Response of sweet potato [*Ipomoea batatas* (L.) Lam.] to secondary nutrients

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THESIS

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2020

DECLARATION

I hereby declare that this thesis entitled **"Response of sweet potato [*Ipomoea batatas* (L.) Lam.] to secondary nutrients"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Vellanikkara

Date: 19/01/2021

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CERTIFICATE

Certified that this thesis entitled **"Response of sweet potato [*Ipomoea batatas* (L.) Lam.] to secondary nutrients"** is a record of research work done independently by **Ms. Th. Nengparmoi (2018-11-137)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associateship or fellowship toher.

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We, the undersigned members of the advisory committee of **Ms. Th. Nengparmoi (2018-11-137)**, a candidate for the degree of **Master of Philosophy in Agriculture** with major field in **Agronomy**, agree that the thesis entitled **"Response of sweet potato [*Ipomoea batatas* (L.) Lam.] to secondary nutrients"** may be submitted by **Ms. Th. Nengparmoi** in partial fulfillment of the requirement for the degree.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

APPENDIX

INTRODUCTION

1. INTRODUCTION

Sweet potato [*Ipomoea batatas* (L.) Lam.] is an important tuber crop cultivated in tropics and warm temperate regions of subtropics from 40^0 N to 30^0 S latitudes. This short duration crop can produce more edible energy per hectare per day than wheat, rice or cassava and has a prominent place in both intensive production systems as well as subsistence farming conditions. It is an important food crop of the world after wheat, rice, maize, potato, barely and cassava (CIP, 2017). In India, sweet potato is the third most important tuber crop after potato and cassava. It has tremendous potential for utilization in food, feed and industrial sectors. It is even considered as a famine relief crop as it played a pivotal role in alleviating the Bengal famine of 1942.

Sweet potato produced in Asia is mainly used for human consumption or as animal feed and to a limited extent as a raw material for industrial products like starch, alcohol, liquid glucose, citric acid, mono sodium glutamate and ethanol. It is an important root crop in countries like China, USA, India, Japan, Indonesia, Philippines, Thailand, Vietnam, and Nigeria. Globally sweet potato is cultivated in 117 countries in an area of 8.62 million ha producing 105.19 million tons with a productivity of 12.20 t/ha and majority of the sweet potato production comes from developing countries, of which China is having the maximum share of 67 % (FAO, 2016). Many processed food items are also made from sweet potato tubers.

In India, it is largely grown in north and eastern parts comprising of Odisha, Bihar, Chhattisgarh, Jharkhand, West Bengal and Uttar Pradesh which together contributes to 90 per cent of the production. It is also cultivated in parts of southern states like Kerala, Tamil Nadu and Karnataka. In Kerala, it is cultivated in an area of 19,230 ha with a production of 3,18,050 t/ha (NHB, 2017).

Annual rainfall of 750 to 1000 mm is considered most suitable, with a minimum of 500 mm in the growing season. Ideal temperature is between 21-26 ^{0}C. The crop grows well on a variety of soils having good drainage, but fertile sandy loam soil is ideal. It is often cultivated as rainfed crop in June-July and irrigated

crop in October-November (uplands) and January-February (low lands).

The crop duration can vary from 90 to 130 days depending on the cultivar and it requires bright sunlight for tuberization and tuber bulking.

Sweet potato is a crop having high nutrient requirement. Many studies have already been done on requirement of major nutrients for this crop. Recently, secondary nutrient deficiencies have been reported in many crops including tuber crops in Kerala. Magnesium deficiency has been reported to affect plant growth and biomass partitioning between root and shoot. Sulphur is a basic component of various amino acids and is required for protein synthesis.

The deficiency of calcium is usually corrected by the practice of liming as the soils are generally acidic. However, in the case of magnesium and sulphur, supplementation through chemical fertilizers is needed. The ad hoc blanket recommendation as per Package of Practices Recommendations (KAU, 2016) is application of magnesium sulphate @ 80 kg/ha in deficient soils, irrespective of crop. Moreover, there are reports that magnesium deficiency in crops can be a consequence of either low magnesium status of soil or an oversupply of K and calcium, indicating the importance of balanced nutrient application in enhancing the production and productivity.

As the deficiency of secondary nutrients is generally encountered in highly leached acid soils in Kerala and the research on supplementation of these nutrients in enhancing the productivity of sweet potato is limited, the present study was taken up with the following objectives

- To assess the influence of secondary nutrients on growth, yield and quality of sweet potato
- To work out the economics of production.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The nutrient demand of sweet potato is fairly high due to its high production potential. The crop removes a considerable quantity of nutrients from soil and the extent of removal can vary with soil, climate as well as variety. Secondary nutrients calcium (Ca), magnesium (Mg), and sulphur (S) are required for the growth and development of all higher plants. They are less often limiting to plant growth compared to primary nutrients nitrogen (N), phosphorus (P), and potassium (K), as the requirement is low. However, recently in Kerala the deficiency of these nutrients is being reported in many crops including tuber crops, which adversely affect crop productivity.

The crop belongs to family Convolvulaceae and is a highly heterozygous plant with chromosome number of 2n (6x) = 90. It is believed to have originated in Central or South America. The plant is a herbaceous vine, the edible tuberous root has smooth skin and skin/flesh color varies from white, cream, yellow to dark-orange, to violet or purple depending on cultivar. It is a rich source of provitamin A, vitamin B1 (Thiamine) and vitamin C (Huang, 1999). The tuberous roots are used as a source of carbohydrate (20-25 % on fresh weight basis). The major carotenoid pigment present in the orange- fleshed sweet potato is β-carotene.

Secondary nutrient deficiency symptoms like necrotic tissues on young leaves, root tip decay, chlorotic leaves accompanied by curling of leaf margins and drying of leaf lamina, long and thin internodes, etc have been reported in sweet potato. Studies show that integrated use of manures and fertilizers including secondary and micronutrients favoured higher tuber yields. Halavatau *et al*. (1998) reported that by satisfying both the major as well as micronutrient requirement, the tuber as well as vine yield could be increased considerably in sweet potato grown in marginal soil.

Literature pertaining to effect of primary, secondary and micronutrients on growth, yield and quality of sweet potato is furnished in this chapter. Information concerning secondary nutrient requirements of sweet potato is rather limited. Hence similar studies in potato are also reviewed.

2.1. Effect of calcium on growth and yield of sweet potato

Calcium (Ca) is usually the dominant basic cation in soils, and in acid soils with low CEC, level of Ca is likely to limit plant growth. Strongly acid soils tend to be high in exchangeable AI, and the toxic effects of Al on root growth may exacerbate the symptoms of Ca deficiency. High levels of K and Mg may reduce Ca uptake, and therefore over use of fertilizers containing these nutrients may lead to Ca deficiency. The primary symptom of Ca deficiency is the development of necrotic tissue on young leaves. The necrosis usually begins along the lateral margins and extends inward mainly in interveinal tissue. Necrotic tissue is pale brown to dark brown and brittle. Necrosis is not usually preceded by localized chlorosis, although the leaves may be uniformly paler than normal. Calcium deficiency inhibited root growth, and in severe cases resulted in root tip dieback. Solution concentrations of 13 µM Ca or below inhibited root growth of sweet potato cuttings (Ila' ava, 1997).

Chew *et al*. (1982) reported remarkably increased tuber and vine dry matter yield and harvest index of sweet potato by liming a Malaysian acid peat soil (pH 3.5 to 3.7). But increased liming decreased tuber yield, dry matter and harvest index. In Kerala, application of CaO @ 200 kg/ha was found to be beneficial in increasing the yield and quality of sweet potato tubers in acid laterite soils (Nair and Mohankumar, 1984). However, Hamid *et al.* (2004) found that high Ca concentration reduced the growth, yield and thickness oftuberous roots of sweet potato.

According to Sud and Sharma (2003), soil application of Ca was more effective than foliar application in increasing the potato yield, mainly due to increase in proportion of large and medium sized tubers.

Hamid *et al*. (2004) studied the effects of Ca concentrations on the length of tuberous root of sweet potato and reported varietal differences in root length. At high Ca concentration the tuberous root length of variety Beniotome was higher, while in variety Kokei it was shorter compared to low Ca concentration. Differences in the responses suggested that the sensitivity to Ca differed between the two varieties.

The effect of Ca on root elongation has been reported as either inhibitory or stimulatory depending on the method of Ca application (Hasenstein and Evans, 1988).

Generally, the size of the tuber is determined by the rate of cell multiplication and cell enlargement. Hamid *et al*. (2004) observed that dry weight of tops and tuberous roots was low at high Ca concentration than at low concentration. The lower fresh weight of tuberous roots at the high Ca concentration was due to slender tubers in addition to the poor growth of the vegetative tops. They also found that though the thickness of the tuberous roots was reduced, the cell size was increased at high Ca, suggesting that a high Ca concentration reduced the cell multiplication rate.

Simango and Waals (2017) recorded significantly more number of tubers and the highest yield in potato with soil application of calcium cyanamide, as compared to control plot. Chowdhur *et al.* (2019) reported that combined application of macro and micro nutrients increased plant height, fresh weight, dry weight and average tuber yield in potato.

2.2. Effect of magnesium on growth and yield of sweet potato

Overfertilization with potassium can induce Mg deficiency. Magnesium deficiency in crops might result either from low Mg status of soil or from an overabundance of K or Ca which inhibit Mg uptake by the plant (Leonard *et al.,* 1948). In strongly acidic soils, Mg deficiency might be induced by the presence of toxic concentrations of Al in the root environment, which inhibited Mg uptake by the plant. The earliest and specific symptom of Mg deficiency is interveinal chlorosis of older leaves. Typically, the main veins retain a relatively broad margin of dark green tissue, but the minor veins are less well defined, resulting in radial bands of pale tissue between the main veins.

In acid peat soils of Malaysia, Yong (1971) observed increased sweet potato yield due to application of $MgCO_3$ @ 5 t/ha.

Sweet potato removed large quantities of Mg from the soil and additional Mg was needed when high dose of potassium was used, to maintain balanced nutrient ratio (Moreno, 1982). It was also documented that Mg deficiency in sweet potato could be the consequence of either low content of Mg in the soil or an oversupply of K and Ca (O'Sullivan *et al.,* 1997).

According to Laxminarayana and John (2014), with application 15, 30 and 45 kg/ha of $MgSO_4$, sweet potato yield increased by 7, 11 and 8 % respectively, and the highest mean tuber yield (11.9 t/ha) and vine yield (18.1 t/ha) was obtained from 20 and 30 kg/ha of $ZnSO_4$ and $MgSO_4$, respectively. Other yield parameters like vine length, number of tubers per plant and average tuber weight also followed the same trend in line with the vine and tuberyields.

In potato, higher tuber yield was obtained with 10 kg/ha of Mg that was statistically comparable to the yield obtained with 15 and 20 kg/ha of Mg and tuber yield tended to decrease with increasing rate of Mg beyond 10 kg. There was 31 % increase in mean tuber yield over no magnesium (Talukder *et al.,* 2009).

AI-Esailyl and EI-Naka (2013) reported that application of magnesium @ 10 kg MgO/fed (0.42 ha) significantly increased plant growth characters (vine length, number of branches, number of storage roots plants, leaf area/plant, fresh and dry weight of different plant parts), photosynthetic pigments in leaves and plant chemical constituents as well as yield in sweet potato and its components compared tocontrol.

2.3. Effect of sulphur on growth and yield of sweet potato

a. Response of sweet potato to sulphur application

As per Purcell *et al*. (1982), sulphur had no effect on yield or composition of the roots of sweet potato. Contradictory to this, Nauarro and Padda (1983), on studying the effect of sulphur on growth and yield of sweet potato observed significant increase in yield with sulphur nutrition.

Yield increase was 30 % with sulphur application @ 2246 kg per hectare over control (no S application).

Alu *et al.* (2012) reported that sulphur application had significant effect on vine length, leaf area (m^2), fresh weight and dry weight of sweet potato and sulphur deficiency was a major nutritional constraint in sweet potato growth and yield. They observed significant increase in growth parameters with the application of S @ 12.5 kg, 25 kg and 50 kg per hectare.

b. Response of potato to sulphur application

Sulphur is one of the seventeen essential nutrient elements and the fourth major nutrient after NPK, required by plants for proper growth and yield. Sulphur deficiency resulted in poor utilization of nitrogen, phosphorus and potassium and a significant reduction of catalase activities at all ages (Nasreen *et al.,* 2003).

Decrease in tuber dry matter yield was observed with sulphur deficiency (Eppendorfer and Eggum, 1994). Singh *et al*. (1995) found increase in dry matter content in potato tuber with sulphur application. Sud and Sharma (2002) attributed increase in tuber yield with increasing sulphur levels to is role in partitioning of the photosynthates in the shoots and tuber.

Similarly, Lalitha *et al.* (2002) also reported significant effect on grade wise tuber yield and increase in bulking rate with sulphur application. Sulphur application had significant influence on potato and the highest tuber yield, number of large and medium sized tubers, and dry matter content resulted with application of sulphur @ 45 kg/ha (Sharma *et al.,* 2011)

Islam *et al.* (2014) reported that plant dry matter, tuber dry matter, number of tubers/m^2, tuber yield as well as marketable yield increased significantly with increasing sulphur level, while plant height and number of leaves decreased with increasing sulphur level. He concluded that potassium and sulphur had positive effect on growth parameters, yield attributes and yield in potato.

2.4. Response of sweet potato to primary nutrients

a. Effect of nitrogen nutrition

Generally, high amount of nitrogen fertilizers encouraged vegetative growth at the expense of storage root development in tuber crops. Nitrogen fed at an early stage of crop development would help in canopy establishment, whereas at later stage of growth, it helped in maintaining the greenness of the canopy and thus maximizes yield (Mark *et al.,* 1983). Taffouo (1994) opined that nitrogen is mainly needed for leaf formation and also for tuber growth and bulking, by ensuring photosynthetic production.

Nauarro and Padda (1983) observed considerable increase in yield from application of 280 kg N per hectare. However, when nitrogen application was increased up to 560 kg N, yield reduction was observed as higher levels of nitrogen favoured vegetative growth. Bourke (1985a) reported that N fertilization up to a rate of 225 kg N ha increased tuber yield, mean tuber weight, total plant dry weight, leaf area index, leaf area duration, number of leaves per plant, crop growth rate and, for some periods, leaf area ratio (LAR) and relative growth rate. It was suggested that N influenced yield by increasing leaf area duration, which in turn increased mean tuber weight, and hence tuber yield.

According to Bourke (1985a) higher rates of N caused a yield decline in sweet potato and the reason for this response was that nitrogen supply had a strong influence on the distribution of dry matter within the plant, particularly affecting root growth relative to top growth. When nitrogen supply was high, plants tended to grow more tops relative to roots. Excessive N rates stimulated vine and root growth and delayed tuber bulking and maturation (Bradbury and Holloway, 1988). Sweet potato tended to respond better to composts of plant materials which contain high potassium relative to nitrogen, than to animal manures, which were lower in potassium. However, this depends on the balance of nutrients present in the soil (Halavatau *et al*., 1996).

In most studies, nitrogen was not as effective as other fertilizers (potassium or phosphorus) in increasing sweet potato yield. Too much nitrogen could result in excessive vine growth, malformed tubers with cracked skin and poor storage qualities (Mascianica *et al*., 1985; Walker and Woodson, 1987).

Hartemink (2003) also documented that higher levels of nitrogen decreased sweet potato yield. However, there were reports that application of N increased the root yield of sweet potato (George and Mitra, 2001; Satapathy *et al.,* 2005).

Some other studies indicate that a moderate dose of 50-75 kg nitrogen per hectare was optimum for root production in sweet potato (Nair *et al.,* 1996; Sebastiani *et al.,* 2006). Nedunchezhiyan and Reddy (2002) reported that with the conjunctive use of 50 % N through fertilizers and 50 % N through any of the organic manures, higher yield, net returns and benefit:cost ratio was obtained when compared with other nitrogen management practices. Hartemink (2003) conducted the experiment on four levels of N (0, 50, 100, 150 kg/ha) and showed that sweet potato yield was increased significantly by applications of N, and the highest yields were obtained at 100 kg N per ha.

Work done in Ghana revealed that when the soil nitrogen level was low, increasing nitrogen fertilization was beneficial to yield, but there was no response to application above 30 kg N/ha. Nitrogen influenced both the number and weight of tubers (SRI-CSIR, 2003)

According to Adeyeye *et al.* (2016) application of urea fertilizer @ 200 kg/ha, produced the highest number of tubers per plant in sweet potato at Research farm of the Federal University Wukari Taraba State, Nigeria.

b. Effect of phosphorus nutrition

Phosphorus (P) as a major plant nutrient is involved in plant respiration, photosynthesis, cell division, energy storage, but in contrast with N it hastens rather than delays maturity. It was reported that phosphorus deficient potato plants typically produce tubers with lower specific gravity compared to those with adequate P nutrition. The P/N balance is also important and, to a degree, adequate P can help counter low specific gravity associated with high N levels. Like nitrogen, phosphorus also affected the unit weight of sweet potato root tubers (Degras, 2003).

Kabeerathumma *et al.* (1986) studied the suitability of rock phosphate as a source of phosphorus to sweet potato compared to single super phosphate and found comparable direct effect but superior residual value for rock phosphate. Generally, response of sweet potato to phosphorus was very low. Nauarro and Padda (1983) reported that phosphorus application did not significantly affect the sweet potato tuber yield. It was confirmed by a Philippine study which commented that at all levels of N and K used, addition of P did not result in any significant increase in yield (Degras, 2003).

According to a study in the Sudan Savanna Zone of Ghana, increasing rate of fertilizer P did not increase tuber yield or number of tubers (SRI-CSIR, 2003). Sweet potato response to phosphorus (P) was very low. However, a dose of 25-50 kg P_2O_5 per hectare was considered optimum for sweet potato (Muhanty *et al*., 2005; Akinrinde, 2006; Sebastiani *et al*., 2006).

Grewel and Trehan (1983) reported that application of poultry manure at 30 t/ha gave significant root tuber yield in white sweet potato. Similar results were obtained by Jayawardene (1985) in a study on the effect of inorganic P fertilizer and poultry manure on yield of sweet potato.

Application of inorganic P did not significantly affect yield and other characteristics of sweet potato. Application of 10 t/ha of poultry manure (PM) however, significantly increased the number of marketable roots. A combination of 100 kg/ha P_2O_5 and poultry manure @ 10 t/ha recorded the highest yield but marketable tuber yield was not influenced by P and poultry manure.

Kareem (2013) studied the effect of phosphorus on vegetative growth, phosphorus uptake and yield of sweet potato. The study revealed that application of phosphorus @ 445 kg/ha gave the highest phosphorus uptake and vegetative growth over control, but tuber yield was low (the highest tuber yield was obtained from control (0 kg).

Dumbuya *et al.* (2016) studied the effect of different rates of phosphorus fertilizers (0, 30, 60, 90 and 120 kg P_2O_5/ha) on growth and yield of sweet potato in Ghana. The study revealed that application of 60 kg P_2O_5/ha gave the highest growth and yield. It was also reported that fertilizer application significantly affected mean number of marketable roots of sweet potato than the control (0 kg P_2O_5/ha).

The highest vine length (139.67 cm), total tuber number per plant (8.0), total tuber yield (24.6 t/ha), marketable tuber yield (23.65 t/ha) was recorded from combined application of 15 t FYM along with 69 kg P_2O_5 per ha (Boru *et al*., 2017).

Kirui *et al*. (2018) reported that application of phosphate fertilizer at the rates of 30 kg P_2O_5/ha and 60 kg P_2O_5/ha had significant effect on growth of sweet potato in terms of the vine length, number of vines and yield over control (0 kg P_2O_5/ha).

c. Effect of potassium nutrition

Potassium is the key element in synthesis and translocation of carbohydrates from the tops to the roots. According to Foth (1978), K was required for efficient water utilization by sweet potato, increased its sugar content and tolerance to diseases. K was significantly crucial in the plant energy status, translocation and storage of assimilates and maintenance of tissue water relations (Marschner, 1995). Potassium appeared to be the most important nutrient in the production of sweet potato (SRI-CSIR, 2003).

A moderate dose of 75-100 kg of potassium was recommended for sweet potato (Mukhopadhyay *et al.*, 1990; Nair *et al.,* 1996; John *et al*., 2001). However, in China sweet potato responded to very high level of upto 300 kg/ha K_2O (George *et al*., 2002). Sweet potato, like all other tuber crops, had a high requirement of potassium fertilizer (Raemaekers, 2001).

According to Chatterjee and Mandal (1976), tuber yield increased proportionally with an increase in potassium dosage. Increasing the rate of potassium fertilization resulted in a significant increase in tuber yield (Foth, 1978). However, Nicholaides *et al.,* (1981) have reported that different K fertilizer levels produced no significant effect on both vine weight and vine length. Villareal (1982) recommended higher K level compared to N for maximum sweet potato yield as increasing N rates tended to decrease root yield.

Sugawara (1938) reported that when potassium application rate increased, tubers swelled and large sweet potatoes were obtained. Bourke (1985b) observed that potassium fertilizer increased the number of tubers per plant and mean tuber dry weight by seven weeks after planting.

Total root yield has been reported to increase with K supply, but the magnitude however depends on the initial potassium status, and K application @ 120 kg K_2O/ha gave the highest yield (Hammett *et al.,* 1984). However, Bourke (1985a) found that K fertilization up to a rate of 375 kg/ha increased tuber yield, number of tubers per plant, mean tuber weight, total plant dry weight, mean leaf area per leaf as well as harvest index. K influenced tuber yield through an increase in the proportion of dry matter diverted to the tubers and increase in tuber number per plant of sweet potato.

In a field study on effect of potassium on yield, Zhi (1991) observed that total root yield significantly increased with K application. The treatment 120 kg K_2O/ha gave the highest yield of 21.4 t/ha while no K (control) gave only 17.7 t/ha. Contradictory to this, Constantin *et al.* (1917) established no significant difference in harvest index and dry matter production in sweet potato among the levels of K fertilizers tried. According to him differences however exist among varieties of sweet potato.

It was important to avoid excessive late-season applications of potash. Starch synthesis and specific gravity increased with increasing K concentration up to an optimum K concentration of 1.8 per cent in tuber. At higher K concentrations, specific gravity decreased as tubers began to absorb more water due to the osmotic effects of increased tissue salt concentrations (Dahnke *et al.,* 1992).

Potassium fertilizer increased total dry matter produced and the proportion of dry matter diverted to the tubers, and there by favourably influenced harvest index (HI) of sweet potato (Byju, 2002). Uwah *et al.* (2013) conducted a field study in Calabar, Nigeria and found that application of K @ 160 kg/ha significantly increased vine length, number of leaves and branches/plant, whereas dry weight of vine, diameter of tubers/plant, weight of tubers/plant, number of tubers/plant and tuber yield/ha were statistically similar at 120 kg K/ha and 160 kg K/ha.

Tuber yield/ha obtained at 120 and 160 kg K/ha rates were more than 7 and 8 times higher than the control treatments.

In a study on the effect of potassium doses (60 kg, 120 kg and 180 kg K_2O/ha) on growth and yield of sweet potato, potassium application increased the growth (vine length, the number of leaves, branches, and roots) and yield of sweet potato, and the highest tuber yield was obtained with 60 kg K_2O/ha (Dumbuya *et al.,* 2017). Wang *et al.* (2019) tried four potassium doses (0, 75, 150, and 225 kg/ha) in sweet potato. They observed that yield increased by 17 %, 30 %, and 35 % in compared with the control (No K) and attributed this to increase in the tuber number and the average tuber weight due to K nutrition. Results of another field experiment by Aboyeji *et al.* (2019) with various levels of potassium chloride fertilizer (0, 40, 80, 120 and 160 kg/ha) applied to sweet potato showed that the highest growth and tuber yield was obtained with 80 kg/ha.

d. Combined effect of NPK application on sweet potato

Sweet potato is a heavy feeder and a crop yielding 30 t/ha of top growth and 22 t/ha of storage roots takes up on an average 80 kg N, 29 kg P and 185 kg K/ha (AVRDC, 1975).

Ravindran and Bala (1987) reported that with increasing levels of N, P_2O_5 and K_2O tuber yield increased under both upland and lowland situations in Kerala, India and N, P_2O_5 and K_2O levels beyond 75:50:75 kg/ha declined the tuber yield.

Yeng *et al.* (2012) conducted field experiments on integrated application of NPK and chicken manure. They observed the highest marketable root yields of 21.4 and 23.0 t/ha from combinations of 150 kg NPK + 1.5 t chicken manure and 100 kg NPK + 3.0 t chicken manure per ha. Constantin (2016) observed the highest marketable tuber weight (12.47 t/ha) and marketable tuber diameter (8.88 cm) from application of NPK fertilizer @ 350 kg/ha. He also reported that NPK @ 350 kg/ha along with FYM 7.5 tons/ha gave highest above ground dry biomass weight (5.70 t/ha), while NPK alone (350 kg/ha) recorded longest vine (235.3 cm) and number of branches per plant (8.89).

In a field experiment carried out by Koodi *et al*. (2017) to determine the effect of NPK, FYM and vermicompost on growth and yield of sweet potato, the maximum vine length (172.9 cm), leaf area (185.3 cm^2), total chlorophyll content (1.178 mg/g), tuber weight (323.62 g), tuber length (15.20 cm), tuber diameter (8.57 cm), tuber yield (12.32 kg/plot) and tuber yield (228.16 q/ha) were observed from combined application of 100 % recommended dose (100:60:100 kg/ha) of NPK + vermicompost 2.5 t/ha.

Application of NPK fertilizers @ 100 kg per ha significantly influenced the tuber yield, total chlorophyll content and dry weight, on the contrary, led to a significant decrease of shoot length and number of leaves per plant (Desire *et al.,* 2017). NPK significantly increased marketable yields by 21 % as compared to control (Gibberson *et al*., 2017).

According to Jalwania *et al.* (2019) application of 100 % N : P_2O_5 : K_2O dose significantly increased the vine length, number of leaves per vine as compared to control. Hayati *et al.* (2020) also reported the highest tuber yield (32.51 t/ha) with application NPK (15:15:15) @ 400 kg/ha.

2.5. Effect of micronutrient application on sweet potato

Gad and Kandil (2008) conducted field experiments to evaluate the effect of cobalt concentrations (0.0, 5.0, 7.5, 10.0, 12.5 and 15.0 ppm) on sweet potato growth, root yield and quality. They reported that addition of 10 ppm cobalt had significant positive effect on growth, root yield and quality. However, concentrations more than 10 ppm adversely affected crop growth.

Laxminarayana and John (2014) observed increase in the mean tuber yield by 12, 19 and 10 % respectively due to application of $ZnSO_4$ @ 10, 20 and 30 kg/ha over control. Adekiya *et al.* (2018) reported that highest values of vine length, vine weight and storage root yield (17.4 % more over control) were realized with application of $ZnSO_4$ @ 45 kg/ha.

2.6. Effect of fertilizer application on tuber quality of sweet potato

a. Effect of Nitrogen

Nitrogen application resulted in increased carotene content of sweet potato tuber (Degras, 2003). In a study conducted in Nigeria on trans-cis β-carotene content of selected sweet potato varieties as influenced by different levels of nitrogen fertilizer application, it was revealed that there was a decline in β-carotene content of sweet potato varieties with the exception of CIP Tanzania when application was above 80 kg N/ha. This trend established that the total β-carotene and all-trans-cis isomers of β-carotene yield were higher at 40 to 80 kg N/ha. The β-carotene values from sweet potato varieties common to Africa were however, low (Ukom *et al*., 2011).

Apart from storage root yield of sweet potato, quality characters were found to be influenced by nitrogen application (Nedunchezhiyan and Ray, 2010).

Continuous use of fertilizer N might, in some situation, have detrimental effects on root quality. Therefore, use of organic source of N is essential to improve the quality characters. However, per ha yield of starch, vitamin C, β-carotene, etc. were more important than percentage content. Nedunchezhiyan *et al.* (2003) noticed discernible variation in the quality characters due to different sources of N and their combinations.

Ukom *et al*. (2009) observed that nitrogen fertilizer significantly increased the total ß-carotene and crude protein with application rate up to 120 kg N/ha. Nitrogen @ 40-80 kg/ha, recorded higher bioavailability of ß-carotene (Provitamin A) and crude protein. Increase in the mineral contents of most sweet potato varieties was also observed.

Increase in the rate of applied N to sweet potato plants caused an increase in root N content but did not affect the non-protein N/total N ratio. Also increase in the rate of K enhanced yield but did not affect root N content nor the non protein N/total N ratio (Purcell *et al.,* 1982).

b. Effect of Phosphorus

El-Morsy *et al*. (2002) and Hassan *et al.* (2005) observed that with an increase in the application of phosphorus @ 15 to 60 kg P_2O_5/fed, total sugars, TSS, carbohydrates, starch and carotenoids contents in sweet potato root tissues were increased. Phosphorus increased the carotene content of tuberous roots (Degras, 2003).

It is reported that with increase in the rate of applied phosphorus from 15 kg P_2O_5 up to 45 kg P_2O_5/fed, the total chlorophyll and carotenoids were increased. Moreover, application of phosphorus at 45 kg P_2O_5/fed significantly increased carotenoids, carbohydrate and total sugars in tuber (El-Sayyed *et al.*, 2011).

According to (Razzak *et al.,* 2013), chemical constituents of sweet potato such as total glucose, total soluble solids, carbohydrates, starch, and carotene content were increased with the application of phosphatic fertilizers @ 50 % (145 kg/ha) or 100 % (290 kg/ha) compared to lower level of P @ 25 % (72.5 kg/ha) or control (0 kg/ha).

c. Effect of potassium

It is well established that potassium enhances translocation of sugars and starches. Since root crops are mainly carbohydrate producers, they have an especially high requirement of potassium, which has a special role in carbohydrate synthesis and translocation. Constantin *et al*. (1917) observed that potassium application increased starch content and altered root shape of sweet potato.

According to Hammett and Miller (1982), potassium increased starch content but decreased crude fibre and firmness of canned tuber. However, carotene content, ascorbic acid levels and soluble carbohydrate levels of sweet potato were not influenced by K application. Nogueira *et al.* (1992) carried out an experiment in Brazil in a red-yel1ow latosol.

They observed that the starch and carotene in roots were favourably influenced by potassium rates. Biswal (2008) also reported that the quality characters like starch and protein content were found to increase with increased level of potassium in sweet potato.

Koodi *et al*. (2017) conducted the study on effect of NPK, FYM and vermicompost on quality of sweet potato. They observed that from F_3 treatment [100 % RD (100:60:100 kg/ha) of NPK + VC (2.5 t/ha)] the quality of sweet potato like TSS (4.56 %), N content (0.348 %), P content (0.310 %), K content (0.646 %), starch content (13.03 %), protein content (2.17 %) and ascorbic acid content (43.49 mg/100g) were found significantly higher over rest of the treatments.

Aboyeji *et al*. (2019) tried various levels potassium fertilizer (0, 40, 80, 120 and 160 kg/ha) in sweet potato. The result revealed that the highest values of protein and fibre were obtained at 40 and 80 kg/ha of potassium chloride fertilizer. They also found that application of K at rates from 0 -160 kg/ha reduced fat and dry matter content and significantly increased moisture, vitamin C and carbohydrate content of tubers.

d. Effect of nutrient application on tuber quality of sweet potato

Lauriea *et al.,* (2012) found that carotene content was 14 % higher for both intermediate (50 %) N : P_2O_5 : K_2O @ 75, 15 and 95 kg/ha and high (100 %) N : P_2O_5 : K_2O @ 150, 30 and 190 kg/ha fertilizer treatments when compared to no fertilizer treatment. Carotene yield increased two-fold at the intermediate fertilizer level and four-fold at the high fertilizer level. Gibberson *et al.* (2017) also reported that NPK fertilizers increased beta-carotene and protein in some sweet potato varieties.

Quality parameters of sweet potato tubers showed an increase in values with application of NPK @ 400 kg/ha, *i.e.,* ash (0.90 % to 1.24 %), crude fat (0.81 % to 1.21 %), crude fibre (2.31 % to 2.49 %), total glucose (3.08 % to 3.27 %), starch (20.75 % to 22.71 %), and beta-carotene (3.10 to 3.55 mg/100g) (Hayati *et al.,* 2020).

e. Effect of secondary and micro nutrients on tuber quality of sweet potato

Maini *et al*. (1973) observed that application of 1000 ppm Mg increased the protein content of sweet potato tubers. AI-Esailyl and EI-Naka (2013) found that magnesium application (@ 20 kg MgO/fed) increased TSS, reducing sugar and total sugar as well as total carbohydrate content of sweet potato tubers.

Research works show that even application of micro nutrients influences sweet potato tuber quality. Gad and Kandil (2008) observed that cobalt @ 10 ppm increased the content of carotenoids, protein, starch, total soluble sugars and ascorbic acid in sweet potato tubers. Application of $ZnSO_4$ @ 20 kg/ha resulted in the highest mean starch content (22.4 %), total sugars (3.61 %) and dry matter (29.4 %) of sweet potato tuber (Laxminarayana and John, 2014).

MATERIALS ANDMETHODS

3. MATERIALS ANDMETHODS

The experiment on "Response of sweet potato to secondary nutrients" was conducted during the period from September 2019 to January 2020 at College of Horticulture, Vellanikkara, Thrissur. Materials and methodology adopted for the study are described in this chapter.

3.1. Location, climate and soil.

The experiment was conducted at Agronomy Farm of the Department of Agronomy, College of Horticulture, Vellanikkara, located at 10°33'N latitude, 76°16'E longitude at an altitude of 40.3 m above Mean Sea Level, coming under Agro Ecological Unit (AEU)-10 (Northern Central Laterities) of Kerala.

The data on weather parameters (rainfall, number of rainy days per month, maximum temperature, minimum temperature, relative humidity, evaporation and sunshine hours) during the cropping period are furnished in Appendix 1. During the experiment the maximum and minimum temperature were in a narrow range between 31.5 °C to 32.9 °C and 21.1 °C to 22.3 °C respectively. The total sunshine hour was 165.7 hours. The relative humidity showed a variation from 61.5 % to 84.8 % and the highest was observed in September and the lowest in the month of December. The total rainfall during the entire crop period was 226.6 mm. The highest quantity of 95.90 mm was recorded in October followed by 93.50 mm in September. The rainfall in November was only 36.70 mm and just 0.50 mm was recorded was recorded in December.

The soil of the experiment site was sandy clay loam with a pH of 4.9. The physico-chemical properties of soil and methods used for the estimation of available nutrients are detailed in Table 1.

3.2. Treatment

The experiment was laid out with 11 treatments replicated thrice. Plot size was 5 m x 3 m and mound system of planting was adopted with a spacing of 75 cm x 75 cm.

Sweet potato variety Sree Kanaka was used. It is a high beta-carotene variety of sweet potato, a selection from Thiruvananthapuram district released from ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram. The vine run up to a length of 1.5-3 m, and has duration of 2.5–3.0 months and an average yield of 20 - 30 t/ha. The tubers are sweet with good flavor, taste and cooking quality. Vine cuttings were collected from the ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram.

The experiment consisted of eleven treatments which were combinations of soil test based N : P_2O_5 : K_2O application (T_1 to T_5) and N : P_2O_5 : K_2O @ 75:50:75 POP recommendation (T_6 to T_{10}) with four different doses of $MgSO_4$ ranging from 40-100 kg/ha along with control (No Magnesium sulphate application). Farm yard manure was applied @ 10 t/ha to all treatments.

In the case of T_{11}, the following manurial schedule was followed as per POP for organic production (KAU, 2016).

Table 1. Physico-chemical properties of soil before the experiment

Particulars		Value	Method used
1. Physical properties (Particle size composition)			
Coarse sand (%) Fine sand (%) Silt (%) Clay (%)		31.90 27.30 18.64 22.16	Robinson's international pipette method (Piper, 1966)
2. Chemical properties			
		Status	
Ph	4.90		1:2.5 soil water ratio (Jackson, 1958)
Organic carbon (%)	1.25	Medium (0.75-1.5)	Walkley and Black method (Jackson, 1958)
Available N (kg/ha)	270	Medium (240-480)	Alkaline permanganate method (Subbiah and Asija, 1956)
Available P (kg/ha)	61	High (24-34.5)	Ascorbic acid reduced molybdo phosphoric acid blue colour method (Bray and Kurtz, 1945; Watanabe and Olsen, 1965)
Available K (kg/ha)	405	High (275-395)	Neutral normal ammonium acetate extraction and estimation using flame photometry (Jackson, 1958)
Available Ca (mg/kg)	158	Low (300 mg kg^{-1})	Ammonium acetate method (Metson, 1956)
Available Mg (mg/kg)	43	Low (120 mg kg^{-1})	
Available S (mg/kg)	49	High (5-10 mg kg^{-1})	Turbidimetric method (Massoumi and Cornfield, 1963)

Organic nutrient management schedule followed in (T_{11}) is given below

Cattle manure was applied @ 10 t/ha at the time of preparation of mounds. Vermi compost 3 t along with 1 t coir pith compost + 1 t ash/ha, azospirillum (2 kg/ha) and PGPR mix I (2.5 kg/ha) were applied in two equal split doses at 3 weeks and 6 weeks after planting. At the time of planting vines were dipped in PGPR mix I.

Treatment details		
	$MgSO_4$ (kg/ha)	N : P_2O_5 : K_2O (kg/ha)
T_1	0	65: 12: 20*
T_2	40	65: 12: 20
T_3	60	65: 12: 20
T_4	80	65: 12: 20
T_5	100	65: 12: 20
T_6	0	75: 50: 75
T_7	40	75: 50: 75
T_8	60	75: 50: 75
T_9	80	75: 50: 75
T_{10}	100	75: 50: 75
T_{11}	Organic management (KAU, 2016)	

As per soil test results, nitrogen was applied @ 84 %, and P_2O_5 and K_2O @ 25 % of recommended dose of POP, respectively.

3.3. Cultivation practices

a. Field preparation

The experimental field was ploughed with disc plough, followed by a cultivator. Weeds and stubbles were removed and experiment was laid out as per Fig. 1. Mounds were taken at a spacing of 75 cm x 75 cm. Bunds were made around the plots and channels were laid for drainage.

b. Application of lime, manures and fertilizers

Farm yard manure was applied basally @ 10 t/ha as per the 'Package of Practices Recommendations-Crops' of the Kerala Agricultural University (KAU, 2016) and incorporated into each mound. Urea (46 per cent N), single super phosphate (1 per cent P_2O_5) and muriate of potash (60 per cent K_2O) were used as the sources of nitrogen (N), phosphorus (P) and potassium (K). Lime (40 g per mound) and dried cattle manure Fertilizer grade magnesium sulphate (15 % MgO and 20 % S) was used in the study. Half dose of nitrogen and full dose of phosphorus and potassium were applied at one week after vine emergence. Second application of fertilizers was done one month after the first application.

c. Planting

Planting was done on 20th September 2019. Vine cuttings of 15 to 20 cm length were prepared and three vine cuttings were planted per mound. Gap filling was done two weeks after planting to maintain the optimum plant population.

d. Weeding and earthing up

Two manual weedings were done at 30 and 60 days after planting just before fertilizer application and earthing up was done to facilitate tuber formation.

e. Irrigation

The crop was given weekly irrigation during November 15 to December 15.

f. Plant protection

Traps were used to control sweet potato weevils, which was the only pest observed. The crop was free from diseases.

g. Harvesting

Harvesting was done 102 days after planting (on 2nd and 3rd January, 2020), when the vines showed yellowing. Tubers were dug out carefully using spade. The days to harvest was uniform among the treatments. Field operations carried out are given in Plate 1 to 7.

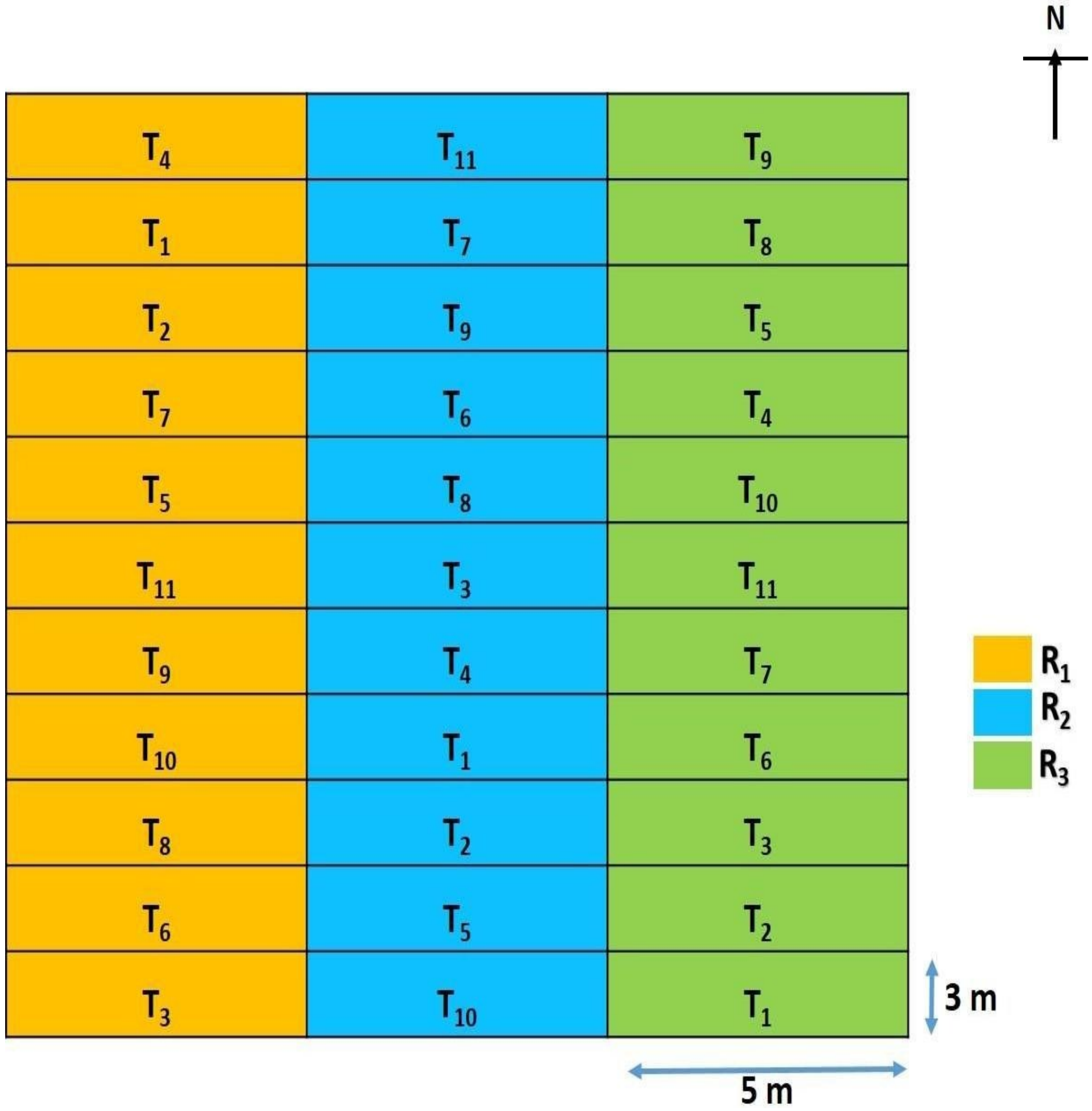

Figure 1. Layout of the field experiment

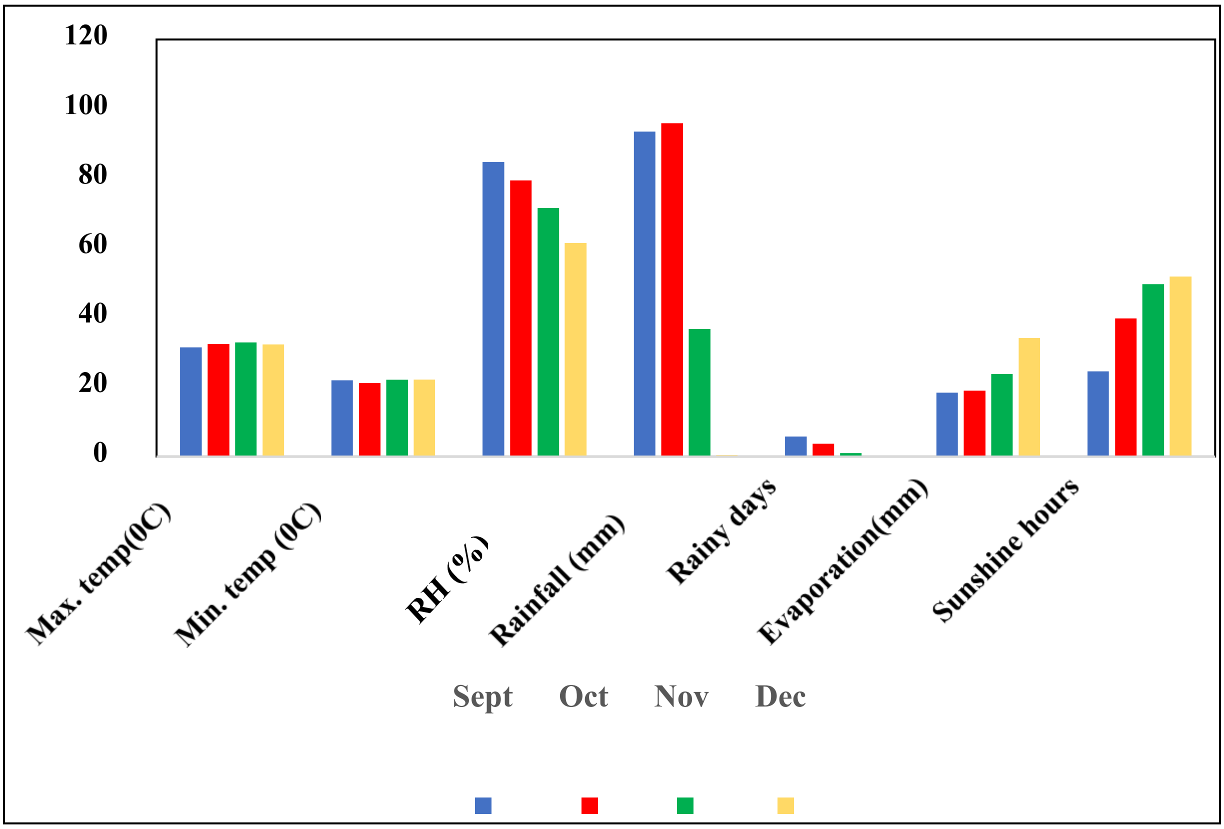

Figure 2. Monthly weather data during experimental period

4.4. Observations

Observations on biometric parameters, chlorophyll content, yield and yield attributes of sweet potato were recorded and the mean values were worked out.

Sampling procedure

For taking observations on growth and yield, five plants were selected at random and tagged from each plot omitting the border rows. Destructive sampling was done for leaf area, dry matter estimation and plant analysis.

1. Growth observations

a) Leaf area index

Sample plants were uprooted at active vegetative stage (60 DAP). Total number of leaves was counted and leaf area of representative sample leaves were read using a leaf area meter (Licor leaf area meter). The average leaf area per leaf was multiplied with total number of leaves to get total leaf area per vine (cm2). The total leaf area of three plants were added and divided by spacing to get leaf area index.

b) Vine length

The length of vine was measured from base of vine to the growing tip at 30, 60 and 90 days after planting and expressed in cm.

c) Total dry matter production

Dry matter accumulation per vine was recorded at harvest by destructive sampling of random plants (one plant per plot). These plants were uprooted from each plot carefully without damaging the roots and tubers. The plants were dried under shade and then oven dried at 70 ± 5°C till constant consecutive weights obtained. Cut tubers were also dried in the same manner.

The dry weight of the whole plant was found out by adding weights of aerial and underground parts and was expressed as gram per plant. This was multiplied with plant population to get dry matter production per ha and expressed as kg/ha.

2. Leaf chlorophyll content

At active growth phase leaf samples were taken and chlorophyll was estimated by acetone method (Arnon, 1949) and expressed as mg/g fresh weight.

3. Yield and yield attributes

a. Tuber yield

Total weight of tubers from each mound was recorded to get tuber yield per hectare and was expressed as t/ha.

b. Number of tubers per vine

Total number of tubers from sample plants from each plot were counted and averaged to get number of tubers per plant.

c. Weight of unmarketable tuber

Under sized, weevil infested and cracking tubers from each plot were collected and weighed and expressed as t/ha.

d. Harvest index

At harvest both the yield of aerial and underground parts of sweet potato were weighed separately for calculation of harvest index. The harvest index was calculated as the yield of tubers divided by the yield of aerial part and tubers.

e. Incidence of pests and diseases

Incidence of pests and diseases during crop period was monitored and timely control measures were adopted.

5. **Plant analysis**

a. Uptake of primary and secondary nutrients at harvest

After harvest, plant samples were processed and analyzed for nitrogen, phosphorus, potassium, calcium, magnesium and sulphur. The samples were dried to constant weight in an electric hot air oven at 70 ± 5°C, ground into fine powder and used for analyzing N, P, K, Ca, Mg and S content as per Table 2. Uptake of nutrients at harvest was calculated by multiplying the values of dry matter production and per cent nutrient content in aerial part and tuber and expressed in g/plant and kg/ha.

6. **Soil analysis**

After the harvest of sweet potato, soil samples were collected from each treatment. It was analyzed for pH, organic carbon, available nitrogen, phosphorus, potassium, calcium, magnesium and sulphur as per the standard procedures mentioned in Table 1.

7. **Tuber quality**

After harvest, tuber samples were processed and analyzed for total and reducing sugar, crude protein and fibre oven at 70 ± 5 °C, ground into fine powder and used for analyzing total and reducing sugars (%), crude. The samples were chopped and dried to constant weight in an electric hot air protein (%) and fibre (%) as per the standard procedures mentioned in Table 3.

Table 2. Methods used for plant analysis

Nutrients	Method used	Reference
N	Modified micro Kjeldahl method	(Jackson, 1958)
P	Vanado-molybdo phosphoric yellow colour method	(Piper, 1966)
K	Flame photometry	
Ca	Ammonium acetate method	
Mg	Ammonium acetate method	
S	Turbidimetric method	(Chesnin and Yien, 1951)

Table 3. Methods used in analysis of tuber quality parameters

Parameters	Method used	Reference
Total and reducing sugars	Fehlings solution	(Lan and Eynon, 1934)
Crude protein	Modified micro Kjeldhal method	(Jackson, 1958)
Fibre	Muslin cloth method	(AOAC, 1984)

3.5. Cost-Benefit Analysis

Cost of cultivation was calculated based on the expenditure incurred. The market price of sweet potato was considered for working out the gross income. Net income was estimated by subtracting cost of cultivation from gross income and expressed in Rs/ha. Benefit cost ratio was worked out as the ratio of gross income to the total cost of cultivation.

3.6. Statistical Analysis

The data was analyzed statistically by applying the techniques of Analysis of Variance (Gomez and Gomez, 1984). The collected data were analyzed using OP Stat.


Plate1. Nursery bed


Plate 2. Land preparation


Plate 3. Mound preparation and planting

Plate 4. Earthing up and irrigation

Plate 5: Tuber at harvest stages

Plate 6. Harvesting and harvested tubers

Plate 7: Field visit by advisory committee

RESULTS

4. RESULTS

A field experiment was carried out to study the "Response of sweet potato [*Ipomoea batatas* (L.) Lam.] to secondary nutrients" at Department of Agronomy, College of Horticulture, Kerala Agricultural University during 2019-2020. Data on growth and yield parameters recorded were statistically analyzed and results are presented in this chapter.

4.1. Vine length

Vine length was recorded at 30, 60 and 90 DAP. The data on vine length as influenced by application of fertilizers are given Table 4. The length of vines increased on an average up to 2.5 m in three months of planting. At 30 DAP higher and comparable vine length was observed in treatment T_3 (65:12:20 + $MgSO_4$ @ 60 kg/ha), T_6 (75:50:75 + $MgSO_4$ @ 0 kg/ha), T_7 (75:50:75 + $MgSO_4$ @ 40 kg/ha), T_8 (75:50:75 + $MgSO_4$ @ 60 kg/ha), T_9 (75:50:75 + $MgSO_4$ @ 80 kg/ha) and T10 (75:50:75 + $MgSO_4$ @ 100 kg/ha) and the vine length was in the range of 47.00 cm to 55.80 cm. Among the treatments, lower vine length was seen in treatment T1 (65:12:20 + no $MgSO_4$), T_2 (65:12:20 + $MgSO_4$ @ 40 kg/ha), T_4 (65:12:20 + $MgSO_4$ @ 80 kg/ha), and T_5 (65:12:20 + $MgSO_4$ @ 100 kg/ha) and T_{11} (organic pop) and were statistically on par. The vine length was in range of 40.50 to 45.00 cm.

At 60 DAP, though the differences were significant, plants in most of the treatments had comparable values of vine length. Treatments T_1, T_2 and T_{11} continued to register inferior values and these were statistically on par. However, these were in turn on par with many other treatments. It was seen that at 60 DAP, all the treatments (T_6 to T_{10}) which received higher doses of N : P_2O_5 : K_2O @ 75:50:75 kg/ha with varying doses $MgSO_4$ registered comparable vine length. NPK application as per soil test, resulted in lower values of vine length compared to NPK application at recommended dose of 75:50:75.

A slightly different trend in vine length was observed at 90 DAP. At this stage, treatments T_3 and T_7, which received $MgSO_4$ @ 60 and 40 kg/ha, registered higher vine length of 233.4 cm and 222.9 cm respectively and were on par. However, T_3 received K @ 20 kg/ha whereas T_7 received higher dose of K @ 75 kg/ha. As in the case of 60 days, the treatments T_1, T_2 and T_{11} continued to register lower values. It was seen that at 90 DAP also, all the treatments which received N : P_2O_5 : K_2O @ 75:50:75 kg/ha with varying doses $MgSO_4$ were statistically on par, similar to performance at 30 and 60 DAP.

4.2. Leaf Area Index

The data of leaf area index is presented in Table 5. The observation was done at 60 DAP when the vines were in the active vegetative stage. The leaf area index ranged from 2.65 to 3.48. Among the treatments, highest leaf area index was registered in T_8 (75:50:75 + $MgSO_4$ @ 60 kg/ha) which was superior than others. The second higher index was observed in T_7 (75:50:75 + $MgSO_4$ @ 40 kg/ha) followed by T_9 (75:50:75 + $MgSO_4$ @ 80 kg/ha) which were statistically different. Thelowest LAI of 2.65 was observed in treatment T_{11} (organic POP). This was followed by T_1 (65:12:20 + $MgSO_4$ @ 0 kg/ha) and T_2 (65:12:20 + $MgSO_4$ @ 40 kg/ha) which differed statistically from each other.

4.3. Chlorophyll content

The data on leaf chlorophyll content estimated at the active growth phase (60 DAP) is presented in Table 6. The sample was taken from fully open physiologically mature leaf (7th leaf from the tip of the vine). The chlorophyll a, b and total chlorophyll content ranged from 1.4-1.7 mg/g, 0.3-0.4 mg/g and 1.8-2.2 mg/g of fresh leaf, respectively.

In the case of chlorophyll a, b and total chlorophyll content all the treatments registered statistically comparable values.

4.4. Dry matter production

Dry matter production of both tubers and aerial parts were recorded separately at harvest.

a. Dry matter production of aerial portion

The data of aerial dry weight of sweet potato is present in Table 7. It is an indication of the vegetative growth of plant. The aerial dry matter production ranged from 77.6 g to 150.9 g/plant. Among the treatments higher and statistically comparable values were observed in treatments T_6 to T_{10} which received N : P_2O_5 : K_2O @ 75:50:75 kg/ha, irrespective of $MgSO_4$ dose and the dry matter production ranged from 128 to 150.9 g/plant. The lower aerial dry matter production was registered in T_{11} (organic POP) which was statistically on par with other treatments (T_2, T_4 and T_5) which received lower dose of N : P_2O_5 : K_2O (65:12:20) with variable $MgSO_4$ dose.

b. Dry matter production of tubers

Tuber initiation was observed within 45-50 days after planting and considerable tuber bulking was noticed by 60 days after planting. The dry matter accumulation by tuber showed wide variation, ranging from 121.6 g/plant to 220.5 g/plant, and thetrend was different from that of aerial portion.

Highest dry matter production was recorded in T_7 (75:50:75 + $MgSO_4$ @ 40 kg/ha) which was on par with treatments T_6 (75:50:75 + $MgSO_4$ @ 0 kg/ha), T_{10} (75: 50:75 + $MgSO_4$ @ 100 kg/ha) and T_{11} (organic POP). Lower tuber dry matter accumulation was seen in all the treatments which received N : P_2O_5 : K_2O @ 65:12:20 kg/ha, irrespective of magnesium sulphate dose and they were statistically on par.

c. Total dry matter production of sweet potato

Application of fertilizers had significant effect on total dry matter production (Table 7). The total dry matter in various treatments was ranged from 219.1 g/plant to 367.3 g/plant. Among the treatments total dry matter accumulation was highest in T_7 which was on par with T_6, T_8, T_9 and T_{10} which received higher N : P_2O_5 : K_2O of 75: 50:75 and variable dose of $MgSO_4$. The lower and comparable dry matter content was registered in treatments T_1 to T_5 which in turn was comparable to organic management (T_{11}).

Table 4. Vine length of sweet potato at different stages of growth

Treatment	Nutrient doses N : P_2O_5 : K_2O (kg/ha) + $MgSO_4$ (kg/ha)	Vine length (cm)		
		30DAP	60DAP	90DAP
T_1	65: 12: 20 + 0	43.2^{bc}	115.7^{c}	179.7^{c}
T_2	65: 12: 20 + 40	44.6^{bc}	134.3^{bc}	189.8^{c}
T_3	65: 12: 20 + 60	55.8^{a}	193.3^{a}	233.4^{a}
T_4	65: 12: 20 + 80	43.2^{bc}	150.2^{abc}	182.2^{c}
T_5	65: 12: 20 + 100	40.5^{c}	163.1^{abc}	202.5^{bc}
T_6	75: 50:75 + 0	46.3^{abc}	171.1^{ab}	208.1^{bc}
T_7	75: 50: 75 + 40	55.6^{a}	186.4^{ab}	222.9^{ab}
T_8	75: 50: 75 + 60	47.0^{abc}	155.8^{abc}	202.1^{bc}
T_9	75: 50: 75 + 80	45.5^{abc}	175.1^{ab}	216.9^{bc}
T_{10}	75: 50: 75 + 100	52.9^{ab}	165.4^{abc}	207.2^{bc}
T_{11}	Organic management	43.5^{bc}	134.0^{bc}	181.9^{bc}
CD (0.05)		10.13	44.39	33.92

In a column, values followed by same alphabets do not differ significantly in DMRT

Table 5. Effect of nutrient management on leaf area index of sweet potato

Treatment	Nutrient doses N : P_2O_5 : K_2O (kg/ha) + $MgSO_4$ (kg/ha)	LAI @ 60 DAP
T_1	65: 12: 20 + 0	2.94^{f}
T_2	65: 12: 20 + 40	2.84^{g}
T_3	65: 12: 20 + 60	3.14^{d}
T_4	65: 12: 20 + 80	2.81^{h}
T_5	65: 12: 20 + 100	3.08^{e}
T_6	75: 50:75 + 0	3.13^{d}
T_7	75: 50: 75 + 40	3.33^{b}
T_8	75: 50: 75 + 60	3.48^{a}
T_9	75: 50: 75 + 80	3.28^{c}
T_{10}	75: 50: 75 + 100	3.12^{de}
T_{11}	Organic management	2.65^{i}
CD (0.05)		0.45

In a column, values followed by same alphabets do not differ significantly in DMRT

Table 6. Effect of nutrient management on leaf chlorophyll content of sweet potato vines

Treatment	Nutrient doses N : P_2O_5 : K_2O (kg/ha) + $MgSO_4$ (kg/ha)	Chlorophyll content (mg/g)		
		Chlorophyll a	Chlorophyll b	Total chlorophyll
T_1	65: 12: 20 + 0	1.5	0.4	2.0
T_2	65: 12: 20 + 40	1.6	0.4	1.9
T_3	65: 12: 20 + 60	1.6	0.4	2.0
T_4	65: 12: 20 + 80	1.6	0.4	1.9
T_5	65: 12: 20 + 100	1.8	0.3	2.2
T_6	75: 50: 75 + 0	1.7	0.4	2.1
T_7	75: 50: 75 + 40	1.5	0.3	1.8
T_8	75: 50: 75 + 60	1.7	0.4	1.8
T_9	75: 50: 75 + 80	1.5	0.3	1.9
T10	75: 50: 75 + 100	1.4	0.4	2.2
T11	Organic management	1.5	0.3	1.8
CD (0.05)		NS	NS	NS

Table 7. Effect of nutrient management on dry matter production of sweet potato

Treatment	Nutrient doses N : P_2O_5 : K_2O (kg/ha) + $MgSO_4$ (kg/ha)	Dry matter (g/plant)		
		Aerial dry weight	Tuber dry weight	Total dry weight
T_1	65: 12: 20 + 0	110.1^{c}	139.3^{cd}	249.4^{bc}
T_2	65: 12: 20 + 40	97.6^{cd}	121.6^{d}	219.1^{c}
T_3	65: 12: 20 + 60	126.4^{bc}	162.6^{bcd}	289.0^{bc}
T_4	65: 12: 20 + 80	101.2^{cd}	149.2^{bcd}	250.5^{bc}
T_5	65: 12: 20 + 100	102.3^{cd}	134.7^{cd}	237.0^{bc}
T_6	75: 50: 75 + 0	128.2^{abc}	176.2^{abc}	304.3^{ab}
T_7	75: 50: 75 + 40	146.8^{ab}	220.5^{a}	367.3^{a}
T_8	75: 50: 75 + 60	150.9^{a}	150.9^{cd}	301.9^{ab}
T_9	75: 50: 75 + 80	145.2^{ab}	160.6^{bcd}	305.8^{ab}
T_{10}	75: 50: 75 + 100	128.9^{abc}	183.9^{abc}	312.7^{ab}
T_{11}	Organic management	77.6^{d}	197.6^{ab}	275.2^{bc}
CD (0.05)		24.67	34.82	49.22

In a column, values followed by same alphabets do not differ significantly in DMRT

4.5. Yield and yield attributes

a. Tuber yield

The treatments had significant effect on the tubers yield of sweet potato. The data on tuber yield is presented in Table 8. The tuber yield per hectare ranged from 19.8 t/ha to 35.9 t/ha. The higher and comparable tuber yield was observed in treatments T_7 (75:50:75 + $MgSO_4$ @ 40 kg/ha) and T_{11} (organic treatment). The lower yield was registered from T_2 (65:12:20 + $MgSO_4$ @ 40 kg/ha) which was on par with treatments T_1, T_3, T_4 and T_5 which received lower doses of N: P_2O_5 : K_2O with varying doses of magnesium sulphate and treatments T_8 and T_9. Among treatments the highest harvest index of 0.72 was observed in treatment T_{11} (organic treatment) which was superior than others. The lower harvest index was seen in treatment T_8 (75:50:75 + $MgSO_4$ @ 60 kg/ha) and T_9 (75:50:75 + $MgSO_4$ @ 80 kg/ha) which was statistically on par with many other treatments. The superior treatment with T_7 had HI of 0.60.

b. Weight of unmarketable tuber

The data on unmarketable tuber yield is presented in Table 9. The yield of unmarketable tuber also differed significantly and ranged from 1044 kg/ha to 1706 kg/ha. The higher and comparable unmarketable yield was observed in treatments T_2 (65:12:20 + $MgSO_4$ @ 40 kg/ha) and T_3 (65:12:20 + $MgSO_4$ @ 60 kg/ha). The lowest unmarketable tuber yield was noticed in treatment T_7 (75:50:75 + $MgSO_4$ @ 40 kg/ha) which registered the highest marketable tuber yield.

c. Number of tubers per vine

The data on number of marketable tubers per vine is presented in Table 9. The number of tubers per vine ranged from 2.7 to 4.7. The higher and comparable number of tubers were registered from treatments T_{11} (organic POP), T_{10} (75:50:75 + $MgSO_4$ @ 100 kg/ha) and T_7 (75:50:75 + $MgSO_4$ @ 40 kg/ha), T_5 (65:12:20 + 100 kg/ha) and T_4 (65:12:20 + $MgSO_4$ @ 80 kg/ha). The lower number of tubers was observed in treatments T_8 (75:50:75 + $MgSO_4$ @ 60 kg/ha), T_6 (75:50:75 + No $MgSO_4$) and T_3 (65:12:20 + $MgSO_4$ @ 60 kg/ha), T_2 (65:12:20 + $MgSO_4$ @ 40 kg/ha) and T_1 (65:12:20 + No $MgSO_4$) which were statistically on par.

Table 8. Effect of nutrient management on tuber yield and harvest index of sweet potato

Treatment	Nutrient doses $N : P_2O_5 : K_2O$ (kg/ha) + $MgSO_4$ (kg/ha)	Tuber yield (g/plant)	Tuber yield (t/ha)	Harvest index (HI)
T_1	65: 12: 20 + 0	453.7^{cd}	22.7^{cd}	0.56^{bc}
T_2	65: 12: 20 + 40	396.0^{d}	19.8^{d}	0.55^{bc}
T_3	65: 12: 20 + 60	529.7^{bcd}	26.5^{bcd}	0.57^{bc}
T_4	65: 12: 20 + 80	486.1^{bcd}	24.3^{bcd}	0.60^{b}
T_5	65: 12: 20 + 100	438.7^{cd}	21.9^{cd}	0.57^{bc}
T_6	75: 50: 75 + 0	573.8^{bc}	28.7^{bc}	0.58^{bc}
T_7	75: 50: 75 + 40	718.2^{a}	35.9^{a}	0.60^{b}
T_8	75: 50: 75 + 60	465.6^{cd}	23.3^{cd}	0.53^{c}
T_9	75: 50: 75 + 80	523.0^{cd}	26.2^{cd}	0.53^{c}
T_{10}	75: 50: 75 + 100	599.0^{bc}	30.0^{bc}	0.59^{b}
T_{11}	Organic management	643.7^{ab}	32.2^{ab}	0.72^{a}
CD (0.05)		113.42	35.33	0.052

In a column, values followed by same alphabets do not differ significantly in DMRT

Table 9. Effect of nutrient management on unmarketable tuber yield, number of tubers per plant of sweet potato

Treatment	Nutrient doses N : P_2O_5 : K_2O (kg/ha) + $MgSO_4$ (kg/ha)	Unmarketable tuber yield (kg/ha)	Number of tubers/plant
T_1	65: 12: 20 + 0	1180^{c}	2.9^{cd}
T_2	65: 12: 20 + 40	1535^{a}	3.1^{bcd}
T_3	65: 12: 20 + 60	1417^{a}	2.7^{d}
T_4	65: 12: 20 + 80	1130^{c}	3.9^{abc}
T_5	65: 12: 20 + 100	1248^{bc}	4.1^{ab}
T_6	75: 50: 75 + 0	1277^{bc}	2.9^{d}
T_7	75: 50: 75 + 40	940^{d}	4.3^{a}
T_8	75: 50: 75 + 60	1302^{bc}	2.4^{d}
T_9	75: 50: 75 + 80	1216^{bc}	3.2^{bcd}
T_{10}	75: 50: 75 + 100	1246^{bc}	4.6^{a}
T_{11}	Organic management	1300^{bc}	4.7^{a}
CD (0.05)		172.35	0.86

In a column, values followed by same alphabets do not differ significantly in DMRT

4.6. Uptake of primary nutrients at harvest

The harvested tubers on an average had 1.75 per cent N, 0.10 per cent P and 0.88 per cent K. The N : P_2O_5 : K_2O dose in aerial portion was 2.30 per cent, 0.17 and 1.24 per cent respectively.

Uptake of primary nutrients N, P and K was higher in the treatments which received N : P_2O_5 : K_2O @ 75:50:75 irrespective of $MgSO_4$ dose than lower dose of N : P_2O_5 : K_2O (Table 10).

The uptake of nitrogen ranged from 220.3 kg/ha to 356.9 kg/ha, phosphorus uptake ranged from 5.2 kg/ha to 16.5 kg/ha and potassium uptake ranged from 124.0 kg/ha to 193.2 kg/ha. The average uptake N, P and K uptake by sweet potato was 281, 10 and 101 kg/ha.

4.7. Uptake of secondary nutrients at harvest

The uptake of secondary nutrients by sweet potato also differed statistically and data are presented in Table 11. The uptake of calcium ranged from 13.6 kg/ha to 27.0 kg/ha. Higher calcium uptake was seen in treatments T_7 (75:50:75 + $MgSO_4$ @ 40 kg/ha) followed by T_6 (75:50:75 + $MgSO_4$ @ 0 kg/ha) which were at par. Lower uptake was observed in T_{11} (Organic POP) which was comparable with treatments T_{10} (75:50:75 + $MgSO_4$ @ 100 kg/ha) and T_2 (65:12:20 + $MgSO_4$ @ 40 kg/ha).

Higher uptake of magnesium was observed in treatment T_9 (75:50:75 + $MgSO_4$ @ 80 kg/ha) and T_7 (75:50:75 + $MgSO_4$ @ 40 kg/ha). The lower uptake was registered from treatments T_2 (65:12:20 + $MgSO_4$ @ 40 kg/ha) and T_{11} (Organic POP). The uptake of magnesium in all treatments also significantly differed and ranged from 9.3 kg/ha to 16.6 kg/ha.

In case of sulphur uptake by sweet potato values ranged from 14.1 kg/ha to 23.6 kg/ha. The higher uptake was seen in treatment T_7 (75:50:75 + $MgSO_4$ @ 40 kg/ha) which was on par with T_8 (75:50:75 + $MgSO_4$ @ 60 kg/ha) and T_{10} (75:50:75 + $MgSO_4$ @ 100 kg/ha). The lower uptake was observed from T_2 (65:12:20 + $MgSO_4$ @ 40 kg/ha) which was on par with treatment T_1, T_3, T_4, T_5 T_6, T_9 and T_{11}.

Table 10. Effect of nutrient management on uptake of primary nutrients by sweet potato

Treatment	Nutrient doses N : P_2O_5 : K_2O + $MgSO_4$ (kg/ha)	Nutrient uptake (kg/ha)		
		N	P	K
T_1	65: 12: 20 + 0	241.2	12.5	136.3
T_2	65: 12: 20 + 40	220.3	8.0	124.7
T_3	65: 12: 20 + 60	287.6	9.6	162.3
T_4	65: 12: 20 + 80	253.7	7.7	140.3
T_5	65: 12: 20 + 100	249.1	11.8	129.0
T_6	75: 50: 75 + 0	299.5	12.2	169.2
T_7	75: 50: 75 + 40	356.9	10.0	193.2
T_8	75: 50: 75 + 60	298.0	9.9	178.8
T_9	75: 50: 75 + 80	329.3	10.1	182.5
T_{10}	75: 50: 75 + 100	319.9	16.5	179.7
T_{11}	Organic management	240.2	5.2	124.0
CD (0.05)		NS		

Table 11. Effect of nutrient management on uptake of secondary nutrients by sweet potato

Treatment	Nutrient doses N : P_2O_5 : K_2O + $MgSO_4$ (kg/ha)	Secondary nutrient uptake (kg/ha)		
		Ca	Mg	S
T_1	65: 12: 20 + 0	18.9^{bcd}	11.3^{f}	14.2^{b}
T_2	65: 12: 20 + 40	16.5^{de}	9.3^{g}	14.1^{b}
T_3	65: 12: 20 + 60	20.0^{bcd}	12.5^{e}	14.3^{b}
T_4	65: 12: 20 + 80	17.5^{cd}	13.4^{d}	19.0^{ab}
T_5	65: 12: 20 + 100	17.6^{cd}	11.3^{f}	15.2^{b}
T_6	75: 50: 75 + 0	24.2^{ab}	14.1^{c}	16.9^{b}
T_7	75: 50: 75 + 40	27.0^{a}	16.1^{a}	23.6^{a}
T_8	75: 50: 75 + 60	21.2^{bcd}	13.0^{d}	19.6^{ab}
T_9	75: 50: 75 + 80	20.7^{bcd}	16.6^{a}	15.3^{b}
T_{10}	75: 50: 75 + 100	16.5^{de}	11.5^{f}	19.1^{ab}
T_{11}	Organic management	13.6^{e}	9.3^{g}	15.6^{b}
CD (0.05)		3.22	1.38	1.74

In a column, values followed by same alphabets do not differ significantly in DMRT

4.8. Tuber quality parameters

a. Sugar content in tubers (%)

The content of total, reducing and non-reducing sugar in sweet potato tuber is presented in Table 12. The content of total sugar in various treatments ranged from 9.4 % to 10.3 %. A slightly higher total sugar content was observed in treatment T_8 (75:50:75 + $MgSO_4$ @ 60 kg/ha) which was statistically on par with T_7 (75:50:75 + $MgSO_4$ @ 40 kg/ha), T_9 (75:50:75 + $MgSO_4$ @ 80 kg/ha), T_{10} (75:50:75 + $MgSO_4$ @ 100 kg/ha) and T_{11} (Organic POP). The lower content was seen in treatment T_1 (65:12:20 + $MgSO_4$ @ 0 kg/ha) and which was comparable with treatments (T_2, T_3, T_5 and T_6).

In case of reducing sugar content, not much difference could be observed. The reducing sugar content in tuber ranged from 2.9 % to 3.4 %. Among the treatments, T_8 (75:50:75 + $MgSO_4$ @ 60 kg/ha) recorded higher reducing sugar content of 3.4 % which was on par with T_7 (75:50:75 + $MgSO_4$ @ 40 kg/ha), T_9 (75:50:75 + $MgSO_4$ @ 80 kg/ha) and T_{11} (Organic POP). There were no significant differences among the treatments with respect to content of non-reducing sugar and the average content was 6.6 %.

b. Crude fibre and crude protein

The content of crude fiber and crude protein in sweet potato tubers is represented in Table 13. Crude fiber content in various treatments ranged from 2.1 % to 3.2 %. However, treatment differences were non significant.

Among the treatments higher crude protein was observed in T_2 (60:15:20+ $MgSO_4$ @ 40 kg/ha) and lower crude protein content was seen in T_1 (60:15:20 + $MgS0_4$ @ 0 kg/ha).

Table 12. Effect of nutrient management on sugar content on dry weight basis of sweet potato tubers

Treatment	Nutrient doses N : P_2O_5 : K_2O + $MgSO_4$ (kg/ha)	Reducing sugar (%)	Non reducing sugar (%)	Total reducing sugar (%)
T_1	65: 12: 20 + 0	3.0^{c}	6.5	9.4^{b}
T_2	65: 12: 20 + 40	3.0^{c}	6.5	9.5^{b}
T_3	65: 12: 20 + 60	2.9^{bc}	6.6	9.5^{b}
T_4	65: 12: 20 + 80	3.2^{bc}	6.6	9.8^{ab}
T_5	65: 12: 20 + 100	3.0^{bc}	6.8	9.7^{b}
T_6	75: 50: 75+ 0	3.1^{bc}	6.7	9.7^{b}
T_7	75: 50: 75 + 40	3.2^{abc}	6.6	9.8^{ab}
T_8	75: 50: 75 + 60	3.4^{a}	6.9	10.3^{a}
T_9	75: 50: 75 + 80	3.1^{ab}	6.9	10.0^{ab}
T_{10}	75: 50: 75 + 100	3.0^{bc}	6.8	9.8^{ab}
T_{11}	Organic management	3.3^{abc}	6.6	9.9^{ab}
CD (0.05)		0.31	NS	0.44

In a column, values followed by same alphabets do not differ significantly in DMRT

Table 13. Effect of nutrient management on crude fiber and protein content on dry weight basis of sweet potato tubers

Treatment	Nutrient doses N : P_2O_5 : K_2O + $MgSO_4$ (kg/ha)	Crude fibre (%)	Crude protein (%)
T_1	65: 12: 20 + 0	2.20	12.03
T_2	65: 12: 20 + 40	2.90	15.31
T_3	65: 12: 20 + 60	2.80	14.22
T_4	65: 12: 20 + 80	2.90	15.31
T_5	65: 12: 20 + 100	2.50	14.22
T_6	75: 50: 75+ 0	2.20	14.22
T_7	75: 50: 75 + 40	2.80	14.22
T_8	75: 50: 75 + 60	2.90	13.13
T_9	75: 50: 75 + 80	2.30	15.31
T_{10}	75: 50: 75 + 100	2.50	15.31
T_{11}	Organic management	2.40	14.22
CD (0.05)		NS	

4.9. Soil parameters after harvest of crop

a. Soil pH, EC and organic carbon

Not much variation in pH of soil could be observed (Table 14). The initial soil pH was 4.8 and the values in various treatments which received chemical fertilizers ranged from 4.73 to 4.90 and all were statistically at par. However, the treatment T_{11} which received organic manures alone registered a slightly higher pH of 5.37 which statistically differed from all other treatments.

The EC of soil after the harvest of sweet potato was lower compared to initial status of 0.42 ms/m, the average was 0.15 ms/m and treatment differences were statistically non significant.

Organic carbon status of soil after the crop did not vary compared to initial value. The values were in medium range of 1.0 to 1.4 %.

b. Available nitrogen

Available nitrogen status of soil after harvest is presented in Table 15. The available nitrogen in the soil after harvest ranged from 109.5 kg/ha to 193.7 kg/ha. Among the treatments, highest available nitrogen content was observed in T_1 (65:12:20 + $MgSO_4$ @ 0 kg/ha) followed by T_3 (65:12:20 + $MgSO_4$ @ 60 kg/ha), T_4 (65:12:20 + $MgSO_4$ @ 80 kg/ha), T_7 (75:50:75 + $MgSO_4$ @ 40 kg/ha), T_9 (75:50:75 + $MgSO_4$ @ 80 kg/ha) and T_{10} (75:50:75 + $MgSO_4$ @100 kg/ha) which were on par. The lower value was seen in T_5 (65:12:20 + $MgSO_4$ @ 100 kg/ha) which is statistically on par with T_6 (75:50:75 + $MgSO_4$ @ 0 kg/ha), T_8 (75:50:75 + $MgSO_4$ @ 60 kg/ha) and T_{11} (Organic POP).

c. Available phosphorus

The available phosphorus status of the soil was very high even after harvest of crop and values ranged from 43.9 kg/ha to 70.5 kg/ha (Table 15). The higher phosphorus status was observed in treatments T_3 (65:12:20 + $MgSO_4$ @ 60 kg/ha), T_1 (65:12:20 + $MgSO_4$ @ 0 kg/ha), T_4 (65:12:20 + $MgSO_4$ @ 80 kg/ha), T_6 (75:50:75 + $MgSO_4$ @ 0 kg/ha) and T_8 (75:50:75 + $MgSO_4$ @ 60 kg/ha) which were statistically on par. Lower phosphorus status of 43.9 kg/ha was registered in treatment T_{11} (organic POP) which was comparable with treatments T_{10}, T_9, T_7, T_5, and T_2.

d. Available potassium

The available potassium status of soil after the harvest of crop ranged from 218.2 to 384.3 kg/ha in various treatments. The treatments which received higher K2O maintained a higher status compared to the treatments which received soil test based application of K2O @ 20 kg/ha. The available potassium in these treatments were in the range of 257 to 384 kg/ha, whereas, in treatments T1 to T5 the range was 218 to 243 kg/ha

e. Secondary nutrient status of soil

The data on secondary nutrient status of soil is presented in Table 16. There was an increase in calcium status of soil compared to initial data (158.4 mg/kg) and the values ranged from 312 mg/kg to 500 mg/kg. Among the treatments, higher and comparable calcium content was seen in treatments T_3 (65:12:20 + $MgSO_4$ @ 60 kg/ha), T_4 (65:12:20 + $MgSO_4$ @ 80 kg/ha), T_7 (75:50:75 + $MgSO_4$ @ 40 kg/ha), T_8 (75:50:75 + $MgSO_4$ @ 60 kg/ha) and T_9 (75:50:75 + $MgSO_4$ @ 80 kg/ha). The lower content was observed in T_1 (65:12:20 + $MgSO_4$ @ 0 kg/ha).

In case of magnesium, the content was in the range between 42 mg/kg to 67 mg/kg. The higher content was observed in T_8 (75:50:75 + $MgSO_4$ @ 60 mg/kg) which was statistically comparable with many treatments. The lower magnesium status was registered in treatment T_1 (65:12:20 + $MgSO_4$ @ 0 kg/ha) which was statistically on par with treatments T_2, T_6, T_7, T_9, and T_{11}.

Available sulphur content in the soil after harvest also showed a decrease compared to initial value except in T_{11} (Organic POP) where an increase was noticed. The highest sulphur content of 60 mg/kg was observed in organic management which was superior to others. The remaining all treatments were statistically on par.

Table 14. Chemical properties of soil after harvest of sweet potato

Treatment	Nutrient doses N : P_2O_5 : K_2O + $MgSO_4$ (kg/ha)	pH	EC (ms/m)	Organic carbon (%)
T_1	65: 12: 20 + 0	4.76[b]	0.128	1.2
T_2	65: 12: 20 + 40	4.82[b]	0.092	1.0
T_3	65: 12: 20 + 60	4.75[b]	0.098	1.1
T_4	65: 12: 20 + 80	4.84[b]	0.115	1.3
T_5	65: 12: 20 + 100	4.69[b]	0.127	1.4
T_6	75: 50: 75 + 0	4.90[b]	0.108	1.1
T_7	75: 50: 75 + 40	4.73[b]	0.138	0.9
T_8	75: 50: 75 + 60	4.80[b]	0.250	1.2
T_9	75: 50: 75 + 80	4.58[b]	0.135	1.4
T_{10}	75: 50: 75 + 100	4.69[b]	0.330	1.3
T_{11}	Organic management	5.37[a]	0.110	1.2
CD (0.05)			NS	NS
Initial value		4.90	0.420	1.3

In a column, values followed by same alphabets do not differ significantly in DMRT

Table 15. NPK status of soil after harvest of sweet potato

Treatment	Nutrient doses $N : P_2O_5 : K_2O + MgSO_4$ (kg/ha)	Available nitrogen (kg/ha)	Available phosphorus (kg/ha)	Available potassium (kg/ha)
T_1	65: 12: 20 + 0	193.7^{a}	61.6^{abc}	224.8^{cd}
T_2	65: 12: 20 + 40	109.5^{b}	53.2^{bcd}	243.1^{bcd}
T_3	65: 12: 20 + 60	139.0^{ab}	70.5^{a}	218.2^{cd}
T_4	65: 12: 20 + 80	147.2^{ab}	62.4^{abc}	236.6^{cd}
T_5	65: 12: 20 + 100	96.7^{b}	50.8^{bcd}	238.3^{bcd}
T_6	75: 50: 75 + 0	109.5^{b}	61.3^{abc}	257.3^{bcd}
T_7	75: 50: 75 + 40	139^{ab}	48.8^{cd}	289.9^{b}
T_8	75: 50: 75 + 60	126.3^{b}	65.4^{ab}	363.1^{a}
T_9	75: 50: 75 + 80	139^{ab}	53.9^{bcd}	272.9^{bc}
T_{10}	75: 50: 75 + 100	144.8^{ab}	48.2^{cd}	367.7^{a}
T_{11}	Organic management	117.9^{b}	43.9^{d}	384.3^{a}
Initial value		270	61	305

In a column, values followed by same alphabets do not differ significantly in DMRT

Table 16. Secondary nutrient status of soil after harvest of sweet potato

Treatments	Nutrient doses N : P_2O_5 : K_2O + $MgSO_4$ (kg/ha)	Calcium (mg/kg)	Magnesium (mg/kg)	Sulphur (mg/kg)
T_1	65: 12: 20 + 0	312^{d}	42^{d}	13^{b}
T_2	65: 12: 20 + 40	410^{abcd}	49^{cd}	20^{b}
T_3	65: 12: 20 + 60	478^{abc}	58^{abc}	24^{b}
T_4	65: 12: 20 + 80	439^{abcd}	58^{abc}	18^{b}
T_5	65: 12: 20 + 100	373^{bcd}	64^{ab}	35^{b}
T_6	75: 50: 75 + 0	339^{cd}	49^{cd}	12^{b}
T_7	75: 50: 75 + 40	550^{a}	53^{abcd}	27^{b}
T_8	75: 50: 75 + 60	493^{ab}	67^{a}	30^{b}
T_9	75: 50: 75 + 80	443^{abcd}	52^{bcd}	27^{b}
T_{10}	75: 50: 75 + 100	354^{bcd}	57^{abc}	23^{b}
T_{11}	Organic management	393^{bcd}	49^{cd}	60^{a}
Initial value		158	43	49

In a column, values followed by same alphabets do not differ significantly in DMRT

4.10. Cost benefit analysis

An analysis of cost of production and economic benefit can help to arrive at a recommendation for commercial production of sweet potato. The tuber yield in various treatments varied from 19.8 t/ha to 35.9 t/ha and indicated that there is scope for enhancing productivity of sweet potato by nutrient management.

Among the treatments the highest yield of 35.9 t/ha was obtained from treatment T_7 (N : P_2O_5: K_2O + $MgSO_4$ @ 75:50:75 + 40 kg/ha) followed by T_{11} (32.2 t/ha) and T_{10} (30.0 t/ha). Lower yields were obtained from treatments T_2 (65:12:20 + $MgSO_4$ @ 40 kg/ha), T_5 (65:12:20 + $MgSO_4$ @ 100 kg/ha) and T_8 (75:50:75 + $MgSO_4$ @ 60 kg/ha) and the tuber yield was 19.8 t/ha, 21.9 t/ha and 23.3 t/ha respectively.

The cost of cultivation ranged from □ 1, 25,319 to □ 1, 94,950. The lowest cost was for T_1 (65:12:20 + $MgSO_4$ @ 40 kg/ha), whereas the highest cost was for T_{11} (organic POP) (Table 17). The organic treatment resulted in higher cost of cultivation due to high cost of organic manures and biofertilizers compared to synthetic fertilizers.

Benefit cost (BC) ratio also is an important attribute to analyze the feasibility of a technology to be adopted. The various treatments in the experiment gave the BC ratios ranging from 2.3 to 4.1. The result showed that T_7 (N : P_2O_5 : K_2O + $MgSO_4$ @ 40 kg/ha) recorded maximum BC ratio (4.1), on account of its higher net income (□ 4,056,19/ha). This was followed by the treatments T_{10} (75:50:75 +$MgSO_4$ @ 100 kg/ha) and T_6 (75:50:75 + $MgSO_4$ @ 60 kg/ha) each with a BC ratio of 3.3 and net returns of □ 3,160,39/ha and □ 3,013,39/ha, respectively. Even though cost of cultivation of organic management was higher, the higher gross returns from this resulted in a BC ratio of 2.5.

Table 17. Cost benefit analysis in sweet potato

Treatments	Nutrient doses N : P_2O_5 : K_2O + $MgSO_4$ (kg/ha)	Total cost of cultivation (Rs/ha)	Gross Returns (Rs/ha)	Net Returns (Rs/ha)	B-C ratio
T_1	65: 12: 20 + 0	1,25,319	3,40,500	2,15,181	2.7
T_2	65: 12: 20 + 40	1,29,039	2,97,000	1,67,961	2.3
T_3	65: 12: 20 + 60	1,29,399	3,97,500	2,68,101	3.1
T_4	65: 12: 20 + 80	1,29,759	3,64,500	2,34,741	2.8
T_5	65: 12: 20 + 100	1,30,119	3,28,500	1,98,381	2.5
T_6	75: 50: 75 + 0	1,29,161	4,30,500	3,01,339	3.3
T_7	75: 50: 75 + 40	1,32,881	5,38,500	4,05,619	4.1
T_8	75: 50: 75 + 60	1,33,241	3,49,500	2,16,259	2.6
T_9	75: 50: 75 + 80	1,33,601	3,93,000	2,59,399	2.9
T_{10}	75: 50: 75 + 100	1,33,961	4,50,000	3,16,039	3.3
T_{11}	Organic management	1,94,950	4,83,000	2,88,050	2.5

DISSCUSSION

5. DISSCUSSION

The results of the experiment on "Response of sweet potato to secondary nutrients" is discussed here with the help of relevant scientific literature on this aspect in various tubercrops.

The treatments consisted of application of varying doses of magnesium sulphate 0, 40, 60, 80 and 100 kg/ha along with N : P_2O_5 : K_2O dose as per soil test results (Treatments T_1 to T_5) and NPK as per blanket recommendation of 75:50:75 kg/ha (T_6 to T_{10}). Additionally, application of organic sources of nutrients alone (T_{11}) as per Package of Practices for Organic Production (KAU, 2017) was tried to see the viability and sustainability of organic nutrition in sweet potato production. The soil was medium in organic carbon and high in available P and K and hence the primary nutrients were applied @ 65:12:20 kg/ha in treatments T_1 to T_5. The soil of experimental field was low in calcium (158 mg/kg) and magnesium status (43 mg/kg) and high in sulphur (49 mg/kg).

Growth and tuber yield

The data on tuber yield indicated the effect of higher dose of potassium on tuber yield apart from effect of K-$MgSO_4$ balance on tuber yield of sweet potato. The tuber yield on an average was 23.04 t/ha with soil test-based N : P_2O_5 : K_2O, whereas it was 28.82 t/ha at blanket dose of 75:50:75. This may be mainly due to higher availability of potassium as K_2O was applied @ 75 kg/ha compared to only 20 kg/ha in T_1 to T_5. Nair and Nair (1992) also observed the highest tuber yield in sweet potato at K_2O level of 75 kg/ha in Kerala soils. As sweet potato is a crop having short duration, and tuberization starts as early as 6-8 weeks after planting (Adubasim *et al*., 2017) it is better to apply enough fertilizers to ensure quick availability as the time available for utilization of soil reserves is limited. Also, as in the case of other tuber crops, the requirement of K is high and this nutrient plays a critical role in starch synthesis and translocation.

This may be reason for low yield in treatments where lower doses of NPK were applied. Magdoff and Bartlet (1980) reported that liming of acid soils can lead to poor availability of K from soil. In the present study, lime was applied uniformly in all treatments @ 600 kg/ha and lime application might have also interfered with availability of K from soil reserves in treatments where a low level of 20 kg MOP was applied.

Many other studies also indicate that higher tuber yield can be realized with higher K application in sweet potato as it promotes photosynthetic activity, increase the number of tubers produced and translocation of carbohydrates to the developing tubers. The NPK nutrition studies in sweet potato indicate that potassium has the greatest effect on tuber yield compared to N or P (Indira and Lakshmi, 1984; Jones *et al*., 1977) and tuber yield increased proportionately with an increase in potassium dosage (Chatterjee and Mandal, 1976) and this crop has a high requirement of K relative to N. Generally, the response of sweet potato to applied P is low and in a study in Philippines, Degras (2003) reported that at all levels of N and K used, addition of phosphorous did not result in any significant increase in yield. Though the soil of the experimental site was high in available K status, application of K_2O @ 20 kg/ha in treatments T_1 to T_5 gave lower yields, probably due to low availability of K from soil K reserves to meet immediate requirements in early growth stage. However, Nicholaides *et al.* (1981) found that total yield in sweet potato increased with K application but the magnitude of response was determined by initial potassium status of soil.

The response to applied magnesium sulphate could not be seen at N : P_2O_5 : K_2O dose of 65:12:20. The treatment T_1, where no $MgSO_4$ was applied registered comparable yield to that at 40, 60, 80 and 100 kg $MgSO_4$/ha (Figure 3 and 4). This is probably due to low K availability and unfavourable K-Mg ratio. The low supply or availability of primary nutrient K which has a major role in starch synthesis might have more pronounced effect on yield compared to secondary nutrient magnesium. However, treatments T_3 and T_4 which received 60 and 80 kg $MgSO_4$ registered 19 % higher yield over average yield of T_1, T_2, T_5 indicating the importance of K-Mg ratio in sweet potato nutrition. Similar trend of lower tuber yield at higher dose of $MgSO_4$ is reported by Talukder *et al.* (2009), who found that in potato higher tuber yield was obtained with 10 kg $MgSO_4$ that was on par with 15 and 20 kg $MgSO_4$ and tuber yield tended to decease with increasing rate of Mg application. The secondary nutrient S supplied by $MgSO_4$ also might have contributed to tuber yield, however the soil of the experimental field was high in S status.

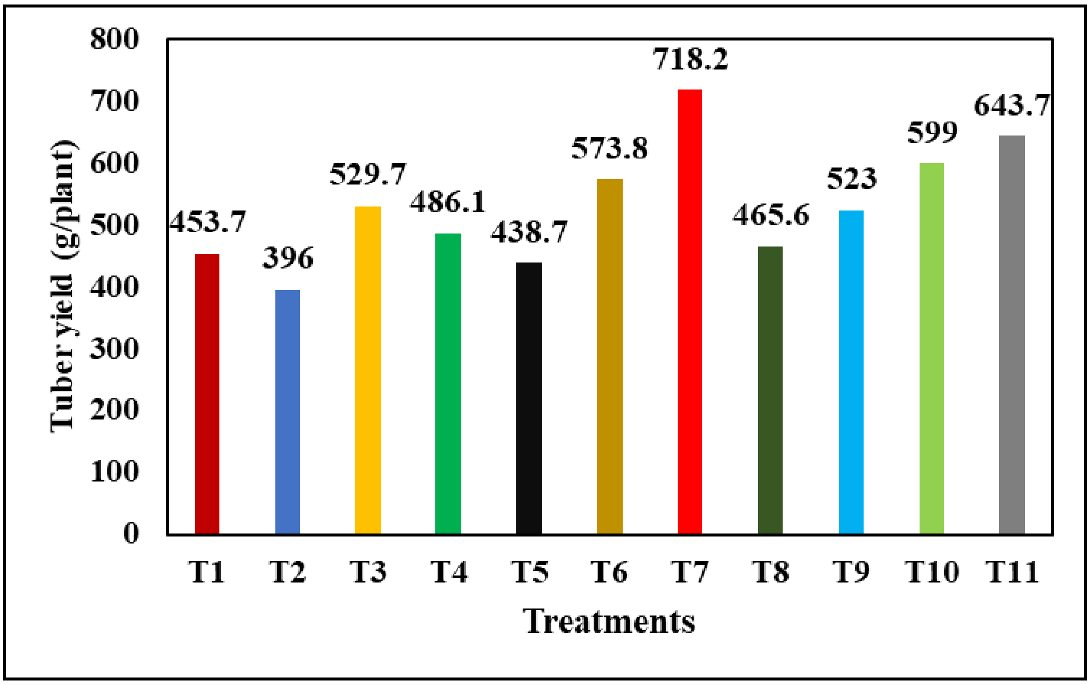

Figure 3. Effect of nutrient management on tuber yield (g/plant) of sweet potato

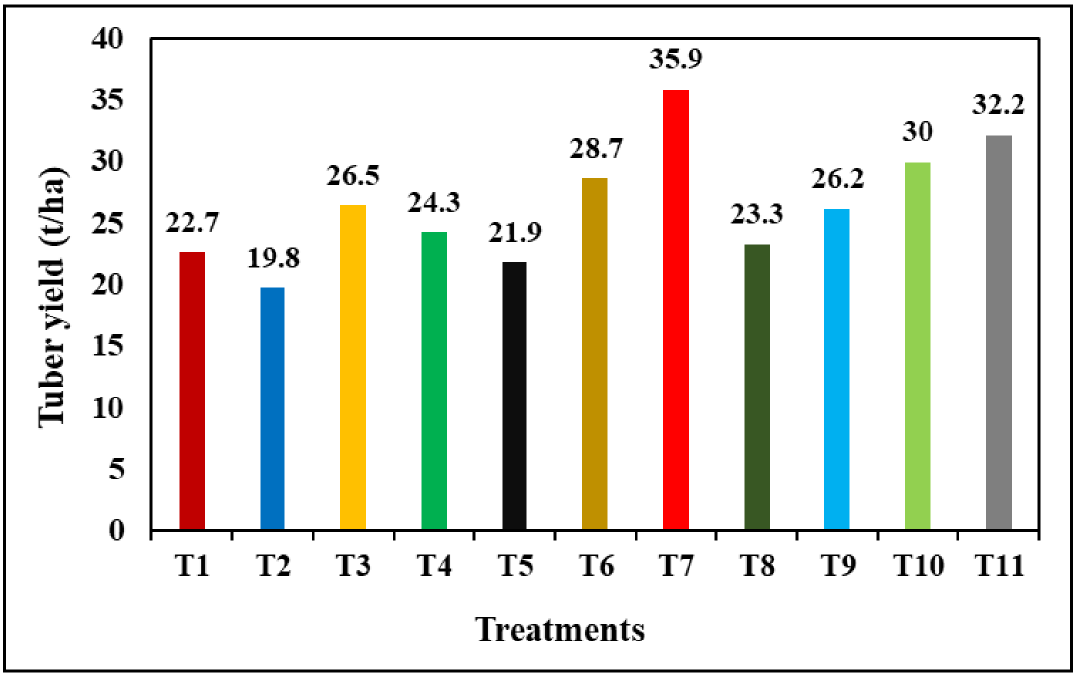

Figure 4. Effect of nutrient management on tuber yield (t/ha) of sweet potato

According to Alu *et al.* (2012) and Nauarro and Padda (1983), sulphur application had significant effect on growth and yield of sweet potato, whereas Purcell *et al*. (1982) could not get any response to applied sulphur in yield or tuber composition of sweet potato.

In treatments T_5 to T_{10} where 75:50:75 N : P_2O_5 : K_2O was applied along with varying levels of magnesium sulphate, the trend in tuber yield was not linear. It can be seen that T_6 where no $MgSO_4$ was applied registered comparable yield to application of $MgSO_4$ at 100 kg, probably due to inhibitory effect of higher dose of $MgSO_4$ on K availability. $MgSO_4$ @ 40 kg/ha (T_7) was the superior treatment with significantly higher yield of 35.90 t/ha which was 25 % higher than no $MgSO_4$ (28.70 t/ha). Tuber yield in T_6, where no Mg was supplied, in turn was on par to T_8, T_9 and T_{10} which received 60, 80 and 100 kg $MgSO_4$ respectively. The average yield of these three treatments was 28.20 t/ha. Hence on an average, yield advantage of 7.70 t/ha could be achieved by application of $MgSO_4$ @ 40 kg/ha along with 75:50:75 N : P_2O_5 : K_2O. According to Laxminarayana and John (2014) magnesium nutrition could improve sweet potato yield by 7-11 %, and the highest mean tuber yield was recorded with magnesium sulphate @ 20 kg/ha. It is also documented that Mg deficiency in sweet potato could be the consequence of either low Mg status of soil or an oversupply of K or Ca (O'Sullivan *et al*., 1997), indicating role of balanced K : Mg : Ca nutrition in enhancing crop productivity.

It is important to note that tuber yield comparable to superior treatment (T_7) could be realized under organic nutrition (T_{11} -32.20 t/ha). This shows that this tuber crop can be raised under organic system of crop production. In this treatment, the plants were given cattle manure @ 10 t/ha at the time of preparation of mounds. Vermi compost 3 t along with 1 t coir pith compost + ash @ 1 t/ha, azospirillum (2 kg/ha) and PGPR mix I (2.5 kg/ha) were applied in two equal split doses at 3 weeks and 6 weeks after planting. At the time of planting vines were dipped in PGPR mix I.

Apart from supply of many essential elements for plant growth, the better performance under organic management might be due to favourable physical and chemical properties of soil resulted from organic manure application. The biofertilizers also might have helped in better nutrient availability.

The pH of soil after experiment shows that it was 5.7 in T_{11} compared to slightly lower values in all other treatments. It is reported that a moderate to slightly acid soil with pH range of 5.6 – 6.5 is ideal for sweet potato.

The rich organic matter status also might have maintained favourable moisture conditions and availability of all essential nutrients which contributed to yield advantage. Yasmin *et al*. (2009) reported that application of PGPR mix increased the nutrient uptake and tuber yield of sweet potato. Also, the dry matter production by vines and tubers indicate that in T_{11}, vine growth was low and much photosynthates were partitioned to underground portion (Figure 5). The high harvest index and early senescence of older leaves was also observed in this treatment compared to plants in other treatments. The highest harvest index of 0.72 under organic management resulted from low aerial growth compared to tuber growth as indicated by data on vine length at different stages of growth and dry matter production of aerial and underground portion. The soil was high in P as well as K, which indicate that if supplied with adequate primary nutrients and ample organic manures, secondary nutrient deficiencies may not occur. Supply of all essential elements according to crop requirement also might have resulted in better yield under organic nutrition. The appearance of tuber was also good in this treatment and tubers were of medium size compared to bigger sized tubers in treatments which received chemical fertilizers. Koodi *et al.* (2017) reported the positive effect of vermicompost application @ 2.5 t/ha on growth and yield of sweet potato under INM system by its influence on growth and yield attributes.

In the case of tuber crops, partitioning of photosynthates to sink is crucial in deciding tuber yield. The data on dry matter production of aerial parts and underground part was recorded separately, in order to get an idea about partitioning of assimilates. In general plant dry matter production was low in treatments which received N : P_2O_5 : K_2O of 65:12:20 and all treatments (T_1, T_2, T_3, T_4 and T_5) were statistically comparable. Here also effect of $MgSO_4$ nutrition was not reflected as in the case of tuber yield. No $MgSO_4$ (T_1) as well as 100 kg $MgSO_4$ (T_5) were statistically at par. This is probably because Mg is not directly involved in vegetative growth and also due to poor growth of vines due to poor availability of primary nutrients. The data on vine length at 60 and 90 days after planting also indicate that treatment differences were not very wide and many treatments had comparable vine length.

The yield of unmarketable tuber also differed significantly and ranged from 939 kg/ha to 1535 kg/ha. The higher and comparable unmarketable yield was observed in treatments which registered lower marketable yield T_2 (65:12:20 + $MgSO_4$ @ 40 kg/ha) and T_3 (65:12:20 + $MgSO_4$ @ 60 kg/ha). This may be probably due to poor availability of potassium which has a direct role in tuber bulking. The lower unmarketable tuber yield was seen in treatment T_7 (75:50:75 + $MgSO_4$ @ 40 kg/ha) which registered the highest marketable tuber yield, due to proper bulking of tubers due to adequate availability of nutrients like K and magnesium.

Application of higher dose of N : P_2O_5 : K_2O of 75:50:75 resulted in enhanced vegetative growth in general and here also effect of varied doses of $MgSO_4$ could not be observed. Vines in no $MgSO_4$ (T_6) plots as well as 100 kg $MgSO_4$ (T_{10}) showed similar aerial dry matter production further indicating poor response to $MgSO_4$ nutrition in vegetative growth.

The same was the trend in vine length also (Figure 6). The treatments with lower vine length resulted in poor aerial dry matter weight due to less vegetative growth and lower number of leaves.

The LAI in different treatments were in a narrow range of 2.65 to 3.48. Higher LAI values were recorded in treatment which received higher dose of NPK irrespective of $MgSO_4$ dose this may be due to adequate availability of primary nutrients. The same trend was seen in vine length. According to Mukhopadhya *et al.* (1992) in sweet potato the highest LAI of 8.56 at 90 DAP, tuber bulking and tuber and vine yields were realized with 75 kg K_2O per ha applied in two splits. Varghese *et al.* (1987) also reported similar findings in a study in Kerala in low potassium soils in a rice fallow. The lowest LAI of 2.65 was recorded in T_{11} due to poor growth of vines as evident from the data on vine length this is probably due to the slow growth of the vines as chemical fertilizers were not applied and more diversion of photosynthates to the underground portion as evident from the data on tuber dry matter production and yield. At 60 DAP the treatments T_1, T_2 and T_{11} had lower values for vine length which is directly related to the number of leaves per plant and LAI.

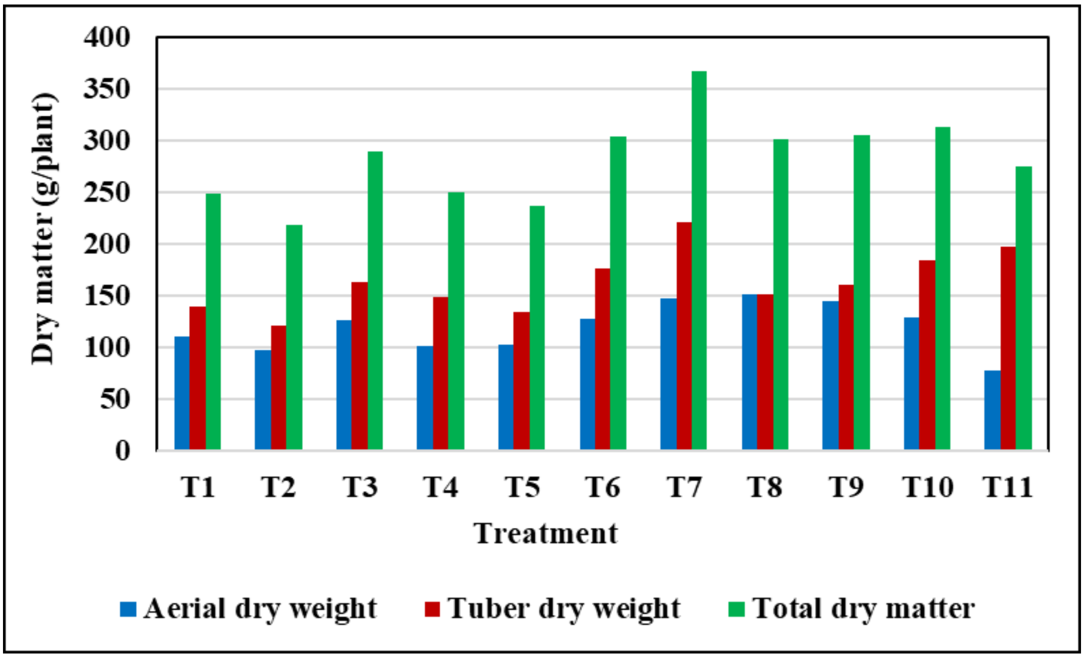

Figure 5. Effect of nutrient management on dry matter production of sweet potato

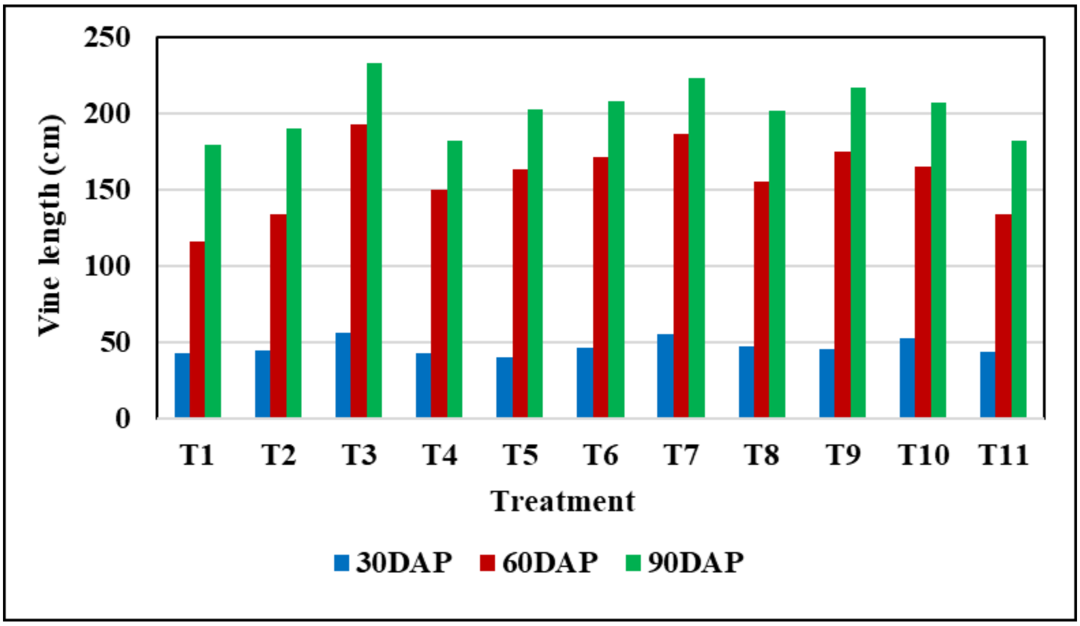

Figure 6. Effect of nutrient management on vine length of sweet potato at different growth stages

Among treatments, significant variation could not be observed with respect to chlorophyll content. Though the role of magnesium in chlorophyll formation is well established, in the present study the response to MgSO4 application was not reflected in chlorophyll content probably due to the greenness of leaves was also due to supply of nitrogen and nitrogen dose was almost similar among treatments (65 kg/ha and 75 kg/ha).

Dry matter accumulation by underground part was higher than aerial portion and values ranged from 121.6 g/plant in T_2 to 197.6 g/plant in T_{11}. Here also the soil test based NPK application 65:12:20 kg/ha resulted in lower values and all the treatments which received this N : P_2O_5 : K_2O registered statistically comparable values though varied doses of $MgSO_4$ was applied. Hence it can be inferred that $MgSO_4$ application did not influence tuber bulking at lower levels of primary nutrients probably due to unbalanced supply.

A marked increase in tuber dry matter production was noted at higher N : P_2O_5 : K_2O dose of 75:50:75 clearly due to more absorption resulting from higher availability of primary nutrients (T_6 to T_{10}). Among these treatments T_6 where no $MgSO_4$ was applied and its increasing doses up to 100 kg/ha resulted in comparable tuber dry matter accumulation probably indicating its negligible role in partitioning of assimilates to tuber. According to Bourke (1985a) K fertilizer application up to 375 kg/ha increased tuber yield, number of tubers per plant, total plant dry weight, mean leaf area as well as harvest index and K fertilizer increased tuber yield through an increase in the proportion of dry matter diverted to tubers and increase in tuber number per plant.

However, the crop performance under organic nutrition indicated higher accumulation of photosynthates by underground portion with a high HI of 0.72. Hence it is clear that more vegetative growth may not necessarily give a good indication of tuber yield. Though the aerial dry matter production in organic nutrition was low, the yield was high due to favourable partitioning of photosynthates to sink which is the economic part.

This also indicate that excess vegetative growth in many treatments are at the expense of tuber bulking. The ratio of tuber dry matter to aerial dry matter production varied from 1.0 to 2.55. The highest ratio of 2.55 was registered in organic nutrition whereas the lowest values of 1.0 and 1.11 were registered in NPK @75:50:75 along with 60 and 80 kg magnesium sulphate. However, the ratio was 1.50 in treatment T_7 where only 40 kg magnesium sulphate was applied and the highest tuber yield was realized.

Application of fertilizers had significant effect on total dry matter production. The total dry matter in various treatments ranged from 219 g/plant to 367 g/plant. Among the treatments the higher as well as comparable total dry matter accumulation was observed in all treatments where NPK @ 75:50:75 was applied irrespective of dose of $MgSO_4$. The lower dry matter content was registered in treatments where NPK was supplied @ 65:15:20. This shows that magnesium sulphate application has no direct effect on dry matter production, whereas NPK application and especially K has a significant effect. This corroborates with the findings of Byju (2002) who reported that potassium fertilizer increased the total dry matter and the proportion of dry matter diverted to tubers thus favourably influencing the HI of sweet potato. Zhi (1991) also observed good response to applied K fertilizers. However, Constantin *et al.* (1917) could not observe significant difference in dry matter production at varying K levels.

No definite trend could be observed in number of tubers per plant with respect to nutrient application, though the tuber yield per plant varied. This is probably because the number of marketable tubers only were accounted in the study and yield increase was due to increase in average weight of individual tubers rather than number of tubers. However, Bao *et al.* (1985) reported that potassium application increased the yield of sweet potato by increasing the number of tubers and the ratio of large to small tubers. In another study Ghuman and Lal (1973) also found that potassium fertilizer increased the tubers numbers in sweet potato.

Effect of nutrient management on tuber quality

Quality is one of the most important parameters deciding the nutritive value of any crop. The content of total sugar in various treatments ranged from 9.4 % to 10.3 %, whereas the reducing sugar content ranged from 2.9 % to 3.4 % (Figure 7 and 8).

Slightly higher content of total and reducing sugar was observed in treatments which received higher N : P_2O_5 : K_2O dose of (75:50:75) along with varied magnesium sulphate as well as in T_{11} (Organic management). The lower content was seen in treatment T_1 (65:12:20 + $MgSO_4$ @ 0 kg/ha) and which was comparable with many other treatments. This clearly indicate that magnesium application had no effect on total sugar content of tuber whereas higher potassium increased the sugar content. The combined effect of potassium and magnesium application on sugar content of sweet potato might be due to enhanced translocation of starches and sugars in the form of sucrose from the leaves to the tubers. These finding are in accordance with the observation of AI-Esailyl and EI-Naka (2013), Laxminarayana and John (2014) in sweet potato.

Contradictory to this Asokan *et al.* (1984) reported that with increasing levels of K, the sugar content decreased whereas starch content increased. In the present study the content of non-reducing sugar in the tuber ranged from 6.5 % to 6.9 % and the treatment differences were not statistically significant.

The content of crude fibre in various treatments ranged from 2.1 % to 3.2 %. No definite trend could be observed in crude fibre percent with variable dose of $MgSO_4$ and NPK. However, Hayati *et al*. (2020), found that with increase in the dose of N : P_2O_5 : K_2O the quality parameters of sweet potato including crude fibre increased.

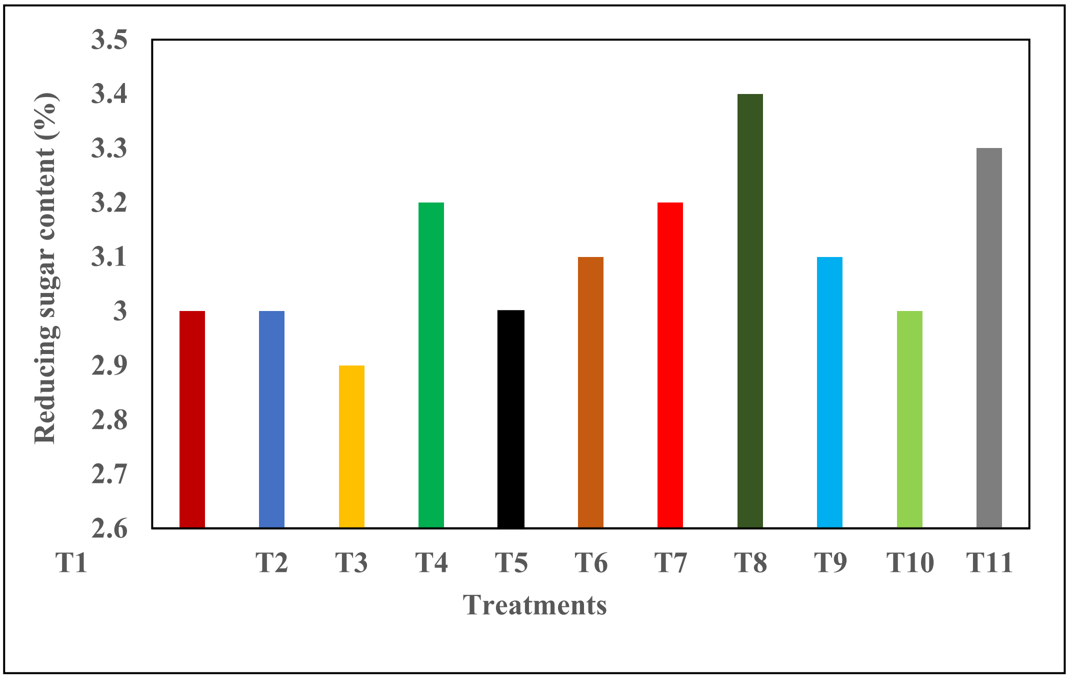

Figure 7. Effect of nutrient management on reducing sugar content (%) of sweet potato

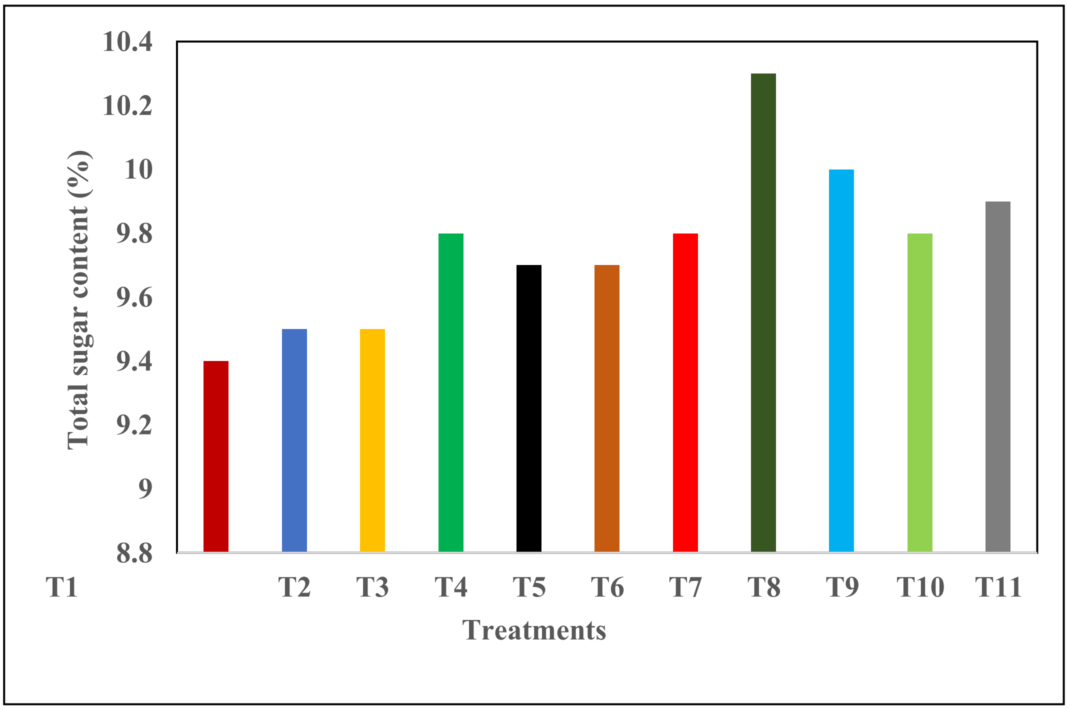

Figure 8. Effect of nutrient management on total sugar content (%) of sweet potato

Nutrient uptake by sweet potato

The uptake of nutrients varied significantly with the treatments. The uptake of nitrogen by sweet potato ranged from 220.3 kg/ha to 356.9 kg/ha, and phosphorus uptake ranged from 5.2 kg/ha to 16.5 kg/ha (Figure 9 and 10). K uptake ranged from

124.0 kg/ha to 193.2 kg/ha (Figure 10). This was due to significant variation in dry matter production as explained earlier. AVRDC (1975) and Mohankumar *et al.* (2000) reported that sweet potato crop yielding 20 t/ha removed 123 kg/ha N, 15.5 kg/ha P and 115 kg/ha K and a crop with tuber yield of 30 t/ha removed and 80 kg/ha N, 29 kg/ha P and 185 kg/ha K.

The uptake of secondary nutrients also was low under organic management due to low dry matter production. Among other treatments no definite trend could be observed. Though varying doses of $MgSO_4$ was applied, much variation with increase in dose applied could not be observed (Figure 11).

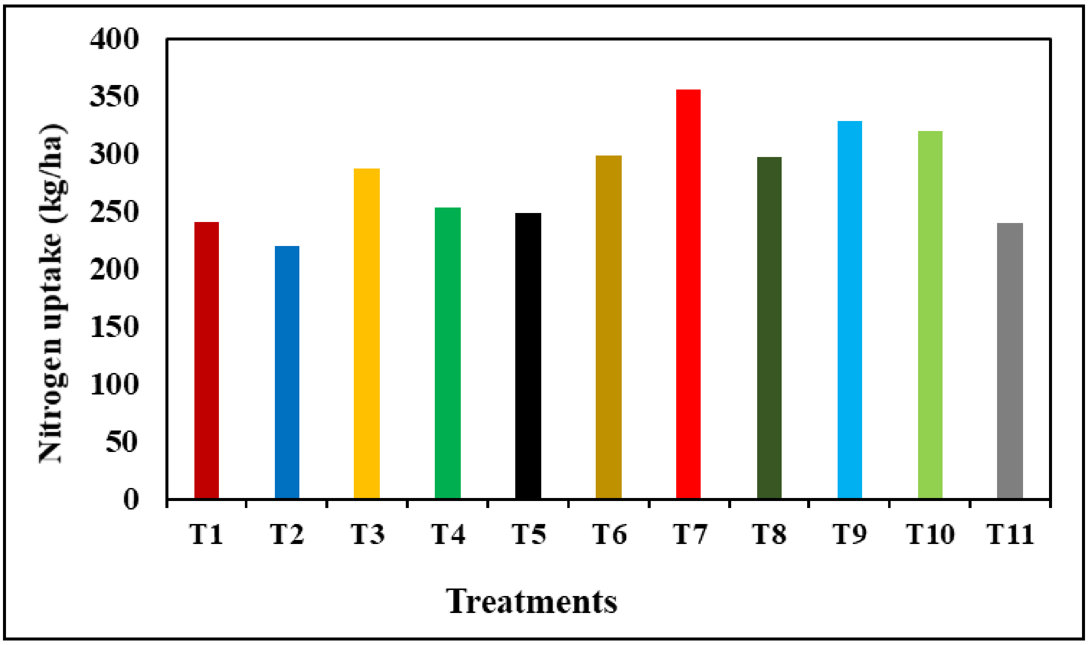

Figure 9. Effect of nutrient management on uptake of nitrogen by sweet potato

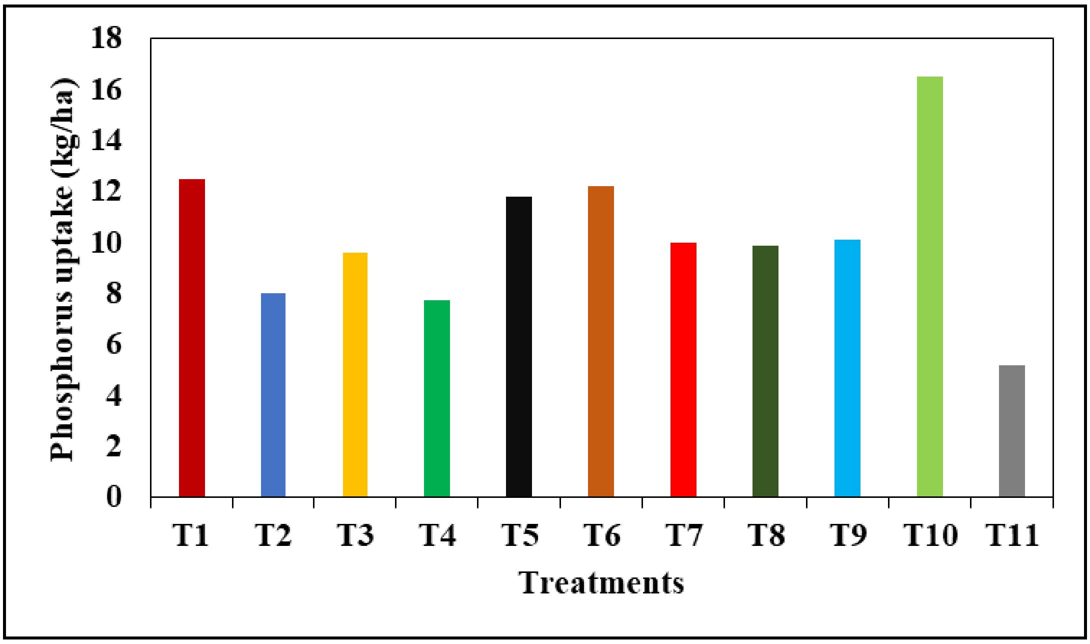

Figure 10. Effect of nutrient management on uptake of phosphorus by sweet potato

Secondary nutrient status of soil after harvest of crop

The nutrient status of soil after the experiment revealed that the level of available magnesium was low even with application of 100 kg $MgSO_4$/ha, probably due to leaching of $MgSO_4$ leading to poor efficiency and poor soil retention. Same was the case with sulphur status of soil after the experiment. It showed a decrease from initial value of 49 mg/kg to as low as 12 mg/kg in treatments where no $MgSO_4$ was applied. With higher doses of applied $MgSO_4$ and increase in sulphur content could be observed. Under organic management higher S content of 60 mg/kg was observed probably due to S addition through organic sources.

This may be the reason for less variability among uptake of magnesium also. However, calcium status of soil could be considerably increased by application of lime @ 600 kg/ha, uniformly in all treatments.

Economics

The economic viability of the various doses of fertilizer application was done taking into consideration the cost involved and returns. As the treatments differed in the quantity of fertilizer nutrients applied, the difference in cost of cultivation was not very wide except in the case of organic management where cost involved was higher compared to chemical fertilizers. The cost was Rs. 1,25,319 per ha in T_1 where NPK was applied @ 65:12:20 kg/ha whereas it was Rs.1,94,950 in the case of organic management (T_{11}). The cost of fertilizer magnesium sulphate was Rs 18 /kg and as the maximum dose tried was 100 kg/ha, the total increase due to magnesium sulphate alone was Rs.1800/ha. As the tuber yield varied significantly, the returns also varied among the treatments. Gross return, net return as well as BC ratio were the highest in treatment T_7 which recorded the superior yield of 35.90 t/ha (Figure 13). In this treatment the additional return due to magnesium application alone (compared to T_6 where same N : P_2O_5 : K_2O was applied) was Rs 1,04,280/ha.

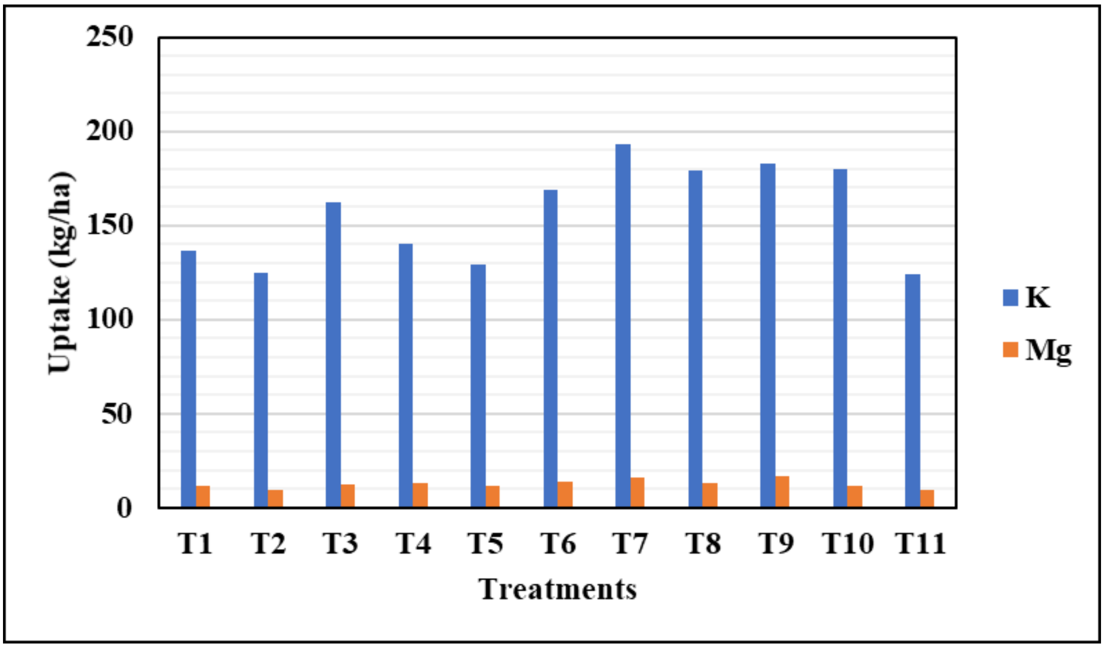

Figure 11. Effect of nutrient management on uptake of potassium and magnesium by sweet potato

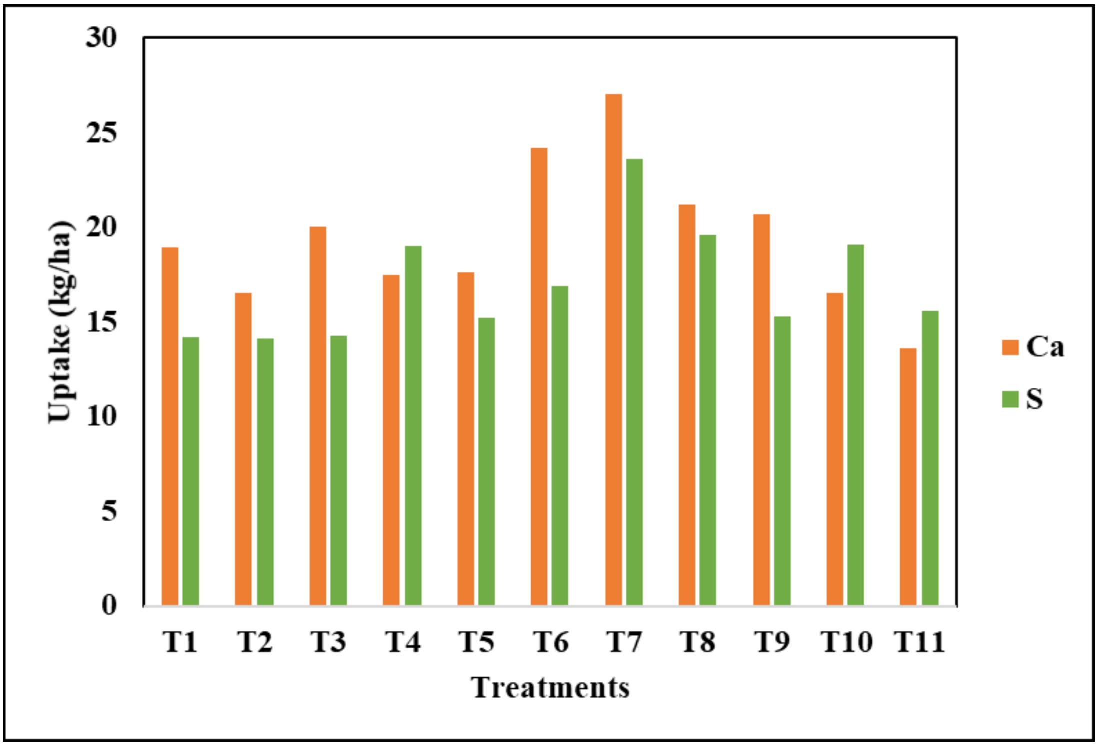

Figure 12. Effect of nutrient management on uptake of calcium and sulphur by sweet potato

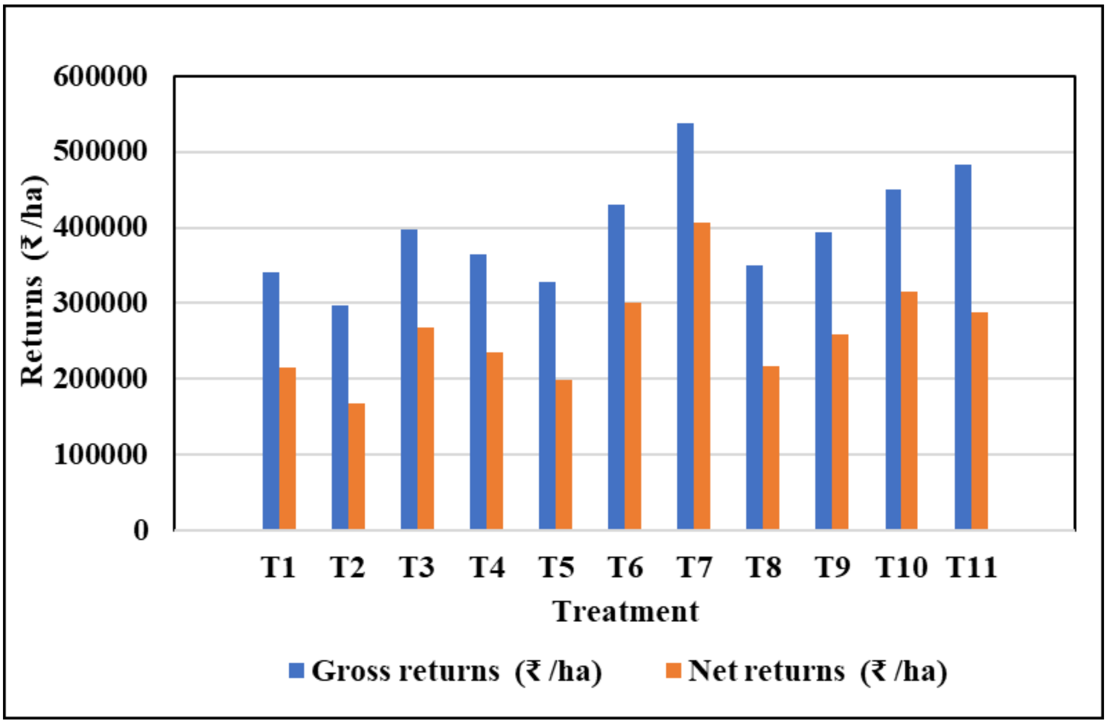

Figure 13. Gross return and net return in sweet potato cultivation as influenced by nutrient management

However, application of Mg at higher rates of 60 and 80 kg per ha resulted in net loss over no magnesium application and a marginal increase in the case of 100kg $MgSO_4$. It can be seen that the net returns with NPK application @ 75:50:75 (Rs 3,01,339/ha) with no magnesium application was 40 per cent higher than the net returns with application of NPK 65:12:20 (Rs. 2,15,181/ha) as the yield was about 25 percent higher.

Though organic nutrition resulted in comparable yield to that of T_7, in net return this treatment was inferior to T_7, as the cost of tuber was calculated in the same rates. However, if a premium price can be fetched, this nutrient management system also will be profitable. If the tuber fetches an additional price of Rs 3 per kg, comparable profits to that of T_7 can be realized and if Rs 5/kg, even more net profits can be realized, with the tuber yield of 32.20 t/ha.

Economic analysis indicates that the application of recommended dose of N : P_2O_5 : K_2O irrespective of soil nutrient status along with 40 kg/ha magnesium sulphate and 10t/ha of organic manure can be recommended in integrated production systems.

Organic management system also can be recommended if premium price can be assured for the produce. From the angle of sustainable soil health also this system can be recommended in sweet potato production.

Hence it may be concluded that more detailed studies are needed to know the role of nutrient management in partitioning of assimilates by which more balanced nutrition can be ensured for better productivity.

SUMMARY

4. SUMMARY

The experiment entitled "Response of sweet potato [*Ipomoea batatas* (L.) Lam.] to secondary nutrients" was conducted with the objectives to assess the influence of secondary nutrients on growth, yield and quality of sweet potato and to work out the economics. The study was conducted from September 2019 to January 2020 at Agronomy Farm, College of Horticulture, Vellanikkara, Thrissur. The salient findings from the experiment are summarized below.

1. At 30 DAS and 60 DAS most of the treatments had higher and comparable vine length though the treatment differences were significant. The vine length increased up to 2.5m with in three months of planting. However, by 90 DAP, a slightly different trend in vine length was observed. Higher and comparable vine length was recorded from treatments T_3 (233.4 cm) and T_7 (222.9 cm) which received $MgSO_4$ @ 60 and 40 kg/ha respectively. The treatments T_1, T_2 and T_{11} continued to register lower values. It was seen that in all stages (30, 60 and 90 DAP) treatments which received N : P_2O_5 : K_2O.@ 75:50:75 kg/ha with varying doses $MgSO_4$ were statistically on par and had higher values compared to N : P_2O_5 : K_2O application @ 65:12:20 kg/ha.

2. The highest leaf area index of 3.48 was registered in T_8 (75:50:75 + $MgSO_4$ @ 60 kg/ha) which was superior to others followed by T_7 (75:50:75 + $MgSO_4$ @ 40 kg/ha). The lowest LAI was seen in treatment T_{11} (Organic POP) followed by T_4 (65:12:20 + $MgSO_4$ @ 80 kg/ha).

3. The content of chlorophyl a, b and total chlorophyll at 60 DAP, in all treatments was not significantly influenced by varied levels of $MgSO_4$ or N : P_2O_5 : K_2O.

4. Higher and statistically comparable values of aerial dry matter was recorded in treatments (T_6 to T_{10}) which received N : P_2O_5 : K_2O @ 75:50:75 along with varied doses of $MgSO_4$. The lower production was registered in T_{11} (organic POP) which was statistically on par with other treatments (T_2, T_4 and T_5) which received lower dose of N : P_2O_5 : K_2O (65:12:20) with variable $MgSO_4$. However, dry matter

accumulation by tuber showed wide variation and the trend was different from that of aerial portion. The highest tuber dry matter production was recorded in T_7 (75:50:75 + $MgSO_4$ @ 40 kg/ha) which is on par with treatments T_6, T_{10} and T_{11}. Lower tuber dry matter accumulation was seen in all the treatments which received lower doses of N : P_2O_5 : K_2O @ 65:15:20 kg/ha, irrespective of magnesium sulphate dose and were statistically on par. Similarly, highest total dry matter accumulation was seen in T_7 which was on par with T_6, T_8, T_9 and T_{10} which received higher dose of N : P_2O_5 : K_2O @ 75: 50:75 and along with varied doses of $MgSO_4$. The lower total dry matter content was registered in treatments (T_1 to T_5) which received lower dose N : P_2O_5 : K_2O (65:12:20) with variable $MgSO_4$ which in turn were on par with organic management (T_{11}).

5. The treatments had significant effect on the tuber yield of sweet potato. The higher and comparable tuber yield was observed in treatments T_7 (75:50:75 + $MgSO_4$ @ 40 kg/ha) and T_{11} (organic treatment) and lower yield was registered from T_2 (65:15:20 + $MgSO_4$ @ 40 kg/ha) which was on par with treatments T_1, T_3, T_4 and T_5, which received lower doses of N: P_2O_5: K_2O with varying doses of $MgSO_4$. The highest harvest index of 0.72 was recorded in treatment T_{11} (organic management) which was superior to others and remaining all treatment values were on par with HI ranging from 0.55 to 0.72.

6. More number of tubers/plant were registered from treatments T_{11} (organic POP), T_{10} (75:50:75 + $MgSO_4$ @ 100 kg/ha) and T_7 (75:50:75 + $MgSO_4$ @ 40 kg/ha), T_5 (65:15:20+ 100 kg) and T_4 (65:15:20 + $MgSO_4$ @ 80 kg/ha) which were on par. The lower number of tubers was observed in treatments T_8 (75:50:75 + $MgSO_4$ @ 60 kg/ha) which was statistically on par with T_6, T_3, T_2 and T_1.

7. Higher unmarketable yield was observed in treatments T_2 and T_3 which received N : P_2O_5 : K_2O @ 65:15:20 + $MgSO_4$ @ 40 kg/ha and 60 kg/ha which were on par. The lowest unmarketable tuber yield was noticed in treatment T_7 (75:50:75 + $MgSO_4$ @ 40 kg/ha) which registered the highest marketable tuber yield.

8. Uptake of primary nutrients N, P and K was higher in the treatments which received N : P_2O_5 : K_2O @ 75:50:75 with irrespective $MgSO_4$ dose than lower dose of N : P_2O_5 : K_2O.

9. N, P and K content in aerial portion was 2.30, 0.17 and 1.24 % respectively whereas in sweet potato tubers it was 1.75, 0.10 and 0.88 % respectively. The uptake of nitrogen by sweet potato ranged from 220.3 kg/ha to 356.9 kg/ha, phosphorus uptake ranged from 5.2 kg/ha to 16.5 kg/ha and potassium uptake ranged from 124.0 kg/ha to 193.2 kg/ha. The average uptake N, P and K uptake by sweet potato was 281, 10 and 101 kg/ha.

10. The uptake of secondary nutrients by sweet potato also differed statistically. Higher calcium uptake was seen in treatments T_7 (75:50:75 + $MgSO_4$ @ 40 kg/ha) followed by T_6 (75:50:75 + $MgSO_4$ @ 0 kg/ha) which were at par. Lower uptake was observed in T_{11} (Organic POP) which was comparable with treatments T_{10} (75:50:75 + $MgSO_4$ @ 100 kg/ha) and T_2 (65:15:20 + $MgSO_4$ @ 40 kg/ha).

11. Higher uptake of magnesium was observed in treatment T_9 and T_7 which received (75:50:75 + $MgSO_4$ @ 80 kg/ha and 40 kg/ha) and lower uptake was registered in treatments T_2 (65:15:20 + $MgSO_4$ @ 40 kg/ha) and T_{11} (Organic POP). Sulphur uptake was on par in all the treatments.

12. Not much difference in the content of total, reducing and non-reducing sugar in sweet potato tuber could be observed. Slightly higher total sugar content was observed in treatment T_8 (75:50:75 + $MgSO_4$ @ 60 kg/ha) which was statistically on par with treatments (T_7, T_9, T_{10} and T_{11}). The lower content was seen in treatment T_1 (65:15:20 + no $MgSO_4$) and which was comparable with treatments (T_2, T_3, T_5 and T_6). Similarly, T_8 (75:50:75 + $MgSO_4$ @ 60 kg/ha) recorded higher reducing sugar content, which was on par with T_7 (75:50:75 + $MgSO_4$ @ 40 kg/ha), T_9 (75:50:75 + $MgSO_4$ @80 kg/ha) and T_{11} (Organic POP). However, there was no significant differences among the treatments with respect to content of non-reducing sugar. Content of crude fibre and crude protein did not vary much with N : P_2O_5 : K_2O or $MgSO_4$ doses and average values were 2.6 and 10.9 %.

13. The soil chemical properties of post-harvest soil showed no variation in soil pH (4.8) except in organic management where pH was high.

Organic carbon content in various treatments ranged from 1.0 % to 1.4 % and was in the medium range similar to initial status.

14. The average available N, P and K content in soil after harvest was 133, 56 and 282 kg/ha respectively. There was an increase in calcium and magnesium status of soil compared to initial status (158.4 mg/kg and 43.0 mg/kg) and all the treatments were statistically on par. The sulphur content decreased compared to initial values (49 mg/kg) except in organic management treatment, where an increase could be observed.

15. The highest net profit was recorded when N : P_2O_5 : K_2O was applied @ 75:50:75 along with 40 kg/ha $MgSO_4$ (□ 4, 05,619/ha) and the lowest was in T_2 which received lower doses of primary nutrient (□ 1, 67,961/ha). The second-best treatment with respect to net profit per hectare was T_{10} (□ 3,16,039/ha) followed by T_6 (□ 3, 01,339/ha) in thirdposition.

16. The B:C ratio ranged from 2.3 to 4.1. Even though cost of cultivation of organic management was higher, the higher gross returns from this resulted in a B:C ratio of 2.5. However, the highest benefit cost ratio of 4.1 was associated with application of N : P_2O_5 : K_2O and $MgSO_4$ @ 40kg/ha.

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APPENDIX

Appendix 1. Monthly weather data during experimental period (September 2019-December 2019)

Month	Maximum temperature (^0C)	Minimum temperature (^0C)	Relative Humidity (%)	Rainfall (mm)	Rainy days	Evaporation (mm)	Sunshine hours
Sep	31.5	21.9	84.8	93.5	5.8	18.4	24.6
Oct	32.4	21.2	79.4	95.9	3.6	19.0	39.7
Nov	32.9	22.1	71.5	36.7	1	23.8	49.6
Dec	32.3	22.3	61.5	0.5	0	34.1	51.8

Appendix 2. Cost of cultivation

Cost of vine: 50 paise/vine

Cost of FYM: Rs. 1.5/kg

Cost of fertilizers: Urea-6 Rs/kg, SSP-9 Rs/kg,

MOP-19/kg, $MgSO_4$-18 Rs/kg

Cost of labour: Rs 600/head/day

Treatment	**Yield (t/ha)**	**Total cost of cultivation (□/ha)**	**Gross returns (□/ha)**	**Net return (□/ha)**	**B-C ratio**
65: 15: 20 + 0	22.7	125319	340500	215181	2.7
65: 15: 20 + 40	19.8	129039	297000	167961	2.3
65: 15: 20 + 60	26.5	129399	397500	268101	3.1
65: 15: 20 + 80	24.3	129759	364500	234741	2.8
65: 15: 20 + 100	21.9	130119	328500	198381	2.5
65: 15: 20 + 0	28.7	129161	430500	301339	3.3
75: 50: 75 + 40	35.9	132881	538500	405619	4.1
75: 50: 75 + 60	23.3	133241	349500	216259	2.6
75: 50: 75 + 80	26.2	133601	393000	259399	2.9
75: 50: 75 + 100	30	133961	450000	316039	3.3
Organic management	32.2	194950	483000	288050	2.5

Response of sweet potato [*Ipomoea batatas* (l.) Lam.] to secondary nutrients

By

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ABSTRACT OF THE THESIS

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Abstract

Sweet potato is an important food crop with short duration and high nutrient requirement. As the deficiency of secondary nutrients is generally encountered in highly leached acid soils of Kerala and the research on supplementation of these nutrients in enhancing the productivity of sweet potato is limited, the present study entitled "Response of sweet potato [*Ipomoea batatas* (L.) Lam.] to secondary nutrients" was carried out. The objective was to assess the influence of secondary nutrients on growth, yield and quality of sweetpotato.

The experiment was conducted from September 2019 to January 2020 at Agronomy Farm, College of Horticulture, Vellanikkara, Thrissur. The experiment was laid out in RBD with 11 treatments replicated thrice. The treatments included five levels of magnesium sulphate *i.e.,* 0, 40, 60, 80 and 100 kg/ha along with N: P_2O_5 : K_2O @ 75:50:75 kg/ha (KAU POP) and N : P_2O_5 : K_2O @ 65:12:20 (soil test based). A high yielding sweet potato variety 'Sree Kanaka' was used.

Growth parameters like vine length, leaf area, and total dry matter accumulation per plant were significantly influenced by nutrient management. Higher doses of N: P_2O_5 : K_2O (75:50:75) irrespective of $MgSO_4$ dose (0 to 100 kg/ha) showed higher values for these parameters compared to treatments receiving lower doses of N : P_2O_5 : K_2O (65:12:20) along with $MgSO_4$. At 30 days after planting (DAP), vine length ranged from 40.5 cm to 55.6 cm and it increased to 2.5m by 90 DAP. At this stage, all the treatments exhibited comparable vine length irrespective of nutrient doses, except T_3 (65:12:20 + $MgSO_4$ @ 60 kg/ha) and T_7 (75:50:75 + $MgSO_4$ @ 40 kg/ha) which registered higher values and differed significantly from others. Higher and comparable total dry matter accumulation was also observed in treatments where N : P_2O_5 : K_2O @ 75:50:75 along with varying doses of $MgSO_4$ was applied.

The highest leaf area index of 3.48 was noticed in treatment T_8 which received N : P_2O_5 : K_2O (75:50:75) with $MgSO_4$ @ 60 kg/ha and the lowest was seen in organic management (T_{11}).

Chlorophyll content at 60 DAP was not significantly influenced by varied doses of nutrients applied.

Marketable tuber yield ranged from 19.8 to 35.9 t/ha and the treatments T_7 (75:50:75 + $MgSO_4$ @ 40 kg/ha) (35.9 t/ha) and T_{11} (organic management) (32.2 t/ha) resulted in higher tuber yields and were on par. Application of lower dose of N: P_2O_5: K_2O based on soil test values resulted in lower yields compared to recommended dose. The highest harvest index of 0.72 was observed in T_{11} (Organic management) followed by T_7 (0.60).

Unmarketable tuber yield ranged from 1.0 to 1.7 t/ha. Higher and comparable unmarketable yield was observed in treatments T_2 (65:12:20 + $MgSO_4$ @ 40 kg/ha) and T_3 (65:12:20 + $MgSO_4$ @ 60 kg/ha) which received lower doses of N : P_2O_5 : K_2O and $MgSO_4$ and registered lower marketable yield. The unmarketable yield was the lowest in superior treatment T_7 (75:50:75 + $MgSO_4$ @ 40 kg/ha).

Quality parameters of sweet potato tuber *i.e.* total, reducing and non-reducing sugar, crude fibre and crude protein were also estimated. In general, higher and comparable reducing sugar and total sugar content was observed in treatments which received higher doses of N : P_2O_5 : K_2O and in tubers from organic nutrient management. Content of non-reducing sugar, crude fibre and crude protein did not vary significantly and the average values were 6.7, 2.6 and 14.3 % respectively.

The soil chemical parameters in post-harvest soil showed a decline in pH and EC except in organic management where an increase in soil pH could be observed. The organic carbon was influenced by nutrient management however, it was in medium range in all the treatments. The average N, P and K uptake by sweet potato was 281, 10 and 156 kg/ha respectively, and the corresponding values for calcium, magnesium and sulphur were 20, 13 and 17 kg/ha respectively.

Application of recommended dose of N : P_2O_5 : K_2O along with 40 kg/ha magnesium sulphate resulted in the highest gross return (Rs. 5,38,500), net return (Rs. 4,05,619) as well as B:C ratio (4.1). Organic nutrient management system was the next best treatment with a net return of Rs. 2,88,050 and B:C ratio of 2.5.

Hence N : P_2O_5 : K_2O @ 75:50:75 along with 40 kg/ha of magnesium sulphate can be recommended in soils deficient in Mg for enhancing productivity of sweet potato. The results also indicate that organic nutrient management also will be economically viable in sweet potato production if premium price can be assured for the produce.