Fruit, Vegetable and Cereal Science and Biotechnology ©2012 Global Science Books

Sweet Potato Agronomy

Maniyam Nedunchezhiyan[1*] • Gangadharan Byju[2] • Susantha K. Jata[1]

[1] Regional Centre of Central Tuber Crops Research Institute, Bhubaneswar – 751 019, India
[2] Central Tuber Crops Research Institute, Thiruvananthapuram – 695 017, India

Corresponding author: * **mnedun@gmail.com**

ABSTRACT

Sweet potato, a bio-efficient crop grown for edible roots has spread into Africa, Asia, Europe and East Indies through batatas line and to the Philippines from Central and South America. Sweet potato is a staple food crop in many of the developing countries and serves as animal feed and raw material for many industrial products. It requires a moderately warm climate (21-26°C) with soil pH of 5.5-6.5. Heavy rainfall, high temperature and excess cloudiness encourage vegetative growth. In sweet potato, close spacing is generally recommended to achieve maximum root yield. Though sweet potato covers the soil quickly, weeding is necessary, particularly, in the early stages of the crop growth. Sweet potato requires, on an average, 2 mm of water per day in the early parts of the growing season which gradually increase to 5-6 mm per day prior to harvest. *Cylas formicarius* Fab. (sweet potato weevil) larvae and adult feeds on the roots and cause extensive damage both in field and in storage. It can be effectively managed by following an integrated pest management strategy. Sweet potato is harvested between 90 and 150 days after planting depending on the location and season. On an average, it yields storage root of 20-25 tonnes ha^{-1} with improved crop management practices.

Keywords: irrigation, population, time of planting, variety, weeding
Abbreviations: ARS, Agricultural Research Service; **CGR**, crop growth rate; **CIP**, International Potato Centre; **CPE**, cumulative pan evaporation; **CTCRI**, Central Tuber Crops Research Institute; **DAP**, days after planting; **IPM**, integrated pest management; **ISP**, industrial sweet potatoes; **IW**, irrigation water; **KNAES**, Kyushu National Agricultural Experiment Station; **LAI**, leaf area index; **NCSU**, North Carolina State University; **SPFMV**, *Sweet potato feathery mottle virus*

CONTENTS

INTRODUCTION

Sweet potato is an important root crop in tropical and sub tropical countries like China, USA, India, Japan, Indonesia, Philippines, Thailand, Vietnam, Nigeria etc. Among the root and tuber crops grown in the world, sweet potato ranks second after cassava (Ray and Ravi 2005). The carbo-hydrate rich root is used as a subsidiary food after boiling/ baking. In some countries, the vine tips are used as vegeta-bles. Vines form an excellent source of green fodder for

Received: 1 November, 2011. Accepted: 1 November, 2012.

Invited Review

Table 1 Sweet potato varieties grown in different countries.

Country	Variety	Reference
Bangladesh	BARI SP-6 (Lalkothi), BARI SP-7 (Kalmegh), BARI SP-8 and BARI SP-9	Golder *et al*. 2000; Bhuiyan *et al*. 2009
China	Xuzhou 18	Guoquan and George 2000
Ethiopia	Balella and Bareda	Teshome Abdissa *et al*. 2011
India	Pusa Safed, Co-1, VL Sakarkand-6, Sree Nandini, Sree Vardhini, Co-2, Co-3, Samrat, Sree Bhadra, Sree Arun, Sree Varun, Sankar, Gouri, Kalinga, Gautam, Sourin, Kishan, H-41, H-42, H-268, Rajendra Sakarakand-5, Sree Rethna, Sree Kanaka, Kamala Sundari, S-1221, WBSP-4, Tripti, Bidhan Jagannath, BCSP-5, Birsa Sakarakand-1 and Indira Sakarakand-1	CTCRI 1999; CTCRI 2006
Japan	Quick Sweet, Kokei No.14, Beniazuma, Norin No.2, Koganesengan and Satsumahikari	Yamakawa 2000
Korea	Mokpo 32, Mokpo 34, Hongmi, Hwangmi, Sinjami, Shinmi, Wonmi, Poongmi, Borami and Enumi	Jeong *et al*. 1986; Jeong 2000
Malaysia	Jalomas, Minamiyutaka, Pisang Kapas, Madu, Bawang, Gendut, Telong, Kangkung Cina, Ikan Selayang, Kangkung Kampung, Bukit Naga, Taiwan and Pasar Borong-1, Serdang, Suberang Perai, Kundang, Bidor, Pontian, Rhu Tapai, Sungai Baging and Kuala Linggi	Tan 2000; Zaharah and Tan 2006
New Zealand	Toka Toka Gold, Owairaka Red and Beauregard	Wright *et al*. 2003
Papua New Guinea (PNG)	Koitaki 2, K9, K42, UIB016, Wanmun murua, Wanmun and Large	Bourke 2005
Taiwan	Taoyuan No.1, Taoyuan No.2 and Tainung No.71	Yi-Shin *et al*. 2000
Thailand	PIS 205, PIS 65-16, PIS 166-5, Maejo and Taiwan	Narin and Reungmaneepaitoon 2005
United States of America	Goldrush, Redgold, Centennial, Beauregard and Jewel	Schultheis and Jester 2000
Vietnam	H12, K51 and TV1	Ngoan 2006

cattle. Development of varieties having high dry matter, starch, carotene and anthocyanin has opened up new vistas in industrial applications apart from traditional usage as food and feed. Industrial products like starch, liquid glucose, citric acid, mono sodium glutamate and ethanol are produced from sweet potato roots in various countries.

Sweet potato yields high amount of energy per unit area per unit time and is expected to bridge the food shortages and malnutrition. The comparative short duration coupled with its innate power for tremendous dry matter production has enabled sweet potato to rank as the foremost root crop in respect of calorie value. It has the potential as a feedstock for bio-ethanol production. However, varieties with high yields and dry matter content termed industrial sweet potatoes (ISP) have to be developed to exploit as bio fuel crop. North Carolina State University (NCSU) has developed varieties which have as high as 67.8 g l^{-1} of ethanol for flour based fermentation and 34.9 g l^{-1} for fresh sweet potato sugar fermentation (Santa-Maria *et al*. 2006; Duvernay 2008). Studies have shown that sweet potato storage root, carbohydrate and ethanol yields were approximately three times that of corn (Rodgers *et al*. 2007; ARS 2008). However, storage root, carbohydrate and ethanol yields were cultivar dependent. Monday (2009) reported that the variety X-1617 and Beauregard produced the highest root and ethanol yield, respectively. Nyiawung *et al*. (2010) reported that the ideal dry matter, starch, and amylase/amylo-pectin content and ratio that a sweet potato variety should have for maximum ethanol yield are 30-33%, 20-24%, 23-30%/70-77% and 0.27-0.46, respectively. The sweet potato varieties, WS 14905 and TU0002 produced 66.0 g l^{-1} of ethanol by flour based fermentation and 34.4 g l^{-1} was obtained from fresh tubers of Beauregard variety (Nyiawung *et al*. 2010). The higher the dry matter and starch, the greater the ethanol yields. Promising varieties of sweet potato along with improved agrotechniques can boost the root production. Adoption of improved agronomic practices alone can increase the yield of sweet potato significantly. The agronomic practices for sweet potato vary from place to place depending upon the environmental conditions and variety. The author has discussed some of the agronomic practices in his earlier publications (Nedunchezhiyan and Byju 2005; Nedunchezhiyan and Ray 2010).

In this paper, an up to date brief account of the various location specific agronomic practices recommended for higher yields are discussed.

CLIMATE AND SOIL

Sweet potato requires moderate temperature (21-26°C); hence it is planted and harvested every month in one part or other in the world. A well distributed rainfall of 75-150 cm is sufficient for its cultivation. Sweet potato requires plenty of sunshine, but shade causes yield reduction. However, sweet potato is intercropped with other seasonal crops like pigeonpea, maize, etc. (Nedunchezhiyan *et al*. 2010a) and also grown as intercrop under plantation/orchard crops with the aim of crop intensification and profit maximization (Nedunchezhiyan *et al*. 2007). Sweet potato can tolerate drought to some extent but cannot withstand water logging (Nedunchezhiyan and Ray 2010). Well drained loam and clay loam soils are good for sweet potato cultivation. However, sandy loam with clay subsoil is ideal. Heavy clayey soils restrict the storage root development due to compactness whereas, sandy soils encourages long cylindrical pencil like roots (Nedunchezhiyan and Ray 2010). Sweet potato is mostly grown in acidic soils, however soil pH of 5.5-6.5 is found to be optimum. High soil pH invites pox and scurf diseases in sweet potato, whereas at low pH sweet potato suffers from aluminium toxicity (Nedunchezhiyan and Ray 2010). Sweet potato is also sensitive to saline and alkaline conditions (Dasgupta *et al*. 2006; Mukherjee *et al*. 2006).

VARIETY

High-yielding varieties

In sweet potato, varieties play a significant role in yield improvement. Many Research and Development organizations working on sweet potato have the major objective of developing location specific sweet potato varieties. The elite clones are developed by following different methods of breeding. The common methods are clonal selection, open pollinated selection, hybridization, mutation and biotechnology (Nayar and Naskar 1994). Some of the high yielding varieties cultivated in different countries are given in **Table 1**.

Orange flesh sweet potato

Normally sweet potato flesh colour is white, but some of the cultivars have orange flesh. The orange fleshed sweet potato contains β-carotene which is a precursor of vitamin A. Sweet potato tubers contain β-carotene up to 20 mg 100 g^{-1} fresh weight (Sakamoto *et al*. 1987; Yamakawa 1997).

One cup of cooked sweet potato can provide 30 mg (50,000 IU) of β-carotene, whereas 23 cups of broccoli are required to provide the same amount of β-carotene (Sakamoto *et al.* 1987).

The orange flesh sweet potato varieties/genotypes that are cultivated in India are Kamala Sundari, Gouri, Sankar, Sree Kanaka, ST14, etc. The carotene content in ST14 is 13.83 mg 100 g^{-1} fresh root (Vimala *et al.* 2006). In Japan, Benihayato, Kyushu No. 114, in Mozambique, MGCL01, 440215, Resisto and in Thailand, PIS 226-24, PIS 227-6 are some of the high yielding orange flesh varieties.

Purple flesh sweet potato

Purple-fleshed sweetpotatoes have purple color in the skins and flesh of the storage root due to the accumulation of anthocyanins (Philpott *et al.* 2004; Terahara *et al.* 2004). Anthocyanins are natural soluble food pigments and contribute to the red, blue and purple colouration of leaves, flowers and other parts of the plants. Red and purple pigmentation in various parts of sweet potato such as stem, leaf and storage root is caused by the presence of acylated anthocyanins (Fan *et al.* 2008). Anthocyanins have applications in pharmaceutical and cosmetic industries due to its bright colour, non-poisonous nature, rich nutrition, safe and health care function (Rice-Evans and Packer 1998). In recent years, interest on anthocyanin has increased due to possible health benefits (Giusti and Wrolstadt 2003). Anthocyanins from purple sweet potatoes have high heat and light stability (Cuevas Montilla *et al.* 2011). Bassa and Francis (1987) first noted that sweet potato anthocyanins are effective natural food colorants for preparation of beverages. Sweet potato anthocyanins are comparable to that of red cabbage in terms of their quality as natural food colorants. Cuevas Montilla *et al.* (2011) reported that purple fleshed sweet potatoes are used in juices, alcoholic beverages, jams, confectioneries, bread, snacks and noodles. The recent findings of the radical scavenging, antimutagenicity and efficacy against liver disease of sweet potato anthocyanins (Terahara *et al.* 2004) indicated that purple flesh sweet potato may contribute to maintaining good health of human beings. Recently, Japanese markets have coupled anthocyanin extracts from purple-fleshed sweetpotato with cordyceps mushroom extracts as a memory enhancing dietary supplement. Both sweetpotato and mushroom extracts had roughly the same radical scavenging activity separately, but DPPH activity was not increased by combining the two extracts. Furthermore sweetpotato extracts were shown to improve performance of ethanol-treated mice, while mushroom extract did not. Overall, the anthocyanins were proved to be the active component in memory enhancement (Cho *et al.* 2003).

In Japan, *Ayamurasaki*, a high anthocyanin sweet potato variety was developed by the Kyushu National Agricultural Experiment Station (KNAES) (Yamakawa *et al.* 1997). Regional Centre, Central Tuber Crops Research Institute (CTCRI), Bhubaneswar, India has developed a high anthocyanin line ST13 (CTCRI 2003). The variety PIS 189-257 from Thailand is rich in anthocyanin (Narin and Reungmaneepaitoon 2005). In Indonesia, three high yielding purple fleshed clones (MSU 01017-16, MSU 01022-12 and MSU 01002-7) have been identified (Jusuf *et al.* 2005).

TIME OF PLANTING

Time of planting has been identified as one of the most important factors affecting growth, yield and quality of roots (Nedunchezhiyan and Byju 2005). In Malaysia, higher root yield was noticed during drier growing season (January to July) compared to wet season (August to December) (Zaharah and Tan 2006). In India, sweet potato is grown throughout the country, utilizing monsoon rain during *kharif*, (June-August), and with supplemental irrigation during *rabi* (October-December). The major area under sweet potato is planted during *kharif* season, though *rabi* planted sweet potato enjoys warm sunny days and cool nights with moderate rainfall conductive for higher root yield. Investigations carried out at different regions of India on the optimum time of planting revealed that rainfed crops should be planted immediately after onset of monsoon (Nedunchezhiyan and Reddy 2006) whereas dry season crops should be planted in October-November (Nath *et al.* 2006) for higher storage root yield. In India, it is observed that the tuber yield of sweet potato is comparatively more during *rabi* than *kharif* season (Nawale and Salvi 1983; Nedunchezhiyan and Byju 2005).

In Solamon Islands, the highest root yields were reported when sweet potato was planted between September and February (Bourke 2005). In Puerto Rico, the highest root yields were obtained when planted in November and the lowest yield in March or May (Badillo-Felieno 1976). In Korea, best results were obtained when sweet potato was planted during May-June (Jeong *et al.* 1986). In Cameroon, sweet potato is planted in May/June and September/October seasons (Njualem *et al.* 2005). Time of planting studies conducted in Puerto Rico with eight varieties, three locations and four seasons (September, December, March and June) indicated that there was significant difference between cultivars, locations and seasons (Martin 1988). In Taiwan, high yields of sweet potato were obtained when the mean daily temperature was maintained around 22ºC for the 1st 60 DAP (Sajjapongse 1989). In Korea, as per the demand of sweet potatoes, transplanting time is advanced from May-June to March-April and the harvesting time is advanced from September-October to June-August with the modification of cultural requirements (Jeong 2000).

Studies on the effect of planting date on sweet potato conducted in Puerto Rico indicated that vine weight at harvest was highest for crops maturing during rainy season. Heavy rainfall encouraged vegetative growth, high temperature accelerated growth process and excess cloudiness reduced the net photosynthetic production (Martin 1988).

NURSERY PREPARATION

Sweet potato is usually propagated through vine cuttings obtained either from freshly harvested plants or from nursery. However, recurrent use of vines can cause increased weevil infestation, even though there is less change of root yield reduction (Ray *et al.* 1983; Nair 2006). Vines obtained from nursery should be healthy and vigorous for maximum root production.

Primary nursery

The nursery preparation starts 3 months prior to planting in the main field. For planting one ha of land, about 100 m^2 of primary area and about 100 kg of medium sized weevil free seed roots (125-150 g each) are required. The roots are planted at a spacing of 20 cm on ridges formed 60 cm apart. To ensure quick growth of vines, it is top dressed with 1.5 kg urea 100 m^{-2} at 15 days after planting (DAP). The nursery is irrigated on every alternate day for the first 10 days and thrice in a week thereafter. On 45th day, the vines are cut to a length of 20-30 cm for further multiplication in the secondary nursery (CTCRI 1987).

Secondary nursery

To produce enough planting material for planting one ha of land, vines obtained from the primary nursery are further multiplied in the secondary nursery to an extent of 500 m^2. Farm yard manure or compost, 500 kg, is applied at the time of preparation of nursery bed and ridges are formed at a spacing of 60 cm apart. Vines obtained from the primary nursery or from freshly harvested crop are planted in the secondary nursery at a spacing of 20 cm within ridges. To ensure enough vegetative growth, 5 kg of urea is applied in two splits on 15 and 30 days after planting. For the better establishment of vines in nursery, irrigations are provided at every alternate day for the first 10 days and thrice in a week thereafter. The vines will be ready for planting in the main field after 45 days (CTCRI 1987).

PREPARATION OF PLANTING MATERIALS

Vine portion and length of cutting

The apical and middle portion of the vine is found to be the best for getting higher root yield (Mukhopadhyay *et al.* 1990). Bottom portions, usually thick and woody, sometimes fail to establish and there is a greater chance of weevil incidence due to proximity with the crown portion where sweet potato weevil multiplies (Nair 2006). A vine length of 20-40 cm with at least 3-5 nodes is found to be optimum for the storage root production in different parts of India (Nair 2006). In Cuba, 25-30 cm long stem cuttings were found to be ideal (Sanchez *et al.* 1985). Studies on planting material production conducted at Bangladesh showed that increasing the number of nodes/vine increased number of vines/plant, vine length and root yield. Apical shoot cuttings resulted in higher yield compared to mid stem cuttings (Choudhary *et al.* 1986). Similar results were reported by Siddique *et al.* (1988) in Bangladesh.

Preparation of vines

Cut vines with intact leaves are stored under shade for two days prior to planting in the main field to promote better root initiation, easy establishment of vines and higher root yield (Ravindran and Mohankumar 1989; Biswal 2008). Vine cuttings stored for 3 days produced plants with highest marketable root yield followed by 4 days old cuttings (Hammett 1983). Storing of vines for a long time caused failure of establishment in the field due to drying. Stored vines were found to be superior to fresh vines in respect of leaf area index (LAI), crop growth rate (CGR), root bulking rate, number of roots per plant and root and vine yields in trials conducted at Kalyani in West Bengal, India (Mukhopadhyay *et al.* 1990). The leaves of the vines can be removed when the vines are to be transported to distant places to reduce the bulkiness. This method can be adopted for multiplication of planting materials which involve transportation costs.

LAND PREPARATION

The land is ploughed or dug to a depth of about 20 cm and harrowed to pulverize the soil. Mound method, ridge and furrow method, bed method and flat method are practiced in sweet potato cultivation in different localities. It is preferable to plant sweet potato on mounds in areas experiencing problems of drainage. In sloppy lands, ridge and furrow system is recommended for the control of soil erosion. In Vietnam, planting is done on beds formed at a width of 1-1.4 m and 0.4- to 0.5 m height (Ngoan 2006). Among different methods of land preparation, the highest root yield was realized when planted on mounds under Indian conditions (Ravindran and Mohankumar 1985). The higher yield recorded when planted on mounds is probably be due to better soil aeration permitted by mounds and less tendency for soil compaction. In Bangladesh, higher yields were reported with trench planting followed by ridge and flat method of planting in alluvial soils under irrigated conditions (Bhuiyan *et al.* 2006).

PLANTING

Sweet potato cuttings are normally planted in the soil with both ends exposed and the middle portion buried in the soil. Vines are also planted in an inclined position with half of its length buried in the soil. Sweet potato cuttings were also planted horizontally to the soil surface with 5 or 6 nodes. Horizontal planting resulted in higher transplant survival and better development of the root system than other methods though it is laborious (Nair 2000). In Orissa, India, farmers plant long size (50-75 cm) vines horizontally (Nedunchezhiyan *et al.* 2006). However, CTCRI, India has recommended to plant the cuttings in the soil with both the ends exposed and the middle portion buried (Nair 2006). According to Dayal and Sharma (1991), vertical planting resulted in higher marketable yield over horizontal planting in a trial conducted at New Delhi, India. In Uganda, planting of cuttings showed that there is neither advantage nor disadvantage in planting through the soil (horizontal) and leaving both ends protruding (Kaggwa *et al.* 2006). Planting of sweet potato vines at depth ranging from 2.5 to 10.0 cm when planted vertically did not have any significant influence on stand establishment and final root yield (Ravindran and Mohankumar 1985). In Cuba, best root yields were obtained when cuttings were planted at 7-10 cm depth (Morales 1981).

SPACING AND PLANT POPULATION

A closer spacing is generally recommended for sweet potato to achieve maximum root yield. A planting distance of 30-60 cm between rows and 15-20 cm between plants has given maximum yield in different parts of India. However, when sweet potato is planted on mounds, no specific spacing is followed and vines are planted on mounds by accommodating 3-6 slips per mounds. CTCRI (1987) in India has recommended a general spacing of 60 cm × 20 cm for sweet potato. By adopting the above spacing, about 83,000 cuttings are required to plant one ha of land. In Uganda, a plant population of 25,000 to 125,000 is suggested (Kaggwa *et al.* 2006). A significant reduction in yield was observed when the plant population was dropped to 12,000 ha^{-1} (Kaggwa *et al.* 2006). In Cameroon, sweet potato clones were grown at plant densities of 10,200 and 300,000 ha^{-1}, plant vigour and root number increases, and weevil infestation and root size decreases with increase in plant density (Woolfe 1992). In Bihar, India it was found that mixed culture of two sweet potato varieties, Cross-4 and RS-5 in alternate rows with 30 cm × 15 cm spacing recorded maximum root yields (Mishra *et al.* 1985). A closer spacing of 45 cm × 30 cm which produced highest root yield of sweet potato could be recommended for sweet potato cultivation under transitional tract of Karnataka, India (Patil *et al.* 1992).

In Korea, a plant spacing of 75 cm between rows and 20 cm within row accorded the highest yield/ha (Jeong *et al.* 1986). In Bangladesh, maximum root yield was obtained when vines were planted at a spacing of 60 cm × 45 cm with two vines/hill (Bhuiyan *et al.* 2006) and in alluvial soils, 60 cm × 30 cm spacing was optimum when planted on flat bed (Golder *et al.* 2007). Abdissa *et al.* (2011) reported that 20 cm × 60 cm between two consecutive plants and rows should be adopted for those farmers involved in sweet potato production in Central Rift Valley of Ethiopia. But for the variety Belella, 20 cm × 80 cm between plants and rows should be followed to come up with economical and dependable root yield.

PLUG TRANSPLANTING

Plug transplants are commercially used for horticultural crops and environmental control technology to achieve rapid and uniform growth of high quality transplants has progressed remarkably in recent decades. Production of sweet potato plug transplants using virus free stock plants in closed systems is followed in Korea. The plug transplants would be directly transplanted into the main fields. The use of the plug transplants has great potential because post transplanting stresses can be reduced and mechanical transplanters can be used. Therefore, high storage root yield and labour saving can be expected by using the plug transplants of sweet potato.

Multicell tray with cell volume of 55 ml is suitable for producing sweet potato plug plants in closed systems using both single node cuttings and shoot tip cuttings with one unfolded leaf. Higher efficiency of sweet potato cultivation can be achieved using the plug transplants because of the labour saving realized by quick production and mechanical transplanting by the transplanters and the high yield of storage roots at harvest (He *et al*. 2000).

MANURES AND FERTILIZERS

Sweet potato removes appreciable quantities of plant nutrients, hence incorporation of considerable amount of organic manure at the time of planting is recommended to maintain soil productivity. Application of manures has significant impact on growth and root yield of sweet potato (Salawu and Mukhtar 2008). Usually farm yard manure/ cow dung compost or green manure is used as organic manure for sweet potato (Kaggwa *et al*. 2006). Sweet potatoes grown in fertile soils generally do not receive dressings of organic manure while soils low in organic matter content have to be supplied with organic manures at 5 to 10 tonnes ha^{-1} to ensure proper development of storage root (Nedunchezhiyan and Reddy 2004). Application of green manure (legume) is found to be an alternative to farm yard manure (Reijintjes *et al*. 1992; Kaggwa *et al*. 2006). On unit nitrogen basis, farm yard manure, pig manure and poultry manure were equally effective (Nedunzhiyan 2001).

Various research results indicated that application of N increased the root yield (George and Mitra 2001; Satapathy *et al*. 2005). However, high amount of N application encourages vine growth rather than storage root development. A moderate dose of 50-75 kg N ha^{-1} is optimum for root production in sweet potato (Nair *et al*. 1996; Sebastiani *et al*. 2006; Biswal 2008). Higher levels of N sometimes depressed the root yield (Hartemink 2003). Conjunctive use of fertilizer N and any of the organic manures to supply 50% each of recommended N produced the maximum vine and storage root yield compared to other N management practices (Nedunchezhiyan and Reddy 2002). Inoculation of *Azospirillum* (free-living N_2- fixing biofertilizer) was found to increase storage root yield (Desmond and Hill 1990; Saikia and Borah 2007), quality (Nedunchezhiyan *et al*. 2004) and soil fertility status in sweet potato field (Nedunchezhiyan and Reddy 2004). *Azospirillum* replaces one-third N requirements and reduces cost of cultivation (Nedunchezhiyan and Reddy 2002; Saikia and Borah 2007).

Quality characters, apart from storage root yield of sweet potato, were found to be influenced by nitrogen application (Nedunchezhiyan and Ray 2010). Continuous use of fertilizer N may, in some situation, have detrimental effects on root quality. Therefore, use of organic source of N is essential to improve the quality characters. However, in the present day situation, per ha yield of starch, vitamin C, β-carotene, etc. are more important than percentage content. Nedunchezhiyan *et al*. (2003) noticed discernible variation in the quality characters due to different source of N and their combinations.

Sweet potato response to phosphorus (P) is very low. A dose of 25-50 kg P_2O_5 ha^{-1} is considered optimum for sweet potato (Mohanty *et al*. 2005; Akinrinde 2006; Sebastiani *et al*. 2006). The relative efficiency of rock phosphate as source of P to sweet potato was equal to single super phosphate in direct effect but superior to it in residual value (Kabeerathumma *et al*. 1986).

Potassium (K) is a major key element essential in the synthesis and translocation of carbohydrates from the tops to the roots (Byju and Nedunchezhiyan 2004). A moderate dose of 75-100 kg K_2O is 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 300 kg K_2O ha^{-1} (George *et al*. 2002). The quality characters like starch and protein content were found to increase with increased K levels (Biswal 2008).

AFTER CULTIVATION

Weeding and earthing up

Sweet potato is a quick growing shallow canopy crop, and it covers the soil quickly. It suppresses most of the weeds when grown closely by reducing availability of light (Ravindran *et al*. 2010) and physical interference (Tesdale and Mohler 1993). Allelopathic potential of sweet potato on certain weeds were also reported (Harrison and Peterson 1991; Adam 1992; Roy Chowdhury *et al*. 2003). However, weeding may become necessary particularly in the early stages of the crop growth, when grown for root yield with wider spacing. Earthing up of the soil also brings about weed control besides improving the physical condition of the soil. About 20-80% reduction in storage root yield was observed in sweet potato due to weed infestation at different stages of growth (CTCRI 1987; Nedunzhiyan *et al*. 1998). *Celosia argentia*, *Digitaria sanguinalis* and *Cleome viscosa* were the dominating weed community in upland sweet potato ecosystem (Nedunzhiyan 1996). Under irrigated lowland ecosystem, *Chloris gyana*, *Paspalam conjugatum*, *Dactylotenium aegptium*, *Panicum repens*, *Cyanodon dactylon*, *Cyperus rotundus*, *Amaranthus viridis*, *Crotolaria juncea*, *Trianthema portulacastrum* and *Desmodium* sp. were found to interfere in sweet potato cultivation (Roy Chowdhury *et al*. 2003). In sweet potato, the crop-weed competition set at early for water and nutrients due to initial slow growth of the crop (Nedunchezhiyan and Satapathy 2002). The critical period of crop weed competition is between 30 and 45 days after planting in India (Nedunzhiyan *et al*. 1998), between 14 and 28 days in Philippines (Talata *et al*. 1978) and from 21 to 63 days in West Indies (Kassasian and Seeyave 1969). To protect the crop from weeds, at least two weedings followed by earthing up have to be given between 15 and 30 and 35 and 60 days after planting (Nedunchezhiyan and Ray 2010).

Herbicides are also used to control weeds in sweet potato. Herbicides use in weed control was extensively studied in USA (Galze and Hall 1990). Application of isoproturon at 1 kg a.i. ha^{-1} as pre-emergence weedicide 2 days after planting (mixed with dry fine sand and broadcasting) followed by one hand weeding on 30 days after planting controlled the weed effectively (Nedunzhiyan 1996). A broader spectrum of weed control was observed when application of a mixture of metribuzin and alachlor (Coffey and Monks 1982; Liu *et al*. 1982) and chlorthal dimethyl and diphenamide (Biswas 1980) was followed. Herman *et al*. (1983) reported that application of alachlor at 3.4 or 6.7 kg ha^{-1} resulted in 88-100% control of weeds in sweet potato plots in North Carolina and most sweet potato samples contained less than 0.05 ppm of alachlor. However, severe reduction in sweet potato growth was observed due to application of diphenamid at 4.4 kg ha^{-1} and chloramben at 3.3 kg ha^{-1} (Monks *et al*. 1992), and bentazone at the rates above 1.1 kg ha^{-1} (Motsenbocker and Monaco 1991).

Mulching

Mulching is a common practice in rain fed ecosystem in small holder farming. Mulching conserves soil moisture and reduces soil temperature as well as augmenting rhizosphere microflora (Kundu *et al*. 2006). In Korea in the 1980s polyethylene film mulching method was developed for producing good quality sweet potatoes (Jeong 2000). As per the demand of sweet potatoes in Korea, sweet potato transplanting time was advanced from May-June to March-April and the harvesting time was advanced from September-October to June-August with mulching by modifying rhizosphere hydrothermal regimes (Jeong 2000). In Japan, black plastic film mulches are used for controlling weeds in high rainfall hilly regions, which also protected the hills from erosion (Yamakawa 1997). Mulched soil retained more moisture and enhanced mineral N (29-87%), P (1.4-12.6%) and K (16-36%) availability when applied for dry season sweet potato (Kundu *et al*. 2006).

Pruning

Sweet potato grows vigourously and produces large quantity of vines when temperature and rainfall are favourable at the cost of storage roots (Nedunchezhiyan and Byju 2005). Part of the vine, preferably the top portion, can be removed and used as leaf vegetable or forage or planting material (Satapathy *et al*. 2006). Higher root yields are not necessarily associated with greater foliage production (Nedunchezhiyan and Byju 2005). In sweet potato, root bulking commences about 4-6 weeks after planting (Pardales and Beemonte 1989; Nedunzhiyan 2001). Removal of 15 cm shoot tip of rainy season sweet potato crop at 60 days after planting did not affect the root yield at Bhubaneswar, India (Roy Chowdhury and Ravi 1990). In Nigeria root yield was found to decrease by 31-48% by removing shoot tips (for use as green vegetable) while removing whole shoots led to root yield decrease of 54-62% (Dahniya *et al*. 1985). Regardless of the time of topping a single topping did not reduce total number marketable total root yield and herbage yield. Total and marketable root yield decreased from 18.8 to 7.9 tonnes ha^{-1} with increase in the frequency of topping (Villamayar and Perez 1988).

IRRIGATION

Sweet potato vines are succulent and fragile and if sufficient moisture is not available in the soil immediately after planting it dries up. Hence, sufficient soil moisture at the time of planting is to be ensured for proper sprouting and establishment of vines. Sweet potato is mostly grown under rain fed conditions. Hence, planting is carried out on rainy day or immediately after rain. It is also grown in dry season under protective irrigation. Under such conditions, if sufficient moisture is not available after planting, irrigation need to be provided on alternate days initially for the first fortnight and thereafter once in 7-10 days. Trials conducted in the sweet potato growing areas have conclusively proved the beneficial effect of irrigation. Sweet potato required on an average of 2 mm of water per day in the early parts of the growing season and gradually increased to 5-6 mm of water/day prior to harvest (Gomes and Carr 2003).

Biswal (2008) found that when soil moisture was high or the soil was compacted sweet potato had luxuriant vegetative growth with little or no tuberization of root. Excessive irrigation should be avoided as poor aeration may cause poor storage root induction or development (Chua and Kays 1981).

In a survey conducted in 26 countries, drought was ranked as the most serious abiotic factor to depress the yield of sweet potato (Lin *et al*. 1983). Moisture stress during crop growth significantly affected the storage root yield (Ravi and Indira 1996). According to Varughese *et al*. (1987) irrigation at IW/CPE ratio of 1.2 with 50 mm water during dry months profoundly influenced the growth, root yield and net income as compared to irrigation at 0.8 and 0.4 ratios.

Indira and Kabeerathumma (1988) imposed water stress for 20 days to sweet potato grown in lysimeter during early growth phase (10-30 days), root development phase (30-50 DAP) and root maturity phase (75-90 DAP) and observed significant reduction in root yield for the stress induced during early growth phase. Stress induced during root development phase however slightly improved the yield while stress during root maturity phase resulted in a slight reduction in yield. Martin (1988) stated that sweet potato could not tolerate dry conditions at planting. According to Yassen and Thompson (1988) irrigation increased the number of root and total marketable yield.

Extended wet periods leading to water surplus reduced root yield and were frequently associated with luxuriant vegetative growth (Bourke 2005; Biswal 2008). The combined effect of a long wet period during root initiation and a drought during root bulking depressed the yield significantly.

According to Goswami *et al*. (1995), three irrigations at root initiation, early bulking and late bulking stages were most favourable for higher number of roots/plant, root bulking rate and dry matter content resulting in higher root yield (27.8 t ha^{-1}). Irrigation at full cumulative pan evaporation (CPE) during root initiation phase significantly enhanced the number of roots per plant and the yield of both total and marketable grade roots (Nair, *et al*. 1996). In a field experiment conducted at Bhubaneswar to study the water requirements of sweet potato under different moisture regimes based on IW/CPE ratio 1.0, 0.8, 0.6, 0.4 and 0.2 with irrigation depth of 3 cm the treatment with the maximum irrigation (IW/CPE=1.0) gave maximum root yield of 25.5 tonnes/ha (Roy Choudhury 1996). Irrigating the sweet potato field at IW: CPE of 0.6-0.8 in silt clay loam soils (Biswal 2008) and IW: CPE of 1.0 in sandy and sandy loam soils recorded higher root yield (Nair *et al*. 1996; Roy Chowdhury *et al*. 2001). It has been observed that irrigation would generally increase yields and improve the grade and quality of marketable roots.

PESTS AND DISEASES

Sweet potato storage root and vine are attacked by various nematodes and insect pests. *Meloidogyne* spp. (root-knot) and *Rotylenchulus reniformis* are the major known nematode pests of sweet potatoes in the tropics (Mohandas 2006). They attack the fibres as well as fleshy roots and reduce yield and quality. Also allow other pathogens to penetrate through the wounds. Nematodes can be controlled by applying neem cake 500 kg ha^{-1} in the last ploughing before ridge and furrow making. Sree Bhadra variety from India is found to be resistant to root knot nematode (Mohandas 2006).

Cylas formicarius Fab. (sweet potato weevil) is a major pest in most sweet potato growing countries (Ray and Ravi 2005). Larvae and adult feed on the roots, causing extensive damage both in field and storage in many parts of the world. The weevil can be effectively managed by following the integrated pest management (IPM) strategy developed by CIP (International Potato Centre, Peru) as well as by CTCRI, India. The IPM is as follows: (1) dip the vine cuttings in fenthion or fentrothion 0.05% solution for 10 min before planting, (2) re-ridge the crop two months after planting, (3) install synthetic sex pheromone traps at 1 trap 100 m^{-2} area to collect and kill the male weevils and (4) destroy the crop residues after harvest by burning. IPM practice reduced 50-60% weevil infested storage roots and increased more than 20% storage root yield (Sethi *et al*. 2003). In sweet potato weevil endemic area early harvest of roots is recommended to avoid the weevil damage (Mohanty *et al*. 2005).

Euscepes postfasciatus (Fairm.) (Scarabee), is a serious pest in the drier parts of South America, the Caribbean and the Pacific (Yasuda 1998). Larvae and adults feed on roots and vines of the sweet potato. The larvae produce narrow tunnels in the roots and like the sweet potato weevil cause the roots to produce bitter toxic terpenoid compounds making them inedible. The sweet potato vine borer, *Omphisa anastomosalis* has been reported in India, Malaysia and China, where it is considered to be as destructive as the sweet potato weevil (Rajamma and Premkumar 1994). Wild pigs, rats and other herbivores cause damage and loss in some countries (Ray and Ravi 2005).

In sweet potato, diseases are observed in field conditions but the severity is less. Fungal diseases are not normally very serious in the tropics in field conditions (Woolfe 1992). Stem rot, *Fusarium oxysporum* Schlect. F.sp. *batatas* is destructive in the United States (Woolfe 1992). Virus diseases may attack the root or the leaves. They include internal cork disease and mosaic virus. More than 12 virus diseases are identified; among them *Sweet potato feathery mottle virus* (SPFMV) is prominent. Viruses are important in parts of East and West Africa but not in the rest of the world. The virus diseases can be managed through field tolerant varieties, use of virus free planting materials as well as meristem cultured plants (Prasanth *et al.* 2006).

HARVESTING

In grain crops, where single harvesting is followed immediately after maturity; otherwise grains get shattered or spoiled if retained few more days in the field. Whereas in sweet potato single harvesting and double harvesting (progressive harvesting) are practiced as root yields are not affected by delaying few days after maturity. Staggered harvesting facilitates marketing and realizing reasonable price for the produce. However, varieties and environment play a significant role in deciding the time of harvest in sweet potato. In Papua New Guinea, non-marketable roots constituted a greater proportion of the total roots with progressive harvesting compared to single harvesting although the yield of marketable roots (100 g above) were 2-3.4 t ha^{-1} higher (Bourke 2006). A trial on double harvesting done between 90 and 150 days at intervals 15-60 days resulted in significantly higher root yield when harvested at 90 and 150 DAP as compared to single harvesting at 150 days under north Bihar conditions (Mishra *et al.* 1985).

In North India, sweet potato takes about 5-6 months for maturity while it matures within 4 months in the South. Within limits, the yield ha^{-1} will increase if the crop remains in the ground longer but the root become less palatable and weevil damage and rots become more noticeable with age. The maturity of the roots can be determined by cutting the roots. The cut surface of the immature roots gives a dark greenish colour, while in mature roots the cut ends dry clearly. The field is irrigated 2-3 days prior to harvesting to facilitate easy lifting of the roots. After removing the vines the roots are dug out without causing injury (Nair 2000). In the tropics, sweet potato harvesting is usually by manual labour.

YIELD

The storage root yield varies with the variety, season of planting, soil conditions and fertility. In general the storage root yield varies from 20-25 t ha^{-1} for promising varieties with improved crop management practices (Nair 2000). Nedunchezhiyan *et al.* (2008) reported that in sandy loam soils sweet potato recorded tuber yield of 13.1 t ha^{-1} under rainfed conditions, whereas Nath *et al.* (2006) reported 26 t ha^{-1} tuber yield under irrigated conditions. Nedunchezhiyan and Byju (2005) reported that the variety Samrat recorded 7.1 and 18.7 t ha^{-1} tuber yield in *kharif* and *rabi* season in laterite soils of Orissa. In alfisols the variety Kishan Registered 13.4 t ha^{-1} tuber yield in Bhubaneswar, India (Nedunchezhiyan *et al.* 2010a). The orange fleshed sweet potato variety ST14 recorded 12.6 t ha^{-1} tuber yield in Bhubaneswar, India (Nedunchezhiyan *et al.* 2010b).

PROBLEMS, CHALLENGES AND FUTURE PERSPECTIVES

The agronomical advancement in sweet potato has increased tuber yield 10-30% in many of the sweet potato growing countries. In the era of climate change and soil degradation, generating eco-friendly, site specific sustainable agro-techniques through well designed research is essential to improve sweet potato productivity. Regions, where sweet potato is already staple food has great potential to improve the agro-techniques so that cheap food continues to be readily available to vast number of people. Strategic and sustainable investments into sweet potato agronomical research will make a major contribution to the food security and livelihood improvement of the poor people.

REFERENCES

Abdissa T, Chali A, Tolessa K, Tadese F, Awas G (2011) Yield and yield components of sweet potato as influenced by plant density in Adami Tulu Jido Kombolcha district, Central Rift Valley of Ethiopia. *American Journal of Experimental Agriculture* **1 (2)**, 40-48

Adam S (1992) Sweet potato can ward off weeds. *Agricultural Research* **November**, 22

Akinrinde EA (2006) Phosphorus fertilization effect on dry matter production and biomass partitioning in sweet potato (*Ipomoea batatas*) grown on an acidic loamy-sand Alfisol. *Journal of Food Agriculture Environment* **4 (3-4)**, 99-104

ARS (2008) Sweet potato out-yields corn in ethanol production study. *Agricultural Research Service Report*, USDA. Available online: http://www.ars.usda.gov/is/pr/2008/080820.html

Badillo-Felieno J (1976) Effect of planting season on the yield of sweet potato cultivars. *Journal of Agricultural University Puerto Rico* **60 (2)**, 163-171

Bassa IA, Francis FJ (1987) Stability of anthocyanins from sweet potatoes in a model beverage. *Journal of Food Science* **52**, 1753-1754

Bhuiyan MKR, Hossain M, Golder PC, Alam MS, Attaluri S (2009) Performance of BARI SP-8 and BARI SP-9: The newly released high yielding sweet potato varieties from Bangladesh. *Journal of Root Crops* **35 (2)**, 148-152

Bhuiyan MKR, Hossain M, Hussain MAE, Attaluri S (2006) Research and development activities of sweet potato in Bangaladesh. In: *14th Triennial Symposium of International Society of Tropical Root Crops*, 20-26 November 2006, Central Tuber Crops Research Institute, Thiruvananthapuram, India, 17 pp

Biswal S (2008) Response of sweet potato (*Ipomoea batatas* L.) to irrigation and fertility levels. PhD thesis, Orissa Agricultural University and Technology, Bhubaneswar, India

Biswas PK (1980) Herbicide selectivity for sweet potatoes. In: *Proceedings of 7th Conference of Asian Pacific Weed Science Society*, Sydney, pp 75-77

Bourke RM (2005) Recent research on sweet potato and cassava in Papua New Guinea. In: *Concise Papers of the 2nd International Symposium on Sweet Potato and Cassava*, 14-17 June 2005, Kuala Lumpur, Malaysia, pp 125-126

Bourke RM (2006) Differences between calendar time and plant time in sweet potato: a potential source of significant experimental error. In: *14th Triennial Symposium of International Society of Tropical Root Crops*, 20-26 November 2006, Central Tuber Crops Research Institute, Thiruvananthapuram, India, pp 253

Bovell-Benzamin A (2007) Sweet potato: A review of its past, present and future role in human nutrition. *Advances in Food and Nutrition Research* **52**, 1-59

Byju G, Nedunchezhiyan M (2004) Potassium: A key nutrient for higher tropical tuber crops production. *Fertilizer News* **49 (3)**, 39-44

Cho J, Kang JS, Long PH, Jing J, Back Y, Chung KS (2003) Antioxidant and memory enhancing effects of purple sweet potato anthocyanin and cordyceps mushroom extract. *Archives of Pharmacal Research* **26**, 821-825

Choudhary SH, Ahmed SU, Sharafuddin AFM (1986) Effect of number of nodes in different types of vine cuttings on the growth and yield of sweet potatoes. *Bangladesh Horticulture* **14 (1)**, 29-33

Chua LK, Kays SJ (1981) Effect of soil oxygen concentration on sweet potato storage root induction and or development. *HortScience* **16**, 17-73

Coffey DL, Monks DW (1982) The effect of formulations and mode of application of metribuzin for sweet potatoes. In: *Proceedings of 35th Annual Meeting of South Weed Science Society*, USA

CTCRI (1987) Cultural practices of sweet potato. *Extension Bulletin*, Central Tuber Crops Research Institute, Thiruvananthapuram, 8 pp

CTCRI (1999) Crops Varieties recommended for release/cultivation under AICRP on Tuber Crops (other than potato). *Technical Bulletin Series 26*, Central Tuber Crops Research Institute, Thiruvananthapuram, 59 pp

CTCRI (2003) *Annual Report* 2002-2003. Central Tuber Crops Research Institute, Thiruvananthapuram, 92 pp

CTCRI (2006) Tuber crop varieties released the Central Tuber Crops Research Institute. *Technical Bulletin Series 24* Revised and Reprinted, Central Tuber Crops Research Institute, Thiruvananthapuram, 64 pp

Cuevas Montilla E, Hillebrand S, Winterhalter P (2011) Anthocyanins in purple sweet potato (*Ipomoea batatas* L.) varieties. *Fruit, Vegetable and Cereal Science and Biotechnology* **5 (Special Issue 2)**, 19-24

Dahniya MT, Hahn SK, Oputa CO (1985) Effect of shoot removal on shoot and root yields of sweet potato. *Experimental Agriculture* **21 (2)**, 183-186

Dasgupta M, Kole PC, Sahoo MR, Mukherjee A (2006) Screening of sweet potato genotypes for salinity stress. In: *14th Triennial Symposium of International Society of Tropical Root Crops*, Central Tuber Crops Research Institute, Thiruvananthapuram, India, pp 166-167

Dayal TR, Sharma RP (1991) Effect of fertilizer, spacing and methods of planting in sweet potato. *Journal of Root Crops ISRC National Symposium 1990 Special*, pp 36-39

Desmond GM, Hill WA (1990) Sweet potato growth and nitrogen content following nitrogen application and inoculation with *Azospirillum*. *HortScience* **25 (7)**, 758-759

Duvernay WH (2008) Conversion of industrial sweet potatoes for the production of ethanol. MS Thesis, North Carolina State University

Fan G, Han Y, Gu Z, Chen D (2008) Optimizing conditions for anthocyanins extracted from purple sweet potato using response surface methodology (RSM). *LWT Food Science Technol*ogy **41**, 155-160

Galze NC, Hall MR (1990) Cultivation and herbicides for weed control in sweet potato (*Ipomoea batatas*). *Weed Technology* **4**, 518-523

George J, Mitra BN (2001) Integrated nutrient management in sweet potato production. In: *International Symposium on Root and Tuber Crops*, 19-22 January 2001, Central Tuber Crops Research Institute, Thiruvananthapuram, pp 66-69

George MS, Lu G, Zhou W (2002) Genotypic variations for potassium uptake and utilization efficiency in sweet potato (*Ipomoea batatas* L.). *Field Crops Research* **77**, 7-15

Giusti MM, Wrolstad RE (2003) Acylated anthocyanins from edible sources and their applications in food systems. *Biochemical Engineering Journal* **14**, 217-225

Golder PC, Hossain M, Bhuiyan MKR, Ilangantileke S, Attaluri S (2007) Performance of BARI SP-6 and BARI SP-7, the newly released high yielding sweet potato varieties from Bangladesh. *Journal of Root Crops* **33 (1)**, 16-19

Golder PC, Hossain M, Bhuiyan MKR, Ilangantileke S, Attaluri S (2007) Performance of 'BARI SP-6' and 'BARI SP -7', the newly released high yielding sweet potato varieties from Bangladesh. *Journal of Root Crops* **33 (1)**, 16-19

Gomes F, Carr MKV (2003) Effects of water availability and vine harvesting frequency on the productivity of sweet potato in southern Mozambique. II. Crop water use. *Experimental Agriculture* **39**, 39-54

Goswami SB, Sen H, Jama PK (1995) Rootization and yield potential of sweet potato cultivars as influenced by water management practices. *Journal of Root Crops* **21 (2)**, 77-81

Guoquan L, George MS (2000) Genotypic variation of sweet potato (Ipomoea batatas L. (Lam)) under low potassium stress. In: *Potential of Root Crops for Food and Industrial Resources*, *Proceedings of 12th Symposium of International Society of Tropical Root Crops*, September 10-16, 2000. Tsukuba, Japan, pp 166-172

Hammett HL (1983) Effects of holding sweet potato cuttings. *Lousiana Agriculture* **26 (2)**, 6-7

Harrison HF Jr., Peterson JK (1991) Evidence that sweet potato (*Ipomoea batatas*) is allelopathic to yellow nutsedge (*Cyperus esculentus*). *Weed Science* **39**, 308-312

Hartemink AE (2003) Integrated nutrient management research with sweet potato in Papua New Guinea. *Outlook on Agriculture* **32 (3)**, 173-182

He D, Chun C, Lok Y, Kozai T (2000) Growth of sweet potato plug transplants in a closed system as affected by cell volume and type of cutting. In: *Potential of root crops for food and industrial resources*, *Proceedings of 12th Symposium of International Society of Tropical Root Crops*, September 10-16, 2000. Tsukuba, Japan, pp 328-331

Herman ND, Monaco TJ, Sheets TJ (1983) Weed control with alachlor and residues in sweet potato and soil. *Weed Science* **31**, 567-571

Indira P, Kabeerathumma S (1988) Physiological response of sweet potato under water stress. I. Effect of water stress during the different phases of tuberization. *Journal of Root Crops* **14 (2)**, 37-40

Jeong BC (2000) Current role of sweet potato and its earlier harvesting by improved PE film mulch cultivation in Korea. In: *Potential of Root Crops for Food and Industrial Resources*, *Proceedings of 12th Symposium of International Society of Tropical Root Crops*, September 10-16, 2000. Tsukuba, Japan, pp 350

Jeong BC, Oh SK, Park KY, Rho SP (1986) Effects of fertilizer amount planting density and date on growth and root yields in planting sprouted root pieces of sweet potato. Research report of the rural development administration, crops. *Korea Republic* **28 (2)**, 184-188

John KS, Shalini Pillai P, Nair GM, Chithra VG (2001) Critical concentration as a reflect of potassium requirement of sweet potato in an acid ultisol. *Journal of Root Crops* **27 (1)**, 223-228

Jusuf M, Hilman Y, Setiawan A (2005) Selection of sweet potato clones with high anthocyanin in Indonesia. In: *Concise papers of the 2nd International Symposium on Sweet potato and Cassava*, held 14-17 June 2005, Kuala Lumpur, Malaysia, pp 40-41

Kabeerathumma S, Mohankumar B, Potty VP (1986) Efficacy of rock phosphate as a source of phosphorus to sweet potato. *Journal of Indian Society of Soil Science* **34 (4)**, 866-869

Kaggwa R, Gibson R, Tenywa JS, Osiru DSO, Potts MJ (2006) Incorporation of pigeon pea into sweet potato cropping systems to increase productivity and sustainability in dry land areas. In: *14th Triennial Symposium of International Society of Tropical Root Crops*, 20-26 November 2006, Central Tuber Crops Research Institute, Thiruvananthapuram, India, pp 186

Kassasian L, Seeyave J (1969) Critical periods for weed competition. *PANS* **15**, 208-212

Kundu DK, Singh R, Roy Chowdhury S (2006) Effect of rice straw mulch and irrigation on nutrient availability in soil and tuber yield of sweet potato (*Ipomoea batatas* L.) in coastal Orissa. In: Naskar SK, Nedunchezhiyan M, Rajasekhara Rao K, Sivakumar PS, Ray RC, Misra RS, Mukherjee A (Eds) *Root and Tuber Crops: in Nutrition*, *Food Security and Sustainable Environment*, Regional Centre of Central Tuber Crops Research Institute, Bhubaneswar, pp 117-122

Lin SSM, Peet CC, Chen D, Hsiao-Leng L (1983) Breeding goals for sweet potation Asia and the Pacific a survey on sweet potato production and utilization. In: *Breeding New Sweet potatoes for the Tropics*, *Proceedings of American Society of Horticultural Science for Tropical Region*, 27 part B, pp 42-60

Liu LC, Acevedo-Borrero E, Ortiz FF (1982) Herbicide evaluation for sweet potatoes. *Journal of Agricultural University Puerto Rico* **66**, 254-260

Martin FW (1988) Planting dates and morphology and growth of four sweet potato clones in Puerto Rico. *Journal of Agricultural University Puerto Rico* **72 (3)**, 437-444

Mishra S, Mishra SS, Ray PK, Singh SJ (1985) Comparison between single and double harvesting of sweet potato. In: *Proceedings of National Symposium on Production and Utilization of Tropical Root Crops*, Nov. 27-28, Trivandrum, India pp 135-137

Mohandas C (2006) Nematode problems in tuber crops. In: *14th Triennial Symposium of International Society of Tropical Root Crops*, 20-26 November 2006, Central Tuber Crops Research Institute, Thiruvananthapuram, India, pp 150-151

Mohanty AK, Sethi K, Samal S, Naskar SK, Nedunchezhiyan M (2005) Relationship of optimum stage of harvest with weevil incidence in sweet potato under different agroclimatic conditions of Orissa. *The Orissa Journal of Horticulture* **33 (1)**, 43-45

Monday T (2009) Industrial sweet potato a viable biofuel crop for Alabama. MSc thesis 2009-07-02, Aub University, Alabama

Monks DW, Kalmowltz KE, Monaco TJ (1992) Influence of herbicides on sweet potato (*Ipomoea batatas*) plant production. *Weed Technology* **6**, 136-138

Moorthy SN, Shanavas S (2010) Sweet potato starch. In: Ray RC, Tomlins KI (Eds) *Sweet Potato: Post Harvest Aspects in Food*, Nova Science Publishers Inc., NY, pp 91-116

Morales (1981) Effect of planting depths on the sweet potato clone, CENSA, 74-228. *Ciencia Tecnica en la Agricultura Viandan Hortalizas y Granos* **4 (2)**, 47-53

Motsenbocker CE, Monaco TJ (1991) Sweet potatoes (*Ipomoea batatas*) differ in response to bentazone. *Weed Technology* **5**, 345-350

Mukherjee A, Naskar SK, Edison S, Dasgupta M (2006) Response of orange flesh sweet potato genotypes to salinity stress. In: *14th Triennial Symposium of International Society of Tropical Root Crops*, 20-26 November 2006, Central Tuber Crops Research Institute, Thiruvananthapuram, India, pp 151-152

Mukhopathyay SK, Sen H, Hana PK (1990) Effect of planting materials on growth and yield of sweet potato. *Journal of Root Crops* **16 (2)**, 119-122

Nair GM (2000) Cultural and manurial requirements of sweet potato. In: Mohankumar CR, Nair GM, James George, Ravindran CS, Ravi V (Eds) *Production Technology of Tuber Crops*, Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, India, pp 44-64

Nair GM (2006) Agro-techniques and planting material production in sweet potato. In: Byju G (Ed) *Quality Planting Material Production in Tropical Tuber Crops*, Central Tuber Crops Research Institute, Thiruvananthapuram, India, pp 55-58

Nair GM, Nair VM, Sreedharan C (1996) .Response of sweet potato to phasic stress irrigation in summer rice fallows. *Journal of Root Crops* **22 (1)**, 45-49

Narin P, Reungmaneepaitoon S (2005) Breeding of sweet potato for health-promoting attributes in Thailand. In: *Concise Papers of the Second International Symposium on Sweet Potato and Cassava*, held 14-17 June 2005, Kuala Lumpur, Malaysia, pp 69-70

Naskar SK, Gupta JJ, Nedunchezhiyan M, Bardoli RK (2008) Evaluation of sweet potato tubers in pig ration. *Journal of Root Crops* **34 (1)**, 50-53

Nath R, Kundu CK, Majumder A, Gunri S, Chattopadhyay A, Sen H (2006) Productivity of sweet potato as influenced by cultivar, season and staggered harvesting in laterite ecosystem of West Bengal. In: *14th Triennial Symposium of International Society of Tropical Root Crops*, 20-26 November 2006, Central Tuber Crops Research Institute, Thiruvananthapuram, India, pp 213

Nawale RN, Salvi MJ (1983) Effects of season on yield of sweet potato. *Journal of Root Crops* **9**, 55-58

Nayar GG, Naskar SK (1994) Varietal improvement in sweet potato. In: Chadha KL, Nayar GG (Eds) *Advances in Horticulture: Tuber Crops* (Vol 8), Malhotra Publishing House, New Delhi, India, pp 101-112

Nedunchezhiyan M, Byju G (2005) Effect of planting season on growth and yield of sweet potato (*Ipomoea batatas* L.) varieties. *Journal of Root Crops* **31 (2)**, 111-114

Nedunchezhiyan M, Byju G, Dash SN (2010b) Effects of organic production of orange fleshed sweet potato (*Ipomoea batatas* L.) on root yield, quality and soil biological health. *International Research Journal of Plant Science* **1 (6)**, 136-143

Nedunchezhiyan M, Byju G, Naskar SK (2007) Sweet potato (*Ipomoea batatas* L.) as an intercrop in a coconut plantation: Growth, yield and quality. *Journal of Root Crops* **33 (1)**, 26-29

Nedunchezhiyan M, Naskar SK, Byju G (2008) Performance of sweet potato (*Ipomea batatas*) varieties under shaded and open field conditions. *Indian Journal of Agricultural Sciences* **78 (11)**, 974-977

Nedunchezhiyan M, Rajasekhara Rao K, Laxminarayana K, Satapathy BS

(2010a) Effect of strip intercropping involving sweet potato (*Ipomoea batatas* L.) on soil moisture conservation, weevil infestation and crop productivity. *Journal of Root Crops* **36 (1)**, 53-58

Nedunchezhiyan M, Ray RC (2010) Sweet potato growth, development production and utilization: overview. In: Ray RC, Tomlins KI (Eds) *Sweet Potato: Post Harvest Aspects in Food*, Nova Science Publishers Inc., New York, pp 1-26

Nedunchezhiyan M, Reddy DS (2002) Nitrogen management in sweet potato (*Ipomoea batatas* L.) under rainfed conditions. *Indian Journal of Agronomy* **47 (3)**, 449-454

Nedunchezhiyan M, Reddy DS (2004) Growth, yield and soil productivity as influenced by integrated nutrient management in rainfed sweet potato. *Journal of Root Crops* **30 (1)**, 41-45

Nedunchezhiyan M, Reddy DS (2006) Effect of time of planting and varieties on growth and yield of sweet potato (*Ipomoea batatas* L.) under rainfed conditions. In: Naskar SK, Nedunchezhiyan M, Rajasekhara Rao K, Sivakumar PS, Ray RC, Misra RS, Mukherjee A (Eds) *Root and Tuber Crops: in Nutrition, Food Security and Sustainable Environment*, Regional Centre of Central Tuber Crops Research Institute, Bhubaneswar, India, pp 123-127

Nedunchezhiyan M, Reddy DS, Ravi A (2000) Effect of sweet potato vine meal on the digestibility of organic nutrients in pigs. *Journal of Root Crops* **26 (2)**, 23-25

Nedunchezhiyan M, Reddy DS, Suryaprakasa Rao J (2004) Characteristics of dry matter production and partitioning in sweet potato. In: *Proceedings of National Seminar on Physiological Interventions for Improved Crop Productivity and Quality: Opportunities and Constraints*, December 12-14, 2003, Sri Venkateswara University, Tirupati, India, pp 110-115

Nedunchezhiyan M, Satapathy BS (2002) A note on the effect of weed management practices on nutrient uptake of weeds in sweet potato. *The Orissa Journal of Horticulture* **30 (2)**, 110-112

Nedunchezhiyan M, Sivakumar PS, Naskar SK, Misra RS (2006) Sweet potato: A suitable crop for rice based cropping system. In: Naskar SK, Nedunchezhiyan M, Rajasekhara Rao K, Sivakumar PS, Ray RC, Misra RS, Mukherjee A (Eds) *Root and Tuber Crops: in Nutrition*, *Food Security and Sustainable Environment*, Regional Centre of Central Tuber Crops Research Institute, Bhubaneswar, pp 135-138

Nedunchezhiyan M, Srinivasulu Reddy D, Haribabu K (2003) Nitrogen management practices on quality characters of sweet potato (*Ipomoea batatas* L. Lam). *Journal of Root Crops* **29 (2)**, 69-72

Nedunzhiyan M (1996) Ecological studies on weed flora associated with sweet potato. *The Orissa Journal of Horticulture* **24**, 69-73

Nedunzhiyan M (2001) Studies on time of planting, genotypes and integrated nitrogen management for rainfed sweet potato (*Ipomoea batatas* L.). PhD thesis, Acharya N.G. Ranga Agricultural University, Hyderabad, India, 359 pp

Nedunzhiyan M, Varma SP, Ray RC (1998) Estimation of critical period of crop-weed competition in sweet potato (*Ipomoea batatas* L.). *Advances in Horticultural Science* **12**, 101-104

Ngoan TN (2006) Status of root crops production, utilization and marketing in Vietnam. In: *14th Triennial Symposium of International Society of Tropical Root Crops*, 20-26 November 2006, Central Tuber Crops Research Institute, Thiruvananthapuram, India, 9 pp

Njualem DK, Leke WN, Yuh RN, Koi JT, Ngeh MN (2005) Status of sweet potato (*Ipomoea batatas* (L.) Lam.) production, research and utilization in Cameroon. In: *Concise Papers of the 2nd International Symposium on Sweet Potato and Cassava*, 14-17 June 2005, Kuala Lumpur, Malaysia, pp 141-142

Nyiawung KZ, Mortley DG, Issah A, Bonsi CK, Hill WA, Vaughan BT (2010) Evaluation of ten sweet potato cultivars as potential feedstock for biofuel production. *Journal of Root Crops* **36 (2)**, 242-249

Pardales JR Jr., Beemonte DV Jr. (1989) Comparative patterns of dry matter production in bushy and spreading sweet potato cultivars. *Experimental Agriculture* **25 (2)**, 243-246

Patil YB, Patil AA, Madalagei BB, Patil VS (1992) Effect of levels of N and K and inter row spacing on growth and yield of sweet potato. *Journal of Root Crops* **18 (1)**, 58-61

Philpott M, Gould KS, Lim C, Ferguson LR (2004) *In situ* and *in vitro* antioxidant activity of sweet potato anthocyanins. *Journal of Agricultural and Food Chemistry* **52**, 1511-1513

Prasanth G, Hegde V, Makeshkumar T, Jeeva ML, Edison S (2006) Development of diagnostics for sweet potato feathery mottle virus. In: *14th Triennial Symposium of International Society of Tropical Root Crops*, 20-26 November 2006, Central Tuber Crops Research Institute, Thiruvananthapuram, India, 145 pp

Rajamma P, Premkumar T (1994) Pests of sweet potato. In: Chadha KL, Nayar GG (Eds) *Advances in Horticulture: Tuber Crops* (Vol 8), Malhotra Publishing House, New Delhi, India, pp 457-484

Ravi V, Indira P (1996) Anatomical studies on tuberization in sweet potato under water deficit stress and stress free conditions. *Journal of Root Crops* **22**, 105-111

Ravindran CS, Mohankumar CR (1985) Effect of method of land preparation and depth of planting on the yield of sweet potato. In: *Proceedings of National Symposiump on Production and Utilization of Tropical Tuber Crops*, November 27-28, Central Tuber Crops Research Institute ,Trivandrum, India, pp 129-133

Ravindran CS, Mohankumar CR (1989) Effect of storage life of vines with and without leaves on the establishment and root yield of sweet potato. *Journal of Root Crops* **15 (2)**, 145-146

Ravindran CS, Ravi V, Nedunchezhiyan M, George J, Naskar SK (2010) Weed management in tropical tuber crops: An overview. *Journal of Root Crops* **36 (2)**, 119-131

Ray PK, Mishra S, Mishra SS (1983) Sweet potato productivity as affected by recurrent use of vine as planting material. *South Indian Horticulture* **31 (6)**, 280-283

Ray RC, Ravi V (2005) Post harvest spoilage of sweet potato and its control measures. *Critical Review of Food Science and Nutrition* **35**, 623-644

Reijintjes C, Harverkort B, Water-Bayer A (1992) *Farming for the Future. An Introduction to Low External Input And Sustainable Agriculture (ILEIA)*, MacMillan Press, London

Rice-Evans C, Packer I (1998) *Flavonoids in Health and Disease*, Marcel Dekker, New York, 504 pp

Rodgers JA, Bomford MK, Geier BA, Silvernail AF (2007) *Evaluation of Alternative Bioethanol Feedstock Crops*, Kentucky Academy of Science, Louisville, KY USA

Roy Choudhury S (1996) Effect of different irrigation treatments on water requirements in sweet potato. *Journal of Root Crops* **22 (1)**, 50-53

Roy Choudhury S, Ravi V (1990) Effect of clipping of vines on the biomass yield in sweet potato. *Journal of Root Crops* **16 (1)**, 4-7

Roy Chowdhury S, Antony E, Singh R, Kar G, Verma HN (2001) Source-sink relationship in sweet potato under different irrigation regimes. *Journal of Root Crops* **27 (1)**, 164-168

Roy Chowdhury S., Kannan K, Verma HN (2003) Crop interference and weed growth in sweet potato (*Ipomoea batatas* L.) field under different irrigation regimes. *Journal of Root Crops* **29**, 1-7

Saikia J, Borah P (2007) *Azospirillum* biofertilizer in sweet potato: growth, yield and economics. *Journal of Root Crops* **33 (1)**, 38-42

Sajjapongse A (1989) The effect of climatic factors on the yield of sweet potato. *IBSRAM Newsletter* **5 (13)**, 7

Sakamoto S, Marumine S, Ide Y, Yamakawa O (1987) 'Benihayato': A new sweet potato cultivar registered. *Bulletin National Agricultural Research Centre Kyushu Okinawa Region* **24**, 255-277

Salawu IS, Mukhtar AA (2008) Reducing the dimension of growth and yield characters of sweet potato (*Ipomoea batatas* L.) varieties as affected by varying rates of organic and inorganic fertilizer. *Asian Journal of Agricultural Research* **2 (1)**, 41-44

Sanchez VEE, Morales TA, Lopez ZYM (1985) The influence of stem cutting length on root yield of sweet potato clone, CEMSACENSA, 74-228. *Ciencia y Tecnica en la Agricultura Viandas Tropicales* **5 (1)**, 49-68

Santa-Maria MC, Yencho CG, Thompson, WF, Kelly R, Sosinski B (2006) Genetic engineering of sweet potato for endogenous starch bioprocessing. *American Society of Plant Biology*. Available online: http://abstracts.aspb.org/pb2006/public/P46/P46020.html

Satapathy MR, Sen H, Chattopadhyay A, Mohapatra BK (2005) Dry matter accumulation, growth rate and yield of sweet potato cultivators are influenced by nitrogen and cutting management. *Journal of Root Crops* **31 (1)**, 129-132

Satapathy MR, Sen H, Chattopadhyay A, Mohapatra BK (2006) Response of sweet potato cultivars to different cutting management practices. *Journal of Root Crops* **32 (1)**, 94-97

Schultheis JR, Jester W (2000) Nitrogen fertilizer management in Beauregard. In: *Potential of Root Crops for Food and Industrial Resources*, *Proceedings of 12th Symposium of International Society of Tropical Root Crops*, September 10-16, 2000. Tsukuba, Japan, pp 188-192

Sebastiani SK, Mgonja A, Urio F, Ndondi T (2006) Response of sweet potato to application of nitrogen and phosphorus fertilizer, agronomic and economic benefits in the Northern highlands of Tanzania. In: *14th Triennial Symposium of International Society of Tropical Root Crops*, 20-26 November 2006, Central Tuber Crops research Institute, Thiruvananthapuram, India, 205 pp

Sethi K, Mohanty AK, Naskar SK, Nedunchezhiyan M (2003) Efficacy of IPM technology over farmers/traditional practices in management of sweet potato weevil (SPW) in tribal areas of Orissa. *The Orissa Journal of Horticulture* **31 (2)**, 65-68

Siddique MA, Rabbani MG, Azam MGN (1988) Effects of plant spacing and number of vines planted per hill on the yield of sweet potato (*Ipomoea batatas* Poir). *Bangladesh Journal of Agriculture* **13 (1)**, 1-9

Talata RL, Mariscal AM, Secreto AC (1978) Critical periods for weed control in sweet potatoes. *Philippines Journal of Weed Science* **5**, 1-6

Tan SL (2000) Sweet potato production on marginal soils in Malaysia. In: *Potential of Root Crops for Food and Industrial Resources*, *Proceedings of 12th Symposium of International Society of Tropical Root Crops*, September 10-16, 2000, Tsukuba, Japan, pp 197-201

Terahara N, Konczak I, Ono H, Yoshimoto M, Yamakawa O (2004) Characteristics of acylated anthocyanin in callus induced from storage root of purple-fleshed sweet potato, *Ipomoea batatas* L. *Journal of Biomedical and Biotechnology* **5**, 279-286

Tesdale JR, Mohler CL (1993) Light transmittance, soil temperature and soil moisture under residue of hairy vetch and rye. *Agronomy Journal* **85**, 673-

680

Varughese K, Mathew J, Pillai GR, Santhakumari G (1987) Effects of irrigation on sweet potato under graded doses of nitrogen and potash. *Journal of Root Crops* **13**, 25-28

Villamayor FG Jr., Perez RD (1988) Effect of time and frequency of topping on storage root and cutting production. *Annals of Tropical Research* **10 (1)**, 26-36

Vimala B, Thushara R, Nambisan B, Sreekumar J (2006) Evaluation of orange fleshed sweet potatoes for higher yield and carotene content. In: *14th Triennial Symposium of International Society of Tropical Root Crops*, 20-26 November 2006, Central Tuber Crops Research Institute, Thiruvananthapuram, India, 55 pp

Woolfe JA (1992) *Sweet Potato: An Untapped Food Resource*, Cambridge University Press, Cambridge, 643 pp

Wright PJ, Lewthwaite SL, Triggs CM, Broadhurst PG (2003) Laboratory evaluation of sweet potato (*Ipomoea batatas*) resistance to sclerotinia rot. *New Zealand Journal of Crop and Horticultural Science* **31 (1)**, 33-39

Yamakawa O (1997) Development of new cultivation and utilization system for sweet potato toward the 21st century. In: *Proceedings of International Workshop on Sweet potato Production System toward the 21st Century*, December 9-10, 1997, Miyakonojo, Miyazaki, Japan, pp 1-8

Yamakawa O (2000) New cultivation and utilization system for sweet potato in Japan. In: *Potential of Root Crops for Food and Industrial Resources*, *Proceedings of 12th Symposium of International Society of Tropical Root Crops*, September 10-16, 2000. Tsukuba, Japan, pp 17-20

Yamakawa O, Yoshinaga M, Hidaka M, Kumagai T, Komaki K (1997) Ayamurasaki: A new sweet potato cultivar. *Bulletin of Kyushu National Agricultural Experiment Station* **31**, 1-22

Yassen AA, Thompson PG (1988) The effect of cultivar plant population, density and irrigation on yield and quality of sweet potato. *HortScience* **23 (5)**, 825-828

Yasuda K (1998) Integrated control of sweet potato weevils *Euscepes postfasciatus* and *Cylas formicarius* (Coleoptera: Curculionidae). In: *Proceedings of International Workshop on Sweet potato Production System toward the 21st Century*, December 9-10, 1997, Miyakonojo, Miyazaki, Japan, pp 317-322

Yi-Shin C, Lee H, Lo S (2000) Sweet potato production and research prospects in Taiwan. In: *Potential of Root Crops for Food and Industrial Resources*, *Proceedings of 12th Symposium of International Society of Tropical Root Crops*, September 10-16, 2000. Tsukuba, Japan, pp 175-178

Yoshimoto M (2010) Physiological function and utilization of sweet potato. In: Ray RC, Tomlins KI (Eds) *Sweet Potato: Post Harvest Aspects in Food*, Nova Science Publishers Inc., NY, pp 59-90

Zaharah A, Tan SL (2006) Performance of selected sweet potato varieties under different growing seasons on bris sandy soil in Malaysia. In: *14th Triennial Symposium of International Society of Tropical Root Crops*, 20-26 November 2006, Central Tuber Crops Research Institute, Thiruvananthapuram, India, pp 225-226