup>-1</sup>	NR for tuber yield (12 t ha <sup>-1</sup> ) + vine yield	NR for tuber yield of 50 t ha <sup>-1</sup>	NR for tuber yield (50 t ha <sup>-1</sup> ) + vine yield
	N	4.2-5.0	26	52	110
P	0.22-0.45	6	9	25	38
K	2.6-6.0	60	90	250	376
Ca	0.9-1.2	3.6	16	15	65
Mg	0.15-0.35	3	6.5	12.5	27
S	0.35-0.45	1.8	4.3	7.5	18
Cl	<0.9	10	18	43	75

Source: O' Sullivan et al. (1997)

\*7<sup>th</sup> - 9<sup>th</sup> opened leaf blade at 28 DAP

### Index leaf and critical nutrient concentration

The youngest fully expanded leaf (YFEL) at one month after planting was taken as the index leaf and the critical concentration of nutrients in this leaf tissue is given in Table 4 (O' Sullivan et al., 1997). At CTCRI, Thiruvananthapuram, Susan John et al. (2001) found that the third youngest fully expanded leaf (YFEL) at 42 days after planting and second YFEL at 42 DAP were the best reflectors for assessing the critical levels of P and K respectively in sweet potato. The critical concentration of P

was 0.41% in the leaf and 122.5 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> in the soil. The critical concentration of K was 3.15% in the leaf and 125 kg ha<sup>-1</sup> K<sub>2</sub>O in the soil.

Table 4. Critical nutrient concentration (CNC) in the index leaf tissue of sweet potato

Nutrient	CNC
N (%)	4.00
P (%)	0.22
K (%)	2.60
Ca (%)	0.76
Mg (%)	0.12
S (%)	0.34
B (μg g <sup>-1</sup> )	40.00
Cu (μg g <sup>-1</sup> )	4.50
Fe (μg g <sup>-1</sup> )	33.00
Mn (μg g <sup>-1</sup> )	19.00
Zn (μg g <sup>-1</sup> )	11.00

Source: O' Sullivan et al. (1997)

### Nutrient movement / Nutrient flow

Among the various factors contributing to nutrient availability, nutrient flow or nutrient movement in the soil - plant root zone is very critical in relation to soil-plant nutrition. The mobility of major nutrients in sweet potato under

controlled condition with different levels of NPK and FYM was monitored by Kabeerathumma and James George (1993) and the nutrient movement showed that only 30-40 % of available N and K were retained in the top 0-30 cm layer, whereas 70% of P accumulated in the surface layer. Sheeja (1994) studied the vertical distribution of micronutrients in the different sweet potato growing soil types of India and it was found that all these soils were well supplied with all micronutrients, except Zn and B. No distinct pattern of availability in the different depths of the profile was seen. However, a decrease in available nutrient status with increase in depth was observed.

### Dynamics of soil K

Byju et al. (2002) elucidated the magnitude of changes in different forms of K due to its application at different rates in sweet potato. Effect of different K levels on various K fractions in soils showed that K maintains a dynamic equilibrium in the soil among its various forms. The equilibrium activity ratio of K ( $Are^k$ ) was more closely correlated with yield response to K fertilizer than exchangeable K. The quantity factors such as labile K ( $K_L$ ), K on non specific sites ( $K_0$ ) and K on specific sites ( $K_x$ ) recorded higher values with increasing K rates indicating a greater K release into the soil solution resulting in a larger pool of labile K. A linear response was observed between K rates and tuber yield of sweet potato. The K use efficiency (kg tuber / kg K uptake) as well as K fertilizer recovery fraction (K uptake / K fertilizer applied) increased with increasing K application rates.

Further studies on the dynamics and transformation of K under sweet potato (Byju et al., 2002) indicated the correlation of Q/I parameters with different forms of K in the soil. It was seen that water soluble and exchangeable K which are easily available to the crop constituted 0.6 – 3% and 1-1.6% of the total K respectively. The non exchangeable and  $HNO_3$  extractable K which are available to the crop after exhaustion of the available K constituted 3.5-19.1 and 7.1-30.9% of the total K respectively. The activity ratio showed significant positive correlation with water soluble, exchangeable and  $HNO_3$ - extractable K. Other Q/I parameters were also significantly and positively

correlated with availability indices indicating that they were all interrelated and measured K intensity of soil. The  $\Delta G$  values indicated that the soils were deficient in available K.

Dempster et al. (2005) found that sweet potato could withstand the atmospheric dynamics in the laboratory biosphere by production of tuber biomass.

### Effect of nutrition on tuber quality

Aregheore and Tofinga (2004) found that the type of mulch material influenced the crude protein, gross energy, macro and trace mineral content in the aerial parts of sweet potato making it an ideal cheap protein and energy source for livestock and humans. In South Western Nigeria, Ukom et al. (2009) studied the influence of different levels of N on the bioavailability of  $\beta$  carotene and crude protein and found that the N rate should be 40-80 kg ha<sup>-1</sup> for good nutrition and health.

### Impact of biofertilizers

Yano and Takai (2005) reported that mycorrhizal association in sweet potato reduced toxic effects of elements causing acidity in acid soils. Byju and Ravindran (2009) reported that the present rate of N (50 kg ha<sup>-1</sup>) could be reduced to 1/3 by integrating with *Azospirillum* by dipping the vines for 15 minutes before planting and soil application of *Azospirillum* @ 10 kg ha<sup>-1</sup> at the time of planting. Dhanya and Potty (2007) isolated and characterized the siderophores produced by AM fungi in the rhizosphere of sweet potato. In sweet potato, integrated use of *Azospirillum* and AM fungi and reduced dose of N and P fertilizers (75% and 50% of the recommended dose respectively) could maintain soil health and ensure high crop productivity (Nair et al., 2001). Trials conducted under the aegis of AICRP on tuber crops indicated that application of 2/3 recommended dose of N along with *Azospirillum* @ 2 kg ha<sup>-1</sup> as vine dipping and *Azospirillum* @ 10 kg ha<sup>-1</sup> as soil application was ideal for Tamil Nadu, Assam, Bihar, West Bengal and Kerala. In Andhra Pradesh, the dose of fertilizer N could be reduced to 1/3 by following the above integration with biofertilizers. Neetha et al. (2009) and Susan John et al. (2010) conducted pot as well as field trials and found that new nutrient efficient strains of N fixer (*Alcaligenes faecalis*) and P solubilizer

(*Enterobacter* sp.) could reduce the dose of N and P fertilizers to 25% and 75% respectively of the present recommendation for sweet potato.

### Deficiency disorders

Bolle-Jones and Ismuadji (1963) reported characteristic symptoms due to mineral nutrient deficiencies in sweet potato. O'Sullivan et al. (1997) studied both deficiency and toxicity symptoms due to major, secondary and micronutrients in sweet potato. O'Sullivan et al. (1996) listed the diagnostic criteria for identifying nutritional disorders in sweet potato including critical concentrations in leaves. Dowling et al. (1995) conducted pot experiments to delineate the response of different nutrients to sweet potato. The deficiencies of P and K were induced under sand culture by Susan John et al. (2004). The first sign of P deficiency is usually premature senescence of older leaves. Generally, the leaves become yellow followed by the development of purple and necrotic lesions in the chlorotic zones, which later become brown and dry. In the case of K deficiency, yellowing appears on the oldest leaves, later they develop chlorosis in marginal and interveinal zones. The chlorotic regions further turn brown necrotic covering the entire leaf blade turning the leaf dry and brittle. The tuber produced will be small with poor quality.

In solution culture, Illaava et al. (1996) studied the sensitivity of sweet potato lines to Ca and Al stress and found that Ca concentration from 4 to 400  $\mu\text{M}$  improved growth of sweet potato where as 25 to 100  $\mu\text{M}$  Al in solution had an adverse effect on growth.

Introduction of more refined and complex forms of fertilizers coupled with an increase in the intensity of cropping limits the yield of crops. Therefore, a timely and precise appraisal of micronutrient deficiencies is necessary to take prompt and appropriate remedial measures to realize best yields. Pillai et al. (1986) induced deficiencies of micronutrients *viz.*, Fe, Mn, Cu, B, Mo and Zn under sand culture and the foliar concentration of these nutrients confirmed deficiency symptoms. In the acid laterite soils of Orissa, Byju et al. (2007) reported that tuber blister resulting in cracking of tubers occurred due to B deficiency. Lot of studies on soil fertility and mineral nutrition including nutrient depletion in different soil types were undertaken at PNG islands (Crasswell et al., 1996). The deficiency symptoms in sweet potato induced under controlled conditions at CTCRI are presented in Table 5.

Blamey (1996) recommended management strategies comprising of liming materials, organic manures and chemical fertilizers to correct the nutritional disorders in sweet potato. The measures to be followed for rectifying the secondary and micronutrient deficiencies encountered in sweet potato are given in Table 6.

## II. Minor tuber crops

The soil fertility requirements including nutrient management aspects of minor tuber crops *viz.*, Chinese potato (*Plectranthus rotundifolius* Poir.), arrowroot (*Maranta arundinacea* L.) and yam bean (*Pachyrrhizus erosus* (L.) are described below.

Table 5. Deficiency symptoms of various micronutrients in sweet potato

Element	Symptoms	
	Foliar	Tuber
Mn	Interveinal chlorosis of younger and middle leaves later changing to complete yellow	Smaller sized tubers with brownish flesh
Zn	Occurrence of yellow spots and interveinal chlorosis, finally complete bleaching of young leaves	Brown coloration in the flesh
Cu	Young leaves turn yellow, stunted and cup shaped in appearance, finally complete bleaching of young leaves	Brown coloration in the flesh
B	Cessation of growth of terminal bud, which becomes short in size and bunched in appearance, finally tips start wilting and drying	No tuber formation

Source: Pillai et al. (1986)



Table 6. Management of secondary and micronutrients in sweet potato

Element	Control measures
Ca	Addition of lime, single and triple super phosphate
Mg	Incorporation of dolomitic lime or magnesium oxide in acid soils ( 20-50 kg ha <sup>-1</sup> Mg) or by band application of kieserite or fertilizer grade magnesium sulphate ( 10-40 kg ha <sup>-1</sup> Mg)
S	Application of S containing fertilizers, gypsum or elemental S or ammonium sulphate or single super phosphate
Fe	Foliar spray of chelated Fe or 1-2% ammonium ferric sulphate solution
Mn	Foliar sprays of 0.1% manganese sulfate or chelate or 2-4 kg ha <sup>-1</sup> Mn, application of mulches and composts
Zn	Dipping the cuttings in 2-4% zinc sulfate for 15 minutes prior to planting, foliar spraying of 1- 2% zinc sulphate heptahydrate solution
Cu	Foliar application of copper sulphate
B	Application of borax or other borates in the soil before planting @ 1-1.5 kg ha <sup>-1</sup> on sandy soils, or up to 4 kg ha <sup>-1</sup> on clayey, alkaline soils
Mo	Application of sodium molybdate or ammonium molybdate @ 0.2-0.3 kg ha <sup>-1</sup> , liming the soil to raise the soil pH above 5.5

Source : Susan John et al. (2006)

## 1. Chinese potato

### Soil requirement

A fertile well drained sandy loam to alluvial soil rich in organic matter is ideal for Chinese potato. Heavy clay soils are not suitable for this crop and the crop cannot withstand water logging or flooded soil conditions. The best soil pH for good growth and tuber production is 6.6-7.0.

### Nutrient management

It is reported that FYM @ 4.5 t ha<sup>-1</sup> along with wood ash @ 1.1-2.2 t ha<sup>-1</sup> was required (Anon, 1950). Thyagarajan (1969) observed that application of N @ 30-60 kg ha<sup>-1</sup> increased tuber yield, whereas P and K had no significant effect. At CTCRI, studies indicated that yield increased up to 60 kg N ha<sup>-1</sup>. Hrishi and Mohankumar (1976) suggested a NPK dose of 80:60:80 kg ha<sup>-1</sup> whereas the recommended dose is 60:60:100 kg ha<sup>-1</sup> (Anon, 1978). Rajmohan and Sethumadhavan (1980) suggested integrated application of FYM @ 10 t ha<sup>-1</sup> along with NPK @ 80:60: 80 kg ha<sup>-1</sup> as the optimum dose. Geetha (1983) observed increased yield by increasing N level up to 120 kg ha<sup>-1</sup>. However, a NPK dose of 60:30:120 kg ha<sup>-1</sup> was found ideal for economic production. A crop yielding 26 t ha<sup>-1</sup> of tuber removed 107 kg N, 13 kg P, 107 kg K per hectare (Kabeerathumma

et al.,1985). Dhanya and Potty (2008) reported siderophore production by *Psuedomonas fluorescens* from the rhizosphere of Chinese potato.

## 2. Arrowroot

### Soil requirement

The crop thrives best in deep, well drained, slightly acid loam soils with partial shade. Arrowroot is thought to be a heavy feeder of nutrients and usually thrives well in fertile sandy loam soil.

### Nutrient management

Ramesan et al. (1996) studied the nutritional requirement of arrowroot on biomass production, rhizome yield, nutrient uptake and available N, P and K status of the soil and found that N and K @ 50 and 75 kg ha<sup>-1</sup> significantly increased rhizome yield. Maheswarappa et al. (2000) and Veena (2000) reported highest uptake of N and K at the highest level of fertilization in arrowroot intercropped in coconut gardens. Suja et al. (2006) studied the influence of nutrient management on arrowroot yield, nutrient uptake and soil nutrient status and found that application of N P and K @ 50:25:75 kg ha<sup>-1</sup> was ideal to obtain better yield (23.29 t ha<sup>-1</sup>), higher uptake of nutrients and substantial improvement in the nutrient status.

Jayakumari and Potty (2008) studied the effect of AM fungal inoculation in arrowroot and found the potential of this fungal endophyte in transforming more roots to tubers.

### 3. Yam Bean

#### Soil requirement

Fertile, well drained, sandy loam soil is best suited for cultivation of yam bean. The crop adapts well to loamy and clay loam soil. It can tolerate higher clay content if the soil is well drained with good humus content. Water logging adversely affects yam bean cultivation. Optimum pH requirement is 6-7.

#### Nutrient management

Ramaswamy et al. (1980) suggested NPK dose of 80:60:80 kg ha<sup>-1</sup> in Tamil Nadu. In West Bengal, NPK @ 80:80:80 kg ha<sup>-1</sup> is recommended (Sen and Mukhopadhyay, 1989). Higher K application reduced cracking of tubers (Mishra et al., 1993). Stamford et al. (1999) studied the effect of P, K and Mg fertilization on yam bean inoculated with *Bradyrhizobium* and reported that yam bean responded to low levels of these nutrients and had the ability to fix N with great potential for biomass production. Mondal and Sen (2006) found that by fertilizing yam bean with NPK @ 50:25:50 kg ha<sup>-1</sup>, the seed yield could be increased. Despite the earlier evidences that there was no need to supply additional N to this leguminous crop, many workers have found later that yam bean responded positively to application of N fertilizer. Nath et al. (2007) concluded that yam bean responded well to N application and 120 kg ha<sup>-1</sup> was optimum for both tuber and seed production. Under the aegis of All India Co-ordinated Research Project on Tuber Crops, Rajendra Agricultural University, Dholi (North Bihar) has standardized the nutrient requirement for yam bean as FYM or compost @ 15-20 t ha<sup>-1</sup> along with NPK @ 80:40:80 kg ha<sup>-1</sup>.

#### Conclusion and future strategies

This review paper clearly establishes the need to undertake more concerted basic studies on the dynamics of major, secondary as well as micronutrients in sweet potato production including nutrient flow, nutrient transformation, nutrient availability and nutrient uptake, which in turn has a direct impact on tuber yield and

tuber quality. In the case of minor tuber crops, greater stress should be given for research on plant nutrition as it has a direct bearing on improving the quality of the produce taking into account the medicinal properties of their active ingredients. At the same time these studies should aim at developing integrated nutrient management strategies for these crops with thrust on developing packages for balanced and efficient fertilizer management under different production systems targeting on sustainable production as well as soil health.

#### References

- Akoroda, M. 2009. Sweet potato in West Africa. In: *The Sweet Potato*. Lobenstein, G. and Thottappilly, G. (Eds.). Springer Science Publishers, pp.441-468.
- Alexander, D., Sadanandan, N. and Nair, R.Y. 1976. Studies on the effect of methods of nitrogen application on mineral uptake of high yielding sweet potato varieties. *Agric. Res. J. Kerala*, 14 (1): 21-26.
- Anonymous, 1950. *Wealth of India*. Raw materials II. Central Scientific and Industrial Research, New Delhi.
- Anonymous, 1978. Research Report, Kerala Agricultural University. pp. 134.
- Aregheore, E. M. and Tofinga, M. 2004. Influence of type of mulch material on distribution and accumulation of nutrients in sweet potato (*Ipomoea batatas*) in Samoa. *Int. J. Agric. Biol.*, 6: 520-524.
- Bao, L., De-Yin, L. and Rong-Gui, W. 1985. Response to potash fertilizers of main crops in China. Potassium in the Agricultural Systems of the Humid Tropics. In: *Proceedings 19<sup>th</sup> Colloquium of the International Potash Institute*, Bangkok, pp. 323-328.
- Blamey, F. P. C. 1996. Correction of nutrition disorders of sweet potato and taro: Fertilizers and soil amendments. In: *Mineral Nutrient Disorders of Root Crops in the Pacific*. Crasswell, C.J., Asher, C.J. and O' Sullivan, J.N. (Eds.). Proceedings of Australian Centre for International Agricultural Research, Publication No. 65, Australia, pp.91-95.
- Bolle-Jones, E.W. and Ismunadji, M. 1963. Mineral deficiency symptoms of the sweet potato. *Emp. J. Exp. Agric.*, 31:60-64.
- Bourke, R.M. 1977. Sweet potato (*Ipomoea batatas*) fertilizer trials on the Gazlele Peninsular of New Britain. *Papua New Guinea agric. J.*, 28:73-95.
- Bourke, M. 2009. Sweet potato in Oceania. In: *The Sweet Potato*. Lobenstein, G. and Thottappilly, G. (Eds.). Springer Science Publishers, pp.489- 502.
- Bouwkamp, J.C. 1985. Production requirements. In: *Sweet Potato Products: A Natural Resource for the Tropics*. Bouwkamp, J.C. (Ed.). CRC Press, Boca Raton, FL, pp.1-33.
- Braun, A.R., Priatna, E., Asmunati, R., Wiyanto, Widodo, Y. and Van de Fliert, E. 1997. Farmer field schools for sweet potato in

- Indonesia. In : *CIP Program Report 1995-1996*, CIP, Lima, Peru, pp. 198-204.
- Byju, G., Manikantan Nair, M. and Ray, R.C. 2002. Forms and quantity – intensity parameters of potassium under sweet potato cultivation. *J. Indian. Soc. Soil Sci.*, 50: 241-243.
- Byju, G., Nedunchezhiyan, M. and Naskar, S. K. 2007. Sweet potato response to boron application on an Alfisol in the sub humid tropical climate of India. *Commun. Soil Sci.Pl. Anal.*, 38: 2347-2356.
- Byju, G. and Ravindran, C. S. 2009. Effect of *Azospirillum* in increasing yield and nitrogen use efficiency of sweet potato cultivation in India. *Adv. Hort. Sci.*, 23: 254-258.
- Campilan, D. 2009. Sweet potato in South East Asia: Assessing the primary functions of a secondary crop. In: *The Sweet Potato*. Lobenstein, G. and Thottappilly, G. (Eds.). Springer Science Publishers, pp.469-482.
- Chew, W.Y., Joseph, K.T., Ramil, K. and Majid, A.B.A. 1982. Liming needs of sweet potato in Malaysian acid peat. *Expl Agric.*, 18(1): 65-71.
- Chude, V.O., Malgwi, W.B., Amapu, I.Y. and Ano, A.O. 2004. *Manual on Soil Fertility Assessment*. FFD / NSPFS, Abuja, Nigeria.
- Craswell, E.T., Asher, C. J. and O'Sullivan, J. N.1996. Mineral nutrient disorders of root crops in the Pacific. In: *Proceedings of Australian Centre for International Agricultural Research Workshop*, Publication No.65, Nuku'alofa, Kingdom of Tonga, 17-20 April 1995, pp.142 .
- CTCRI. 1997. *Annual Report*. Central Tuber Crops Research Institute, Sreekariyam, Thiruvananthapuram, pp. 27-28.
- Dasgupta, M., Mukherjee, A., Naskar, S. K. and Kole, P. C. 2006. Physiological response of orange-fleshed sweet potato (*Ipomoea batatas* L.) genotypes to sodium chloride stress conditions. *J. Root Crops*, 32: 53-58.
- Dempster, W.F., Allen, J.P., Alling, A., Silverstone, S. and Thillo, V. M. 2005. Atmospheric dynamics in the 'Laboratory biosphere' with wheat and sweet potato crops. *Adv. Space Res.*, 35: 1552-1556.
- Dhanya, M.K. and Potty, V.P. 2007. Characteristics of siderophores produced by arbuscular mycorrhizal fungi in the rhizosphere of sweet potato, yam and elephant foot yam. *J. Root Crops*, 33: 141-143.
- Dhanya, M.K. and Potty, V.P. 2008. Siderophore production by *Pseudomonas fluorescens* isolated from the rhizosphere of *Solenostemon rotundifolius*. *J. Root Crops*, 33: 138-140.
- Dowling, A.J., Blamey, F.P.C. and Hoa, T.1995. Limitations to sweet potato growth in small volumes of soil imposed by water and nutrient stress, acidity and salinity. *Papua New Guinea J. Agric. For. Fish.*, 38p.
- Edison, S., Hegde, V., Makesh Kumar, T., Srinivas, T., Suja, G. and Padmaja, G. 2009. Sweet potato in the Indian sub continent. In : *The Sweet Potato*. Lobenstein, G. and Thottappilly, G. (Eds.). Springer Science Publishers, pp.391-414.
- FFD. 2002. Federal Fertilizer Department. In: *Fertilizer Use and Management Practices for Crops in Nigeria*. Aduayi, E.A., Chude, V.O., Adebusuyi and Olayiwola, S.O. (Eds.). FMA, Abuja, Nigeria.
- Fuentes, S. and Chujoy, E. 2009. Sweet potato in South America. In : *The Sweet Potato*. Lobenstein, G. and Thottappilly, G. (Eds.). Springer Science Publishers, pp. 415-440.
- Geetha, K. 1983. Nutritional management in coleus (*Coleus parviflorus Benth.*) *M.Sc. (Ag.) Thesis*, Kerala Agricultural University.
- George, J. and Mitra, B.N. 1996. Effect of application of fly ash and paper factory sludge as source of micronutrients on the performance of sweet potato. In: *Tropical Tuber Crops in Food Security and Nutrition*. Balagopalan, C., Nayar, T. V. R., Sundaresan, S., Premkumar, T. and Lakshmi, K. R. (Eds.). Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi. pp. 338-343.
- Gupta, V.K. 1995. Zinc research and agricultural production. In: *Micronutrient Research and Agricultural Production*. Tandon, H.L.S. (Ed.). pp. 132-164.
- Hamid, S., Sasaki, O., Tomohide, S., Naoya, C. and Shunji, I. 2004. Effect of calcium concentration on the shape of sweet potato (*Ipomoea batatas* L.) tuberous roots. *Pl. Prod. Sci.*, 7: 191-194.
- Hrishi, N. and Mohankumar, C.R. 1976. Coleus for homestead garden. *Indian Fmg*, 26:33-35.
- Illaava, V.P., Blamey, F.P.C. and Asher, C.J. 1996. Sensitivity of sweet potato lines to Ca and Al stress in solution culture. In: *Mineral Nutrient Disorders of Root Crops in the Pacific*. Craswell, C.J., Asher, C.J. and O' Sullivan J.N. (Eds.). Proceedings of Australian Centre for International Agricultural Research, Publication No. 65, Australia, pp. 53-57.
- Jansson, R. K. and Ramon, K.V. 1991. Sweet potato pest management: A global overview. In: *Sweet Potato Pest Management: A Global Perspective*. Jansson, R.K. and Ramon, K.V. (Eds.). West view press Inc., Boulder, Co. pp. 2-12.
- Jayakumari, T. R. and Potty, V.P. 2008. Yield parameters of canna (*Canna edulis*) as influenced by arbuscular mycorrhizal fungal inoculation. *J. Root Crops*, 34:137-141.
- Kabeerathumma, S. and James George. 1993. Dynamics of major nutrients in acid ultisol under continuous sweet potato cultivation. *J. Root Crops*, 19:14-20.
- Kabeerathumma, S., Mohankumar, B. and Nair, P. G. 1985. Uptake of NPK by coleus (*Coleus parviflorus*) at different stages of growth. In: *Proceedings of the National Symposium on Production and Utilization of Tropical Tuber Crops*, Central Tuber Crops Research Institute, India, pp.165-169.
- Kabeerathumma, S., Mohankumar, B. and Potty, V. P. 1986. Efficiency of rock phosphate as a source of phosphorus to sweet potato. *J. Indian Soc. Soil Sci.*, 34: 806-809.
- Laxminarayana, K., Susan John, K. and Naskar, S.K. 2008a. Influence of lime, biological, inorganic and organic manures on soil fertility,

- yield, nutrient uptake and quality of sweet potato in an Ultisol. In: *Abstracts of the National Seminar on Developments in Soil Science-2008*, University of Agricultural Sciences, Bangalore, 27-30 November 2008.
- Laxminarayana, K., Susan John, K., Mukherjee, A. and Naskar, S.K. 2008b. Effect of inorganic, biological and organic manures on yield and quality of sweet potato. In: *Abstracts of the 3<sup>rd</sup> Indian Horticulture Congress*, Orissa University of Agriculture and Technology, 6-9 November 2008.
- Laxminarayana, K., Susan John, K., Ravindran, C.S. and Naskar, S.K. 2011. Effect of lime, inorganic and organic sources on soil fertility, yield, quality and nutrient uptake of sweet potato in Alfisols. *Commun. Soil Sci. Pl. Anal.*, 42(20):2515-2525.
- Lobenstien, G. 2009. Origin, distribution and economic importance. In: *The Sweet Potato*. Lobenstein, G. and Thottappilly, G. (Eds.). Springer Science Publishers, pp. 9-12.
- Lobenstien, G., Cohen, J. and Dar, Z. 2009. Sweet potato in Israel. In: *The Sweet Potato*. Lobenstein, G. and Thottappilly, G. (Eds.). Springer Science Publishers, pp. 483- 488.
- Low, J., Lynam, J., Lemaga, B., Crissman, C., Barker, I., Thiele, G., Namanda, S., Wheatley, C. and Andrade, M. 2009. Sweet potato in Sub Saharan Africa. In: *The Sweet Potato*. Lobenstein, G. and Thottappilly, G. (Eds.). Springer Science Publishers, pp. 359-390.
- Maheswarappa, H.P., Nanjappa, H.V., Hegde, M.R. and Biddappa, C.C. 2000. Nutrient content and uptake of arrowroot (*Maranta arundinacea*) as influenced by agronomic practices when grown as an intercrop in coconut (*Cocos nucifera*) garden. *Indian J. Agron.*, 45:86-91.
- Maini, S.B., Indira, P. and Mandai, R.C. 1973. Effect of boron, magnesium and iron on flowering, yield and quality of sweet potato. *Madras agric. J.*, 60 (8): 1024-1025.
- Mandal, R. C., Singh, K.D., Maini, S.B. and Magoon, M.L. 1971. Response of sweet potato to spacing and nitrogen fertilization. *Indian J. Agron.*, 16(1): 85-87.
- Mishra, S., Singh, C.P., Singh, K.P., Singh, N.K. and Sinha, U.P. 1993. Response of potassium application on yield, quality and cracking of yam bean tuber. *J. Root Crops*, 19:118-121.
- Mohankumar, B. and Nair, P.G. 1990. Nutritional requirement of sweet potato. In: *Course Manual of the Second International Training Course on Sweet potato Production*, 17-23 September 1990, Central Tuber Crops Research Institute, Thiruvananthapuram, pp.81-91.
- Mondal, S. and Sen, H. 2006. Effect of time of sowing and fertility level on seed yield of yam bean (*Pachyrrhizus erosus*). *J. Root Crops*, 32:37-40.
- Moreno, R.A. 1982. Intercropping with sweet potato (*Ipomoea batatas*) in Central America. In *Proceedings of the 1<sup>st</sup> International Symposium on Sweet potato*. Villareal, R.L. and Griggs, T.D. (Eds.). pp. 243-254.
- Morita, T. 1967. Effect of application time of nitrogenous fertilizers on the top growth, tuber formation and development of sweet potatoes. *J. Jap. Soc. Hort. Sci.*, 36(1): 114-121.
- Morita, T. 1970. Effect of application time of nitrogenous fertilizer on the top growth and the development of the root system during the tuber formation period in sweet potato. *J. Jap. Soc. Hort. Sci.*, 39(4): 41-47.
- Murata, T. and Akazava, T. 1968. Enzymic mechanism of starch synthesis in sweet potato roots. 1. Requirement of potassium ions for starch synthetase. *Arch. Biochem. Biophys.*, 126: 839-879.
- Muthuswami, P., Govindaswamy, M. and Kothandaraman, G.Y. 1981. Influence of sources and levels of potash in combination with nitrogen levels on sweet potato. *Madras Agric. J.*, 68 (6) : 351-354.
- Nair, G. M. 2000. Cultural and manurial requirements of sweet potato. In: *Production Technology of Tuber Crops*. Mohankumar, C.R., Nair, G. M., James George, Ravindran, C. S. and Ravi, V. (Eds.). Central Tuber Crops Research Institute, Sreekariyam, Thiruvananthapuram, pp. 44-72.
- Nair, G. M. and Sadanandan, N. 1973. Performance of sweet potato varieties under varying levels of nitrogen and time of its application in red loam soils of Vellayani. *Agric. Res. J. Kerala*, 11 (1): 14-16.
- Nair, G. M., Potty, V. P. and Susan John, K. 2001. Influence of bio-fertilizer (*Azospirillum*) on the growth and yield of sweet potato. *J. Root Crops*, 27(1): 210-213.
- Nair, P. G. and Mohankumar, B. 1984. Response of sweet potato (*Ipomoea batatas* L.) to NPK and lime in acid laterite soil. *J. Root Crops*, 10: 17-21.
- Nath, R., Chattopadhyay, A., Mukhopadhyay, S.K., Kundu Gunri, S.K., Mazumder, A. and Sen, H. 2007. Effect of nitrogen on tuber and seed production of yam bean under red and laterite zone of West Bengal In: *Proceedings of the National Seminar on Eco-restoration of Soil and Water Resources Towards Efficient Crop Production*, Bidhan Chandra Krishi Viswavidyalaya, West Bengal, 6-7 June 2007, pp. 171-173.
- Navarro, A.A. and Padda, D.S. 1983. Effect of sulphur, phosphorus and nitrogen application on the growth and yield of sweet potatoes grown on Fredensbory clay loam. *J. Agric. Univ. Puerto Rico*, 61 (2): 108-116.
- Neetha Soma John, Susan John, K., Priya Nair, Poornima, R. and Misra, R.S. 2009. Molecular identification of a new isolate of N<sub>2</sub> fixing bacteria and its evaluation in sweet potato. In: *Proceedings of the 21<sup>st</sup> Kerala Science Congress*, Kerala State Council for Science, Technology and Environment, Government of Kerala, Kollam, Kerala, 28-31 January 2009, pp.180-182.
- Onwudike, S. U. 2010. Effectiveness of cow dung and mineral fertilizer on soil properties, nutrient uptake and yield of sweet potato (*Ipomoea batatas*) in South Eastern Nigeria. *Asian J. Agric. Res.*, 4: 148-154.
- O' Sullivan, J.N., Asher, C.J. and Blamey, F.P.C. 1996. Diagnostic criteria for nutrition disorders of root crops in the South Pacific. In: *Proceedings of Australian Centre for International*



- Agricultural Research Workshop*, Nuku'alofa, Kingdom of Tonga, 17-20 April 1995, Canberra, Australia.
- O'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. 48, 136p.
- Palaniswami, M.S. and Shirly Raichel Anil. 2006. *Region Specific Technologies for Tropical Tuber Crops in India. Technical Bulletin Series No.47*. All India Coordinated Research Project on Tuber Crops, Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, India, pp. 31-39.
- Pillai, N.G., Mohankumar, B., Kabeerathumma, S. and Nair, P.G. 1986. Deficiency symptoms of micronutrients in sweet potato (*Ipomoea batatas* L.). *J. Root Crops*, 12:91-95.
- Rajmohan, K. and Sethumadhavan, P. 1980. In: *Proceedings of the National Seminar on Tuber Crops Production Technology*, Tamil Nadu Agricultural University, pp.193-194.
- Rajput, S.C., Kadam, B.A. and Patil, V. K. 1981. Spacing-cum-nutritional requirement of sweet potato. *J. Root Crops*, 7(1&2): 25-27.
- Ramaswamy, N., Muthukrishnan, C.R. and Shanmugavelu, K.G. 1980. Varietal performance of Mishrikand. In: *Proceedings of the National Seminar on Tuber Crops Production Technology*, Tamil Nadu Agricultural University, Coimbatore, pp.199-200.
- Ramesan, K.K., Ahmed, P. and Oommen, M. 1996. Management of major plant nutrients for producing quality rhizomes in arrowroot. In: *Proceedings of the 8<sup>th</sup> Kerala Science Congress* Kerala State Council for Science, Technology and Environment, Government of Kerala, Kochi, 27-29 January 1996, pp.133-134.
- Ravindran, C.S. and Bala Nambisan, 1987. Effect of FYM and NPK on the yield and quality of sweet potato. *J. Root Crops*, 13(1): 35-39.
- Rendle, C.J. and Kang, B.T. 1977. Phosphorous requirement of three sweet potato cultivars. In: *Proceedings of the 4<sup>th</sup> International Symposium on Tropical Root Crops*. Cock, J., MacIntyre, R. and Graham, M. (Eds.). CIAT, Cali, Colombia, pp. 117-121.
- Sakal, R and Singh, A. P. 1995. Boron research and agricultural production. In: *Micronutrient Research and Agricultural Production*. Tandon H.L.S. (Ed.). IBH & Oxford Publishing Company, New Delhi.
- Sen, H. and Mukhopadhyay, K.S. 1989. Effect of nitrogen and potassium on tuber yield and quality of yam bean (*Pachyrhizus erosus*). *J. Root Crops*, 15: 33-37.
- Shanmugavelu, K. G., Thamburaj, S. and Shanmugam, A. 1973. Effect of soil and foliar application of nitrogen on the yield of sweet potato. *Fert. News*, 18(5): 51-52.
- Sheeja, S.1994. Micronutrient status and their distribution in major tuber crops growing soils of India in relation to soil properties. *Ph.D. Thesis*, Kerala University, 188 p.
- Smith, T.P., Stoddard, S., Shankle, M. and Schultheis, J. 2009. Sweet potato production in the United States. In : *The Sweet Potato*. Lobenstein, G. and Thottappilly, G. (Eds.). Springer Science Publishers, 287-324.
- Sreelatha, A. K., Ravindran, C. S. and Kabeerathumma, S. 1999. Fertilizer recommendation based on soil tests for targeted yield of sweet potato. In: *Tropical Tuber Crops in Food Security and Nutrition*. Balagopalan, C., Nayar, T. V. R., Sundaresan, S., Premkumar, T. and Lakshmi, K. R. (Eds.). Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi. pp. 328-330.
- Stamford, N.P., Santos, C.E.R.S., Medeiros, R. and Freitas, A.D.S.1999. Effect of phosphorus, potassium and magnesium fertilization on yam bean inoculated with *Bradyrhizobium* and growing in an alic latosol soil. *Pesq. Agropec. bras. Brasília*, 34:1831-1838.
- Suja, G., Nayar, T.V.R. and Ravindran, C.S. 2006. Influence of nutrient management in arrowroot (*Maranta arundinacea* L.) on biomass production, nutrient uptake and soil nutrient status. *J. Root Crops*, 32:162-165.
- Susan John, K., Shalini Pillai, P, Nair, G.M. and Chitra, V.G. 2004. Phosphorus and potassium deficiency symptoms in sweet potato under a sand culture experiment. *J. Root Crops*, 30: 5-9.
- Susan John, K., Suja, G., Edison, S. and Ravindran, C.S. 2006. *Nutritional Disorders of Tropical Tuber Crops. Technical Bulletin Series No. 48*, Central Tuber Crops Research Institute, Sreekariyam, Thiruvananthapuram, Kerala, India, 74p.
- Susan John, K., Neetha Soma John and Anjana Devi, I.P. 2010. Agronomic investigation of new microbial isolates as bio-fertilizers in sweet potato grown in an Ultisol of India. In: *Proceedings of the 11<sup>th</sup> European Society of Agronomy Congress (Agro 2010)*, Montpellier, France, 29 August-03 September 2010, pp. 167-168.
- Thyagarajan, B. 1969. Studies on Koorka (*Coleus parviflorus* Benth.) to graded doses of fertilizer application. *M.Sc. (Ag.) Thesis*, Kerala Agricultural University.
- Tsuno, Y. and Fujise, K. 1968. Studies on dry matter production of sweet potato. *Proc. Crop Sci. Japan*, 37(1): 12-16.
- Ukom, A. N., Ojimelukwe, P.C. and Okpara, D. A. 2009. Nutrient composition of selected sweet potato (*Ipomoea batatas* L.) varieties as influenced by different levels of nitrogen fertilizer application. *Pakistan J. Nutr.*, 8: 1791-1795.
- Van de Fliert, E., Oanh, N.T.K., Son, N.T., Hoa, T.D., Thanh, P.D., Hung, L.Q., Khoang, L.H. and Lan, N.T. 2001. The sweet potato production-post harvest use system in Vietnam: Participatory needs and opportunity assessment. In: *Scientist and Farmer, Partner in Research for the 21<sup>st</sup> Century. CIP Program Report 1999-2000*, CIP, Lima, Peru, pp. 343-351.
- Veena, V. 2000. Integrated nutrient management for arrowroot (*Maranta arundinacea* L.) under partial shade. *M.Sc. ( Ag.) Thesis*, Kerala Agricultural University, 107p.
- Watts, V.M. and Cooper, J.R. 1943. Influence of varied soil reactions on growth and yield of vegetable crops on Newtonia silt loam and Ruston fine sandy loam soils. *Ark. Agric. Exp. Stn. Tech.*



*Bull. No.* 433.

- Yano, K. and Takai, M. 2005. Mycorrhizal alleviation of acid soil stress in the sweet potato (*Ipomoea batatas*). *Soil Biol. Biochem.*, 37: 1569-1572.
- Yong, C.W. 1971. Yield and growth responses of some leguminous and root crops grown on acid peat to magnesium lime. *Malay. Agric. J.*, 48(2): 142-158.
- Zhang, L., Wang, Q., Liu, Q. and Wang, Q. 2009. Sweet potato in China. In: *The Sweet Potato*. Lobenstein, G. and Thottappilly, G. (Eds.). Springer Science Publishers, pp. 325-358.