Current and potential systems for maintaining sweetpotato planting material in areas with prolonged dry seasons: a biological, social and economic framework

By

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DECLARATION

I certify that this work has not been accepted in substance for any degree, and is not concurrently being submitted for any degree other than that of Doctor of Philosophy (PhD) being studied at the University of Greenwich. I also declare that this work is the result of my own investigations except where otherwise identified by references and that I have not plagiarised the work of others.

Signed…………………………

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This thesis has been submitted for examination with our approval as university supervisors.

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Dedication

To my children: Emmanuel, Hope, Daniel, twins Joshua and Caleb. The stride is yours.

Abstract

This study on sweetpotato seed systems was conducted in Mukono, Kamuli, Bukedea and Soroti districts in Uganda, and in Mwanza, Shinyanga and Meatu regions in the Lake Zone of Tanzania during 2007 – 2011. It aimed at developing simple, affordable and applicable technologies for conserving and multiplying sweetpotato planting material for early season planting after the long dry season. The study sought to understand and describe farmers' existing approaches, improve on rapid multiplication techniques and develop rational use of available planting material.

Complete lack of or insufficient planting material for early planting immediately following the long dry season was reported. Farmers recognised that obtaining planting material early was beneficial as it resulted in increased root yield, an early source of food and sales at high prices. The Triple S (Sand, Storage and Sprouting) method of producing ample planting material for early season planting was developed in Uganda after testing various ways of storing the roots during the dry season so as to eliminate dry season mortality. Using roots obtained from crops planted in the conventional time and planting them out in watered gardens 1-2 mths before the rains to act as sources of sprouts for vine cuttings was the most appropriate. The method was validated in Tanzania which has a longer dry season. The use of 20cm cuttings instead of the mini cuttings (10 cm) in rapid multiplication of vines needed less labour and care. Pre-planting fertiliser (NPK: 25:5:5) doubled the quantity of planting material generated, and planting shorter and fewer cuttings than recommended saved planting material to enable more extensive plant coverage and doubled potential production. All these findings greatly contribute to the improvement of the conservation and multiplication of planting material, especially to improving the availability of early planting material.

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ACRONYMS

ACMV	African Cassava Mosaic Virus
ANOVA	Analysis of Variance
AOSPPA	Abuket Orange-fleshed Sweetpotato Producers and Processors Association
CBO	Community based organisation
CIP	International Potato Center
CRBD	Completely randomized block design
CRS	Catholic Relief Services
FAO	Food and Agriculture Organisation of the United Nations,
GenStat	General Statistical programme,
LGP	Length of growing period,
LZARDI	Lake Zone Agricultural Research and Development Institute
NaCCRI	National Crops Resources Research Institute
NARO	National Agricultural Research Organisation
NBS	National Bureau of Statistics
NPK	Nitrogen: Phosphorus: Potassium (A composite fertiliser)
NRI	Natural Resources Institute
OFSP	Orange-fleshed sweetpotato
REU	Reaching End-User
RH	Relative humidity
RMT	Rapid multiplication technique
SASHA	Sweetpotato Action for Security and Health in Africa project,
SOSPPA	Soroti Sweetpotato Producers and Processors Association
SPFFS	Sweetpotato farmer field school

SPSS	Statistical Package for Social Scientists
SPVD	Sweet potato virus disease
SSA	Sub-Saharan Africa
UBOS	Uganda Bureau of Statistics
USD	United States Dollar
VAD	Vitamin A deficiency
WAP	Weeks after planting

CHAPTER 1

Introduction

1.1 Background

Sweetpotato is the sixth most important World food crop after rice, wheat, potatoes, maize, and cassava, and the fifth most important food crop in developing countries after rice, wheat, maize and cassava (FAOSTAT, 2010). Sweetpotato is one of the most widely grown root crops in Sub-Saharan Africa (SSA), covering around 2.9 million hectares with an estimated production of 12.6 million tonnes of roots in 2007 and expanding faster than any other major food crop (FAOSTAT, 2008; Low *et al*., 2009). Uganda, with an annual average output of about 2.8 million tonnes, is the second largest producer of sweetpotato in the World after China (FAOSTAT, 2010) and is among four SSA countries (Uganda, Rwanda, Burundi and Malawi) with an annual *per capita* consumption of over 85 kg (FAOSTAT, 2008). Uganda accounts for 20.5 percent of sweetpotato production in SSA (FAOSTAT, 2008).

Sweetpotato ranks third after bananas and cassava as most important crops grown in Uganda (FAOSTAT, 2010) and is the most widely cultivated and most widespread of all crops there (Mwanga & Wanyera, 1987). It is an important staple crop throughout the country (Dundar, 1969), widely grown by smallholder famers as a supplement to bananas, finger millet and cassava (Bashasha & Mwanga, 1992; Bashasha *et al*., 1995; Mwanga & Wanyera, 1987). In north-eastern Uganda, sweetpotato becomes a seasonal staple during the dry season when supplies of most other food stuffs are exhausted (Hall *et. al*., 1998; CIP, 1999) and commercial sweetpotato production has emerged in some areas (Low *et al*., 2009). Sweetpotato is a popular food item. In times of scarcity of other food sources, it is often the only means of survival for low income people when it is consumed as a cheap substitute for cereals (Rashid, 1990).

Sweetpotato combines a number of advantages which gives it an exciting potential role in combating the food shortages and malnutrition that may increasingly occur as a result of population growth and pressure on land (Woolfe, 1992). Globally, sweetpotato provides significant amounts of energy and protein and its production efficiency of edible energy is outstanding amongst crops in the developing World (Woolfe, 1992). Sweetpotato can produce an acceptable yield with a minimum of inputs including a less fertile soil, where other crops such as maize are difficult to raise (Bouwkamp, 1985; Ewell, 1990; Rashid, 1990; Woolfe, 1992). An average tropical yield of 7 t/ha at 30% dry matter for sweetpotato is relatively better than that achieved by some other major crops in developing countries including maize (1 t/ha), rice (2 t/ha), sorghum and millet (<1 t/ha each) (FAOSTAT, 2010). Sweetpotato is typically a smallholders' crop, often grown on marginal soils with limited inputs (CIP, 1999); it has a degree of tolerance to water deficits but also responds very favourably to the use of inputs such as fertilizer and irrigation (Rashid, 1990). Total crop failure due to adverse weather conditions is rare and many farmers plant sweetpotato as a fallback for family food in case of emergency (Woolfe, 1992; Kapinga *et al*., 1995). It is relatively free from diseases and insect pests; thus its production does not require much cost for plant protection and some varieties of sweetpotato are very good sources of carotene (Woolfe, 1992), the precursor of vitamin A.

Lack of sustainable seed systems (including virus management, seed quality and supply) is one of the key constraints to sweetpotato productivity in SSA (Low *et al*., 2009). Reports of shortages of planting material caused by prolonged dry seasons are common in the literature: e.g., from Uganda (Dunbar, 1969), Tanzania (Mwanbene *et al*. 1994; Kapinga *et al*., 1995; 1998) and Swaziland (Nsibande & McGeoch, 1999). Lack of planting material is often particularly acute at the onset of the rains after the long dry season has desiccated the foliage (Ewell, 1990; Gibson, 2009). Traditional vine sources often fail to provide adequate planting material then (Bashaasha *et al*., 1995), resulting in delayed planting. The common sources of planting material in areas with a prolonged dry season include growing a crop in wetlands, planting under shade and waiting for sprouting shoots that emerge from buried roots after the rains have started (Gibson, 2009; Namanda *et al*., 2011). All the methods have major disadvantages: shoots from volunteer plants are associated with late planting by up to 2 months (and low quality planting material), potential wetland areas for irrigation are limited and watering throughout the dry season is laborious, and tree shade provides very limited planting material (Gibson, 2009; Namanda *et al*., 2011). Consequently, sweetpotato as a major staple food remains largely restricted to areas close to the Equator where the rains are evenly spaced and there is no long dry season to desiccate the crop so access to planting material is easy (Gibson, 2009). For areas with a long dry season, there remains a need to explore methods that will ensure sufficient early availability of planting material with minimal watering.

Sweetpotato is a short term, early maturing crop that can help fill the food supply gap created by the long dry season during which farmers depend on stored food reserves harvested during last season. These reserves are mainly composed of dry cereal grains which generally take more than 120 days after planting to realise a new harvest. Sweetpotato provides storage roots for piece-meal harvesting as early as 75 days after planting. Sweetpotato can thus potentially provide valuable food nearly two months before the main grain crops. Unfortunately, lack of planting material at the onset of the rains means that the main sweetpotato crop is planted late instead yielding after the main cereals harvest. It yields when the period of famine is over, failing to achieve a role as a famine saver crop and also failing to be available when prices are at their highest (Hall *et al*., 1998).

The crop is particularly sensitive to water deficits during establishment, vine development and storage root initiation (Valenzuela *et al*., 2000); various authors (Edmond *et al*., 1971; Bouwkamp, 1985; Kay, 1987; Peet, 2007) identify a specific period within 40 – 60 days from planting as a critical development stage that requires adequate soil moisture. The duration of the first rainy season in north-eastern Uganda is about 90 days and is then followed by a dry spell of about 30 days. This short dry season [June/July in Uganda] occurs north and south of the Equator where the rainfall pattern remains bimodal but is tending to unimodal. If planting is much delayed, this critical development stage may coincide with it. Thus, this is an additional reason to conserve planting material during the dry season so as to be able to plant early.

Multiplication and conservation of sweetpotato planting material during dry periods requires sufficient water for irrigation. However, in areas with prolonged dry spells, there is normally high competition for water, the limited water often being communally shared, with households and animals having the greatest priority. Additional activities such as vine conservation therefore have to be harmoniously integrated so as to not cause stress to water access by the community. Farmers may want to plant a dry season crop in a swamp for production of both roots and vines for early season planting. The availability of such areas for establishing a crop is very limited, conflicting with the environmental protection of wetlands and alternative commercial uses. The planting material collected from such an old crop may have a high weevil infestation and not be vigorous. Even the price of such material may be prohibitive to the majority of the growers. Farmers were also reluctant to apply rapid multiplication techniques that have been promoted through farmer field schools because of the high frequency of watering making them labour intensive (González, 2006). There was therefore a clear need to develop vine conservation techniques that rely on minimal use of water for irrigation.

The facts summarised below generated interest in conducting research on how to improve the availability of planting material at the beginning of the planting season following the long dry season and its likely effects:

a) Sweetpotato is one of the main staples of the food systems of Uganda with *per capita* production of around 100 kg per year. Thus, increasing sweetpotato production and utilisation is often considered a means to improve incomes and food security among the poorer segments of the rural population (Kapinga *et al*., 2007).

b) In Uganda, sweetpotato has an increasing demand in urban areas as a cheap alternative food and Soroti/Kumi areas have specialized to supply sweetpotato to these urban areas (Bashaasha *et al*., 1995; Kapinga *et al*., 2007).

c) Sweetpotato is widely grown and consumed in Uganda and is a staple crop in the north east including Soroti/Kumi districts which experience a long dry season. Planting material completely desiccates resulting in a lack of planting material at the beginning of the subsequent rainy season (Kapinga *et al*., 2007).

d) Lack of planting material at the beginning of the planting season results in delayed planting and limiting the area planted as farmers have to travel long distances to buy planting material at expensive prices (González, 2006; Namanda *et al*., 2011).

e) Sweetpotato can grow reasonably well with no inputs on degraded soils over a wide range of rainfall patterns (Edison, 2000).

f) Early planting of sweetpotato achieves high yields and early harvesting, bridging the hunger gap that occurs between the beginning of first season planting and first crop harvests. It also means farmers will not need to prematurely harvest the grain crops, resulting in overall increased crop yields (Namanda *et al*., 2011).

This study starts with a review of sweetpotato generally and then in Africa, with particular reference to conserving planting material. Then there is a study on the farming systems in north-eastern Uganda and sweetpotato's role in them. It makes the first comprehensive study of the seed systems currently used by farmers there and how adequately they supply the current demands for seed, especially at the beginning of the first rains. In regard to the importance of supplying demand for planting material then and the constraints related to conservation of planting material during the long dry season, attention was given to the improvement of the rapid multiplication method of producing planting material, using longer cuttings as planting material [as used by many farmers] than recommended and using fertiliser to boost productivity. Besides producing sweetpotato cuttings for early planting, the available scarce vines could be manipulated to cover a larger area during planting. In Uganda, the length of vine cutting and number of cuttings planted varies from location to location and in some areas, from season to season. The variation in length of vine cuttings and the number of cuttings planted each season are apparent farmers' responses towards relative plenty and scarce vine availabilities. This raised the questions that, in areas where planting material is scarce, what is the optimal use of the available vines? Options include use of shorter and/or fewer cuttings and both were tested. The novelty of the thesis study is mainly, however, its focus on manipulating sprouting from roots so that this supply of planting material becomes timely and under the control of farmers. This led to the development of a completely new method of obtaining planting material and potentially revolutionises production of sweetpotato in areas with a long dry season.

1.2 Hypotheses

1. High density vine bed planting combined with pre-planting compound fertiliser (NPK) application greatly increases the number of cuttings harvested for planting per unit bed area.
2. Reducing the number and/or length of planting cuttings increases the area planted with the available quantity of planting material without compromising the yield of storage roots.
3. Manipulating sprouting of roots can enhance the availability of planting material for early planting.

1.3 Objectives:

The specific objectives of the study were to:

1. Characterise and understand the current system of producing sweetpotato planting material.
2. Investigate the extent of the lack of planting material in different agro-ecologies and the implications for early sweetpotato planting especially in areas that experience prolonged dry seasons.
3. Assess the effect of using longer cuttings and fertiliser application in high density vine beds for production of planting material, and using cuttings of different vine lengths at varied plant densities for production of roots.

4. Understand and examine the factors affecting the use of roots in producing planting material in areas with prolonged dry seasons.
5. Test and validate a protocol for using roots to produce planting material in areas with varying lengths of dry seasons.

As well as developing specific measures for the improvement of seed supply for sweetpotato, the study tried to provide a holistic view of the whole farming system, taking into account why farmers acted in particular ways as well as how to improve specific aspects. The driving goal was to explore opportunities for realizing the crop's importance as a short term, early maturing staple food and cash crop in areas with a long dry season, particularly to alleviate the periodic food shortages that occur immediately after it.

CHAPTER 2

Literature review

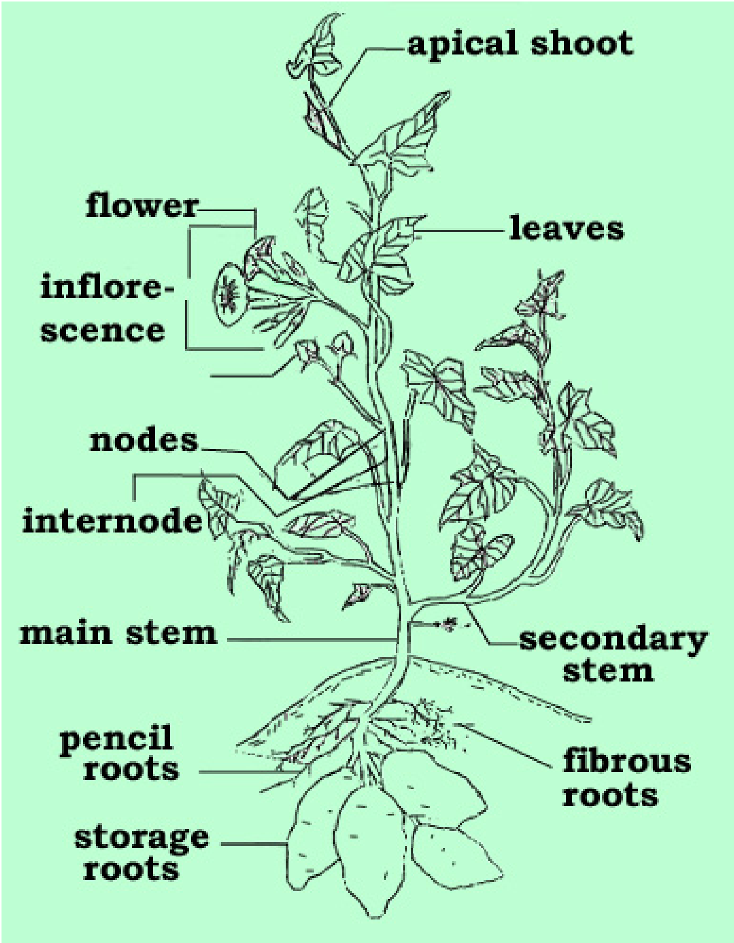
In the light of the Objectives described in the introductory Chapter, the Literature Review covers:

1. A description of sweetpotato, botanically and as a crop
2. A description of the farming systems studied in Uganda
3. Current systems of conserving and multiplying planting material, with special reference to provision of planting material following the long dry season
4. Current knowledge of the storage of sweetpotato roots

2.1 A description of sweetpotato botanically and as a crop

2.1.1 Botanical characteristics and plant parts

Botanically: Sweetpotato (*Ipomoea batatas* (L.) Lam.) is a herbaceous perennial plant belonging to the *Convolvulaceae* family but is normally grown as an annual (Woolfe, 1992). It has a vine system that expands rapidly and horizontally along the ground (Rossel *et al.*, 2008); some varieties are twining. Although its growth habit is usually prostrate, it varies from spreading to semi-erect and erect (Rossel *et al.*, 2008). It forms swollen storage roots that provide the main yield of the crop. Plate 1 below shows the different parts of the sweetpotato plant.



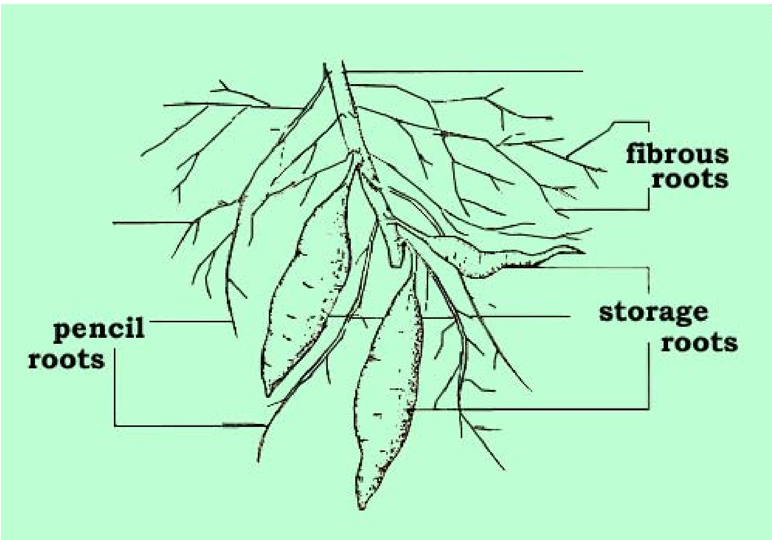


Plate 1: Sweetpotato plant parts (Z. Huaman, 1987).

Table 1: Description of different sweetpotato plant parts (after Kays, 1985)

Plant part	Description/ function
Sweetpotato plant	Herbaceous perennial vine, bearing alternate heart-shaped or palmately lobed leaves and medium-sized sympetalous flowers. Sweetpotato has two types of roots: i) Adventitious roots – those arising from the underground portion of a vine cutting or transplant or from a root piece when used for propagation including a) storage roots; b) primary fibrous roots and c) pencil roots. ii) Lateral roots – those arising from existing roots including a) primary; b) secondary and c) tertiary.
Aboveground plant parts	Comprised of a) Leaves that absorb light energy converting it into carbohydrates through fixation of atmospheric carbon. The shape and colour of sweetpotato leaves depend on variety b) Leaf petioles and stems which form the conduits for transport of the carbon through the plant, and determine the special arrangement of the leaves within the canopy. Vine length, thickness and internode length determine whether the plant is bushy, intermediate or vining type. Stems are cylindrical with colours varying from green to a reddish-purple. Cultivars with erect stems grow up to 1 metre tall and those with prostrate stems spreading out on the ground grow up to 5 metres wide. c) Flowers which are trumpet-shaped and contains both a male stamen and a female pistil. The ability of an individual variety of sweetpotato to flower varies; a few do not produce flowers. Although sweetpotato is ordinarily propagated by cuttings, they produce fruit containing seeds which remain dormant for years and are very difficult to germinate
Underground stem	Translocation of the photosynthates through the plant, survival and development of sprout shoots at the onset of first rains.

Table 1 (continued)

Storage root	Sweetpotato forms a storage root. The storage root is long, swollen and broadly tapered, with a smooth skin whose colour ranges between yellow, orange, red, brown, purple, and pink and flesh ranges from pink through white, red, pink, violet, yellow, orange, and purple, depending on genotype. The orange pigment is β-carotene, a precursor of vitamin A; the blue pigments are mainly anthocyanins, also valuable to human nutrition as anti-oxidants. Storage roots arise from thick young roots where the cells between the protoxylem points and the central metaxylem cell do not become lignified. The proximal end of the root is connected to the plant by a storage root stalk which is 10 to 15 cm in length and storage roots are found clustered around the stem. If separated from the parent plant, sprouts emerge from the end of the root closest to the stem because of proximal dominance. At the distal end, the storage root continues to grow in the soil forming a root system similar to the primary fibrous roots.
Pencil roots	Generally pencil thick, adventitious roots which occur under conditions which are not conducive for development into storage roots. Kays (1985) indicates that their size is 5 and 15 mm.
Primary fibrous roots	Emerge largely from thin adventitious roots although under adverse conditions they may be from thick roots.
Lateral roots	Emerge from existing roots, thus each type of adventitious root have a profusion of lateral roots at varying densities along the axis. The primary lateral roots emerge from adventitious roots which grow profusely downward into the soil forming secondary laterals (laterals emerging from primary laterals); in some cases tertiary laterals also emerge from secondary laterals.

2.1.3 Growth stages of generating planting material from storage roots

Growth stage 1: Sprouting root

Growth stage 2: Sprout shoots developing green leaves

Growth stage 3: Shoots grown into vines

Plate 2: Sweetpotato “Sprouting” to “Shooting” to “Vining” (Namanda *et al.*, 2012)

2.1.4 Sweetpotato in development: A review of sweetpotato production and utilisation trends

Table 2a: World ranking of the highest producing ('000 metric tonnes) countries of sweetpotato in the World during 2007 to 2010 (FAOSTAT, 2007; 2008; 2009; 2010)

Country	2007		2008		2009		2010	
	'000 MT	Rank	'000 MT	Rank	'000 MT	Rank	'000 MT	Rank
China	758,002	1	78,443	1	76,773	1	81,176	1
Uganda	2,602	2	2,707	3	2,766	2	2,838	2
Nigeria	2,432	3	3,318	2	2,747	3	2,704	3
Indonesia	1,887	4	1,877	4	2,058	4	2,051	4
Viet Nam	1,438	5	1,326	6	1,208	6	1,317	6
U.R. Tanzania	1,322	6	1,379	5	1,381	5	1,400	5
India	1,067	7	1,094	7	1,120	7	1,095	7
Japan	968	8	1,011	8	1,026	8	864	12
Angola	949	9	820	14	983	9	987	9
Madagascar	895	10	903	9	911	11	919	11
Mozambique	875	11	566	16	900	12	920	10
Burundi	874	12	900	10	484	17	-	-
USA	820	14	837	12	883	13	1,082	8
Kenya	812	15	895	11	932	10	384	20

Table 2b: Ranking production ('000 metric tonnes) of agricultural commodities in Uganda during 2007 to 2010 (FAOSTAT, 2007; 2008; 2009; 2010)

#	Crop	2007		2008		2009		2010	
		'000 MT	Rank	'000 MT	Rank	'000 MT	Rank	'000 MT	Rank
1	Bananas	9,231	1	9,371	1	9,512	1	9,550	1
2	Cassava	4,973	2	5,072	2	5,179	2	5,282	2
3	Sweetpotatoes	2,602	3	2,707	3	2,766	3	2,838	3
4	Sugar cane	2,350	4	2,350	4	2,350	4	2,400	4
5	Maize	1,262	5	1,266	5	1,272	5	1,373	5
6	Millet	732	6	783	6	841	6	850	6
7	Potatoes	650	7	670	7	689	8	695	8
8	Vegetables Fresh	610	8	631	8	748	7	760	7
9	Beans	574	9	583	9	592	9	600	9
10	Sorghum	456	10	477	10	497	10	500	10

Table 2c: Sweetpotato crop area and production by region in Uganda in 2008

Region	Area planted ('000Ha)	% total area planted	Production ('000MT)	% total production	Yield/ Ha
Central	146	22.3	467	17.3	3.2
Eastern	238	36.3	1,263	46.6	5.3
Northern	91	13.8	435	16.1	4.8
Western	181	27.6	542	20.0	3.0
Total	655	100	2, 707		4.1

Source: MAAIF (2011) (Uganda Census of Agriculture).

Table 2d: Total production (MT) and percent total production of sweetpotato in eastern and central Uganda regions by district in 2008/09

Sweetpotato production (MT) in Eastern region			Sweetpotato production (MT) in Central region		
District	MT	%	District	MT	%
Bugiri	15,163	1.2	Kayunga	45,770	9.8
Bukedea	3,791	0.3	Luwero	23,352	5.0
Iganga	404,338	32.0	Masaka	50,440	10.8
Jinja	89,713	7.1	Mityana	12,610	2.7
Kaliro	54,333	4.3	Mpigi	32,226	6.9
Kamuli	226,177	17.9	Mubende	54,177	11.6
Kumi	31,589	2.5	Mukono	56,045	12.0
Mayuge	24,008	1.9	Nakaseke	16,346	3.5
Namutumba	32,853	2.6	Nakasongola	99,013	21.3
Soroti	243,866	19.3	Rakai	13,544	2.9
Tororo	59,387	4.7	Wakiso	34,561	7.4
Other 13 districts	78,341	6.2	Other 5 districts	28,956	6.2
Total	1,263,559	100	Total	467,040	100

Source: MAAIF (2011) (Uganda Census of Agriculture)

Half of the 10 most important countries for producing sweetpotato in the World are from sub-Saharan Africa (Table 2a). Uganda, the leading sweetpotato producer in Africa, has an increasing annual production now reaching nearly 3 million tonnes (Edison, 2000; FAOSTAT, 2008; 2010). Sweetpotato is the third most important staple food crop in Uganda after bananas and cassava (Table 2b), and plays a primary role in food security especially in eastern Uganda (Table 2c) where two crops per year are grown for both home consumption and to supplement household income by sale to local and urban markets (Namanda *et al*., 2007). Eastern Uganda is the leading (46.6%) followed by northern region (16.1%) in production of sweetpotato in Uganda (Table 2c). Average yields in the eastern and northern regions are higher than the national average of 4.1 tons per hectare (MAAIF, 2011). Kamuli, Soroti and Mukono are among the leading sweetpotato producers in eastern and central regions in Uganda (Table 2d).

Sweetpotato is the fifth most important food crop on a fresh weight basis in developing countries, after rice, wheat, maize and cassava; >105 million tonnes are produced globally each year, 95 percent in developing countries (Scott, 1998; FAOSTAT, 2010). Sweetpotato is the second most important cultivated root crop after cassava in the Tropics (Scott *et al*., 2000; Low *et al*., 2009). Sweetpotato has an important role in the food systems particularly of people inhabiting marginal ecosystems having unreliable rainfall (Khatana *et al*., 1999). About 80 percent of the World's sweetpotato is grown in Asia and just under 15 percent in Africa (FAOSTAT, 2010) where it has been a staple food of many communities for centuries (Onwueme, 1978). In Africa, the highest *per capita* production figures are concentrated within 10^0 of the Equator where bimodal rainfall occurs; further north and south of the Equator, the dry season generally becomes longer and the supply of planting material increasingly constrained (Gibson, 2009). Sweetpotato, covering around 31.2 million hectares and producing 129.40 million tonnes of roots (FAOSTAT, 2008), is one of the three most widely grown crops in sub-Saharan Africa.

Many of the developing World's poorest and most undernourished households depend on roots and tubers as an important source of food and nutrition (Scott *et al*., 2000). Sweetpotato combines a number of advantages including provision of a nutritious, cheap food, with larger quantities of energy (carbohydrates) produced per acre per day in comparison to cereals (Woolfe, 1992; FAOSTAT, 2010), and a rich source of proteins, lipids and calcium (Srivivas, 2009). It is a valuable source of vitamins B, C, and E and a moderate source of iron and zinc; orange-fleshed varieties are important source of β-carotene, the precursor of vitamin A (Low *et al*., 2009).

Globally, sweetpotato production grew at 0.4 percent *per annum* during 1991 – 2000, mainly due to growth in Africa and Asia (Srivivas, 2009). All the major sweetpotato growing African countries, especially Nigeria, Tanzania, Uganda, Kenya and Rwanda, have positive growth in production averaging 2.7 percent from 1961 – 2006 (Srivivas, 2009). Most of the growth in Africa is in response to pressure on local food system due to population growth, civil war and economic hardship (Tardif-Douglin, 1991; Bashaasha *et al*., 1995) and it is outpacing the growth rate of other staples (Low *et al*., 2009).

In East Africa, sweetpotato is intensively cultivated in mid elevation areas

(Dunbar, 1969) and is widely grown by small famers as a supplement to banana, finger millet and cassava in Uganda (Bashaasha *et al.,* 1995; Mwanga & Wanyera, 1998). In north-eastern Uganda, sweetpotato becomes a seasonal staple during the dry season when supplies of most other foodstuffs are exhausted (Hall *et al*., 1998). The importance of sweetpotato in Uganda increased after the decline of the cassava production due to the attack of *African Cassava Mosaic Virus* (ACMV) from 1986 onwards, changing it from one of several food crops to a dominant crop for both consumption and income generation in many areas (Mwanga *et al*., 2004a). With its potential to alleviate vitamin A deficiency (VAD) in Uganda (Yanggen & Nagujja, 2006), promotion of orange-fleshed sweetpotato (OFSP) has become part of the overall national strategy to address VAD, add value to the crop and expand market opportunities (Odongo *et al*., 2004a). Sweetpotato utilization in Uganda is largely limited to human consumption (>85%) with an overall annual *per capita* consumption of 85 kg (in producing areas it is much bigger) while other uses including use of the foliage for livestock feed are only 15% (Okoth, 2005). Sweetpotato is a popular food item and often the main means of survival when there is scarcity of other food sources, consumed as a substitute for cereals by low income people (Rashid, 1990).

The extent of trade in sweetpotato is unknown but regional and international trade of sweetpotato and its products has existed for some time and is growing (Srivivas, 2009). Sweetpotato is replacing maize as a cash crop in areas with a relatively prolonged dry season (e.g., Bukedea district) (Pfeiffer and Mclafferty, 2007) as well as replacing the traditional low-yielding finger millet and sorghum with a higher yielding crop (Low *et al*., 2009). Soroti and Kumi districts are the leading suppliers of sweetpotatoes to markets in Kampala, Jinja, Mbale and other urban areas in the country (González, 2006).

Sweetpotato is mostly grown as a monocrop though it is sometimes intercropped with early maturing beans, maize and similar crops. It may be grown as a mixture of varieties but even then each variety is usually grown by itself in one patch rather than all mixed together. It is grown on either mounds or ridges. The ridges are usually up to 1 m wide and 30 – 40 cm high though they occasionally are prepared as a very wide ridge of 2 – 3 m width. Mounds occur in a greater range of forms, ranging from quite small ones about 0.5 m^2 to much larger ones (Stathers *et al*., 2005). A mound is usually carefully constructed so as to heap the vegetation in the centre where it cannot sprout but slowly decays to feed the plant. Ridges are usually planted with vines spaced at about 30 cm intervals; mounds are planted in a variety of manners, sometimes just pushing a bundle of ~3 vines into the centre or by inserting individual vines around the top of the heap. A wide range of vine length are used but usually they are a minimum of 30 cm long; when very long vines are used, they are sometimes inserted as a U so that both the shoot tip and the shoot base protrude. Generally, cuttings of 20 – 45 cm from the stem apex are preferred to those from the middle and basal portions of the stem (Stathers *et al*., 2005). Cuttings with 7 or more nodes are favoured since they normally give higher root yields than cuttings with only a few nodes (Kay, 1973; Stathers *et al*., 2005) but a length of about 30 cm is recommended, as longer cuttings tend to wasteful and much shorter ones establish more slowly and may give poor yields (Onwueme & Winston, 1994). Cuttings of old vines from crops that are no longer growing rapidly do not root well and are slow in establishing themselves, which reduces yield (Folquer, 1978; Stathers *et al*., 2005). There is great variation in the number of cuttings planted to the hectare, depending upon whether they are planted on mounds or ridges and on spacing (Stathers *et al*., 2005; Mwanga & Wanyera, 1987) but there is relatively little difference in the overall yields in plant populations over the range from 25,000 to 125,000 plants/ha; when the population dropped to 12,500 plants/ha there was significant reduction in yield (Kay, 1973; NRI, 1987; Mwanga & Wanyera, 1987). Plant density may be manipulated with advantage in areas where planting material is scarce (Aldrich, 1963). Vines are occasionally wilted prior to planting as this is claimed by some to improve rooting. In dry weather, vines may initially be completely covered and the shoot tip revealed only once rooting has occurred. Planting should be done when the rains are still irregular, so that by the time the rains are regular, they are established and enough growing time is available to the plants before the dry season (Onwueme, 1978; Stathers *et al*., 2005). After planting, water availability is very important, not only until new roots are produced but to avoid lignifications of potential storage roots (Stathers *et al*., 2005). In the Tropics, most root initiation occurs 4-7 weeks after planting and the rest of the season is devoted to root enlargement (Woolfe, 1992). Sweetpotato has a short growing season and growth is closely related to the availability of water during establishment (Franklin, 1988). Sweetpotato grows at latitudes ranging from 40°N to 32°S (Rossel *et al*., 2008) and, on the Equator, it is grown at altitudes from sea level to 3000 masl (Huaman 1987). The crop grows best between 20 and 30°C with abundant sunshine and warm nights (Rossel, 2008). The crop requires at least 500 mm of rain during the growing season (an annual rainfall of 750–1000 mm is ideal and low humidity as the crop reaches maturity (Kay, 1973; Ahn, 1993; Stathers *et al*., 2005). If there is no dry season, sweetpotato can be planted at any time but, in regions with a dry season, planting early in the rainy season is the best (Stathers *et al*., 2005). Sweetpotato can tolerate considerable periods of drought but yields are very much reduced if a water shortage occurs within 6 weeks (Woolfe, 1992) or 50-60 days after planting when storage root initiation has begun (Kay, 1973; NRI, 1987). The crop has a relatively low nitrogen requirement; excessive nitrogen fertilization produces much foliage but few roots (Gush, 2003). However, some is needed and efficient management of this nutrient is prerequisite to its sustained production (Villordon & Franklin, 2007). The crop is often piecemeal harvested over a prolonged harvesting season of 3 – 6mths or so to provide daily meals, individual roots being removed from plants as they achieve maturity and only after several months is the crop completely harvested. The seasonality of sweetpotato in Uganda differs with rainfall and temperature conditions (González, 2006). In the eastern part of the country, where rainfall is less reliable, a seasonal production and consumption pattern is more apparent (Bashaasha *et al*., 1995). Farmers prefer to plant at the onset of the rains in March but lack of planting material then may affect the production (Bashaasha *et al*., 1995). Farmers who produce sweetpotato as a cash crop start planting earlier in order to harvest the roots when there is still a poor supply to the market and the prices are high (Heyd & Qaim, 2006). Farmers cannot delay harvest or store fresh roots for a long period as they store poorly, normally resulting in a glut at the main harvest and low prices (González, 2006).

2.2. A description of the farming systems studied in Uganda

Uganda is a small landlocked country in the centre of Africa, lying across the Equator between latitudes 4^0 12’ N and 1^0 29’ S and longitudes 29^0 34’ to 35^0 0’ E. The country borders South Sudan to the North, Kenya to the East, The United Republic of Tanzania and Rwanda to the South and the Democratic Republic of the Congo to the West. Much of the country lies at an altitude of 900 to 1500m with an average altitude of 1200m. It has an equatorial climate with small regional variations in annual temperature and humidity (FAO, 2009). It is 236,040 km^2 but its land surface is only 208,759 km^2, large areas being comprised of Lake Victoria, Lake Kyoga and other lakes; the area under cultivation is about 120,000 ha (FAO, 1980). The population of the country was estimated at 34.5 million in UNFPA 2011 with annual rate of increase of more than 3 percent and 88% of the population living in rural communities (FAO, 2009).

The economy of Uganda is estimated to be growing at 6.6 %, with agriculture, the largest sector, contributing about a third of gross domestic product. Agriculture is the major source of income for almost 80 % of the total economically active population (UBOS, 2002; FAO, 2009). Ugandan agriculture is largely dependent on small- and medium-scale farmers with average land holdings of 2.5 ha (FAO, 2009). The main food crops are bananas (*matoke*), cereals (maize, rice, millet and sorghum), cassava, sweetpotato, beans, peas, simsim, groundnuts and fruits MAAIF (2011). Soils include vertisols in the north east, volcanic deposits in isolated areas of the west and east, black clays and lithosols in some places in the north-east and mainly sandy loams and sandy clays loams in the remaining areas (Mwanga & Wanyera, 1987).

Uganda is among countries such as Burundi and Rwanda that have two rainy seasons enabling the availability of sweetpotato most of the year (Low *et al*., 2009). The southern part of the country is generally well-watered with two rainfall peaks occurring in March-May and August-November (FAO, 2009). Close to the Equator in Uganda, crops planted during the previous rainy season can survive the two short dry seasons, allowing farmers to obtain planting material for following season planting (Gibson, 2009). Further away from the Equator, even just 2^{o} north in Soroti district, farmers need to preserve planting material in swamps or in shade, or depend on cuttings from sprouting roots left over from previous crops (Gibson, 2009; Namanda *et al*., 2011). Extending to 3^{o} north in Arua and Gulu, the supply of planting material is increasingly constrained (Bashaasha *et al*., 1995; Gibson, 2009). Generally, the further south or north from the Equator, the longer the dry season becomes, the more difficult it is for sweetpotato to survive the dry season and the supply of sweetpotato planting material becomes increasingly constrained. Limited sweetpotato production in countries located at greater latitudes is attributed to the general lack of planting material when the rains start because the crop loses all its foliage during the long dry season and special methods are needed to produce the vine cuttings used in its propagation (Gibson, 2009).

The amount of rainfall also decreases towards the north (Hall *et. al*., 1998; FAOSTAT, 2012), turning into just one rainy season per year and a marked dry season from November to March in the extreme north. Mean annual rainfall varies from 510 mm in parts of Karamoja (N.E. Uganda) to about 2160 mm in the Ssese Islands in Lake Victoria. The rainfall is mainly bimodal with rainfall peaks in April-May and October-November (FAO, 2006b). Mean annual minimum and maximum temperatures vary from 10^0C to 20^0C and between 22.5^0C and 32.5^0C, respectively (FAO, 2009).

Dryland savannah covers large regions of otherwise productive farmland in northern and eastern Uganda, characterised by annual rainfall levels ranging from 400 – 1000 mm concentrated in one long or two short rainy seasons. Besides erratic rainfall with high intensity and extreme spatial and temporal variability, the length of growing period is only 75 – 125 days (Rockstrom, 2000). The result is very high risk for annual crops (Rockstrom, 2000). Short periods of water stress (dry spells) can have serious effect on crop yields if occurring during water sensitive development stages like, e.g., during flowering (Rockstrom & de Rouw, 1997). In areas with dry periods lasting 4 months or longer, lack of sufficient planting material is often a major constraint to expanding sweetpotato production and in many drier parts of East Africa, planting late exposes sweetpotato to drought, especially at the critical time of root formation (6 – 8 weeks after planting), and weevil damage as the production period extends into the dry season (Low *et al*., 2009).

Mukono, Kamuli, Bukedea, Kumi and Soroti districts, the study areas, represent different climatic areas in Uganda with different rainfall patterns. Soroti meteorological data show its climate is normally characterized by a short dry spell between the two rainy seasons during mid-June to mid-July, and a long dry season sets from mid-November through to early March (Friis-Hansen *et al*., 2004; Friis-Hansen *et al*., 2005). Rainfall ranges from 1000 mm to 1200 mm but its reliability is poor, often leading to frequent droughts and floods (Friis-Hansen *et al*., 2004; Friis-Hansen *et al*., 2005). Soroti, Kumi and Bukedea districts are both located in eastern Uganda and have served as a test bed for many agricultural development initiatives (Friis-Hansen *et al*., 2004), while Mukono and Kamuli are within the lake crescent region experiencing more equal dry and wet periods.

2.3 Current systems of conserving and multiplying planting material, with special reference to provision of planting material following the long dry season

Sweetpotato is usually propagated through vine cuttings (Nedunchezhiyan & Ray, 2010). The use of roots for direct planting is not recommended because it usually results in very poor yields (Onwueme, 1978). Vegetatively propagated crops are in general much more sensitive to desiccation and pest attacks than seed-propagated crops (FAO, 1993). Obtaining vines for planting material direct from a mature crop is the easiest and cheapest means and is the general practice throughout the Tropics wherever cropping is year-round (Gibson, 2009). Throughout most of Africa, especially East Africa, this is the most common propagation system. Preferably the cuttings are sourced from a crop 2 – 3 months old (Stathers *et al*., 2007), when plants are vigorous; this also avoids build-up of pests and diseases. A vine length of 20 – 40 cm with at least 3 – 5 nodes is found to be optimum for the storage root production in India (Nair, 2006) and 30 cm long cuttings are recommended in Uganda (Stathers *et al*., 2007).

Where the dry season has become sufficiently harsh to prevent crops surviving with foliage, farmers depend on the re-growth of un-harvested small roots from previous crops to provide a major source of cuttings (Yanggen & Nagujja, 2006; Gibson, 2009; Namanda *et al*., 2011). Effective propagation systems need to provide the different categories of farmers with planting material in sufficient quantities, at the right time, of an appropriate physiological state, vigour and health, and at an affordable price (Setimela *et al*., 2004). Traditional vine sources usually fail to provide sufficient planting material at the onset of the rains, delaying planting, preventing the crop from satisfying its potential as an early source of fresh food during the hunger gap (Onwueme, 1978; Namanda *et al*., 2011). Overall, a reliable source of supply rather than the chance supply by volunteer re-growth is required (Gibson, 2009).

2.3.1 Methods of producing sweetpotato planting material

Seven traditional methods besides the rapid multiplication technique (RMT) by which farmers in Africa currently obtain their planting material have been described (Gibson, 2009) and are listed, together with their advantages and disadvantages, in Table 3 below. These can be further grouped into two main methods: either maintaining a vegetative crop by growing in a wet location, watering or growing it in the shade, or using the volunteer plants that sprout from unharvested roots from previous ware crops when it rains (Namanda *et al*., 2011).

Table 3: Summary of methods of growing sweetpotato planting material in preparation for the long rains in East Africa (Gibson *et al*., 2009).

<table>
<tr><td>Method</td><td>Comments</td></tr>
<tr><td>1. Growing in wetlands (no watering): Farmers have traditional areas of wetlands where they plant sweetpotato as an otherwise normal crop on mounds or ridges at the beginning of the dry season</td><td rowspan="2">Disadvantages

Wetlands are often either not available or in limited supply.

Wetlands are increasingly being protected from farmer use in order to conserve natural resources.

A lot of labour may be required to clear wetlands before planting

Being the only green vegetation around, the sweetpotato plots attract grazing domestic and wild animals.

When the rains do come, the wetlands may be flooded, destroying the planting material or making it unavailable

During extremely prolonged dry seasons, the water supply may fail and the entire crop lost.

Where watering is done: If the dry season exceeds 4 – 5 mths, a sequential crop may need to be established but establishing cuttings during the dry season is difficult

Advantages

Planting material is generated in time for the arrival of the rains.

Large quantities of planting material are generated in some areas, e.g., around the shore of Lake Victoria, sufficient to plant large areas of land

There may be surplus planting material which can be sold at profit. An example is Chibe village in Shinyanga district where farmers reported obtaining 90 – 140 USD equivalents each year by selling to farmers.

Large roots generated can be sold or eaten during a period of food scarcity

Where watering is done: The land may be high enough to avoid flooding.</td></tr>
<tr><td>2. Growing around waterholes and watering: Where the water table is relatively high, shallow wells are dug and plants are established at the end of the rainy season</td></tr>
</table>

Table 3 (continued)

<table>
<tr><td>3. Planting in the backyard, watering with ‘waste’ water: Planting in a small depression near the homestead that is watered ‘automatically’ by water from washing, runoff from the roof etc</td><td>Disadvantages

Because the amount of water available is limited, only small quantities of planting material are generated.

No storage roots are generally generated.

Advantages

Labour-saving

The crop is easily protected against grazing or theft

It doesn’t requires access to special land; more-or-less everyone can do it</td></tr>
<tr><td>4. Taking cuttings from shoots sprouting from roots missed during harvest: No special activities</td><td rowspan="2">Disadvantages

Because sprouting starts with the arrival of the rains, planting material is generally available only 1 – 2 mths later

The planting material is difficult to protect from grazing animals and theft

Any exposed roots are destroyed by weevils

Advantages

Very easy and labour-saving.

Apparently very reliable; some roots seem to survive even the most prolonged dry season

One surviving root can generate many cuttings</td></tr>
<tr><td>5. Taking cuttings from shoots sprouting from roots of un-harvested crops: Farmers may plant a special late crop</td></tr>
</table>

Table 3 (continued)

6. Planting in the shade: Planting in the shade of bananas is common	**Disadvantages** In areas with prolonged dry seasons, bananas are rarely grown and even trees may lose their leaves No storage roots are generally generated. **Advantages** Very easy and labour-saving
7. Planting a late crop that survives the dry season: Planted late, the crop it is still growing vigorously when the dry season starts.	**Disadvantages** The crop is often badly attacked by weevils [Sandy soil may minimise this]. The cuttings are physiologically old and unlikely to yield well It only works where the dry season is relatively short and where crops can be protected from grazing animals **Advantages** As well as supplying planting material for the start of the rains, it also provides roots for food or sale, especially during the early part of the rains when food is scarce.
8. Rapid Multiplication technique: Mini cuttings (2 – 3 nodes) planted at high plant density in regularly watered beds	**Disadvantages** The method is labour intensive Involves regular watering to prevent the mini cuttings from drying Limited to locations with stable source of water **Advantages** Many cuttings are generated from the limited available material Large amounts of planting material produced per unit area

Yanggen & Nagujja (2006) reported that most farmers in Soroti and Kumi districts a) mentioned scarcity of vines after long drought as their number one constraint to adoption and dissemination of improved orange-fleshed sweetpotato and, b) obtained vines from volunteer plants that sprout from roots left in harvested fields from the last crop season – and this increased pest and disease infestation.

2.3.1.1 Impact of weevil infestation on sweetpotato production

Sweetpotato weevils are the most important pests of sweetpotato in Africa and worldwide, and production losses may often reach 60 to 100 percent (Stathers et al., 2003). The two species found in sub-Saharan Africa (SSA) are *Cylas puncticollis (*large and black weevil) and *Cylas brunneus* (brown and small weevil) (Stathers 2005; Low *et al*., 2009). . There is a positive relationship between vine damage or weevil density, and tuber damage but the principal form of damage to sweetpotato is mining of the tubers by larvae resulting into infested roots riddled by cavities, spongy in appearance, and dark in colour. A complete life cycle requires one to two months, with 35 to 40 days being common during the summer months (Stathers et al., 2005). Generally, the search for sources of resistance to sweetpotato weevil in the crop's germplasm has not yielded reliable results and hence no conventional breeding has been possible to date (Low *et al*., 2009); sanitation is particularly important for controlling the weevil population including removal of discarded tubers and unharvested tubers (Stathers 2005).

2.3.1.2 Impact of millipedes (*Scaphiostreptus parilis)*

Millipedes also known as "thousand-legged worms" or "Mombasa train" have recently become important pests of sweet potato in some areas of East Africa (Ebregt, 2007); infestation tends to be severe at the beginning of the long rainy season often contributing to perennial shortage of sweetpotato planting material and causing farmers to plant late

(Abidin, 2004; Ebregt *et al*., 2004a, b; 2005). Millipedes are normally a problem in nurseries located in shady sites (for example, under a tree), especially if the nurseries are used for a long time (Ebregt et al., 2004b), and it is recommended not to rotate alternate crops especially groundnuts and beans with sweetpotato crops (Ebregt, 2007). Delayed harvesting or in-ground storage of roots on the plants during dry season and harvesting done at the first rains of the following growing season results in high millipede infestation ((Ebregt et al., 2004a).

2.3.2 Experiences in conserving planting material for early planting

Having a sustainable supply of healthy vine planting material and obtaining sufficient quantities at the right planting time is not easy after a long drought (González, 2006). There are common reports of shortages of planting material caused by prolonged dry seasons: e.g., from Uganda (Dunbar, 1969), Tanzania (Mwanbene *et al*., 1994; Kapinga *et al*., 1995; 1998) and Swaziland (Nsibande & McGeoch, 1999) and special means have to be made in order to obtain planting material during the rainy season (Namanda *et al*., 2003a). All the methods have major disadvantages: shoots from volunteers are associated with late planting by up to 2 months and low quality planting material, potential wetland areas are limited, watering throughout the dry season is laborious and tree shade provides very limited planting material; consequently, sweetpotato as a major staple food still remains limited to areas lying close to the Equator (Gibson, 2009). Conserving and multiplication of sweetpotato planting material are key elements to alleviating the chronic shortages (Kapinga *et al*., 1998; Namanda *et al*., 2003a).

2.3.2.1. Rapid Multiplication Technique (RMT)

A rapid multiplication technique (RMT) was devised by NARO, NRI and CIP to reduce the time taken for vines to mature in nurseries (Benesi *et al*., 1998; Mudiope *et al*., 2000; Stathers *et al*., 2005) aimed at producing large amount of planting material. Cuttings taken from established plants or sprouted roots are cut into small pieces called “mini” cuttings of about 10 cm length using sharp knives to ensure clean cuts. Each piece should have three nodes, two of which will be buried and the top leaf remaining attached. The tip of the vine does not need to be discarded unless it is very thin. Only healthy, disease and pest-free vines from a two to three month old crop are used for multiplication. Since vine production is the goal, the nursery bed is planted at a high density (100 cuttings/m^2). The nursery bed needs to be regularly watered two or more times a day, especially in the first few days of establishment to avoid becoming dry. The nursery bed can be lightly shaded with grass to protect it from excessive loss of moisture. The vines will be ready for harvesting after a period of two to four weeks and have to be removed from the seedbed carefully to avoid damaging the roots. Generally, RMT has not been adopted for generating planting material during the long dry season because of the need for frequent watering and other intensive care (González, 2006; Yanggen & Nagujja, 2006).

2.3.2.2 Experiences in using roots to multiply and conserve sweetpotato planting material

In Dumka district in Bihar State, India, sweetpotato tubers are buried in a 2-3 feet deep pit in November/December. The tubers stay in the pit for about three months during the dry season, by which time they have developed small sprouts. These roots are taken out and planted near a source of water and allowed to grow till the end of April. The resulting vines are cut into pieces of 30 – 40cm and replanted over a larger area to provide planting material for the main crop in July - the planting time for sweetpotatoes. The root to vine method of generating planting material was observed by farmers to produce more vigorous planting material compared to the vine to vine method. However, earlier studies reported that, under the pit method of storage, roots sprouted within a month and there was excessive rotting of stored roots (van Oirschot *et al*., 2007). Thus, the need to investigate the methods and conditions of root storage and maintain the health status of the seed roots until an appropriate time of planting out (Ray & Ravi, 2005; Ray *et al*., 2010).

In temperate regions, planting material is produced from roots which are stored over winter and planted out in early spring in beds, often heated. Roots that are 2.5 cm to 5 cm in diameter should have 2.5 cm or more between them, and larger seed roots should be spaced so that roots do not touch. The beds are covered with 2.5 to 7.5 cm of sand. Vine slips are harvested when they are 20 to 30 cm long or when there are 8 or more leaves. It is recommended that sprouts be cut at the soil line to help prevent the spread of disease that might occur when underground portions are also taken (Garrett, 1988). Source of cuttings can be improved by fertilizing the beds, taking cuttings when the plants are vigorously growing and about 2 – 3 months of age (Franklin, 1988). Nitrogen fertiliser (50kg N/ha) should be applied to boost growth but excessive nitrogen fertiliser application causes rankness (tenderness of vines), which results in weak vines (Franklin, 1988; Moyo, 2000) A complete fertiliser is recommended for plant beds (Jonathan, 1998) at the rate of 142 g/m2 of 10-10-10 fertilizer. Urea and ammonium nitrate are preferred to ammonium sulphate as it tends to acidify many tropical soils (Morita, 1969).

2.4 Current knowledge of the storage of sweetpotato roots

The information in this section relates to the storage of sweetpotato roots for sprouting to produce planting material even though the references apply to the storage of roots for consumption. However, the two objectives differ only in the length of the storage period. Storage for food aims at keeping roots for up to 6 months; storage for seed is for about 3 months when they are planted in watered nursery beds.

Sweetpotato roots are perishable and are not normally stored long in the tropics (Kay, 1973); home storage is not possible for more than 2-3 months (Rashid, 1990). The shelf-life (a few days to a few weeks) of roots depends on the cultivar, the conditions prevailing at the time of harvest and the (high) respiratory rate immediately after harvest (Ray *et al*., 2010). In Uganda harvested roots are rarely kept for more than 4 days especially when damaged, as rotting quickly sets in. Options for farmers are to leave them in the ground where they get infested with weevils or to store them in underground pits covered with grass, usually for about a week (Mwanga & Wanyera, 1987). Rees *et al.* (2001) proposed that the short shelf-life of roots was due to cuts, weevils, rotting and superficial damages. Other factors causing postharvest losses of stored roots included factors such as moisture and temperature (Ray & Ravi, 2005) and damage occurring during harvest and during transport and marketing (Tomlins *et al*., 2000; Tomlins *et al*., 2010). Curing promotes rapid healing of wounds inflicted during harvesting, increases the toughness of the skin (periderm) of the root to minimize infection by micro-organisms during storage and makes the roots more resistant to wounding during subsequent handling (Onwueme, 1978). It is achieved by keeping the roots at high temperatures (27 – 29.5^{0}C) and high relative humidities (85 – 90%) for 4 – 7 days (Onwueme, 1978). In the Tropics, artificial curing may not be necessary as the roots will cure under ambient conditions.

Various storage methods including pits, a sand bed, sawdust, earthen pots and heaps in the corner of a house are practiced in the Tropics (Ray & Balagopalan, 1997). Notably, sweetpotato can successfully be stored at 13 – 16^{0}C and RH of 85 – 90 % if subjected to 27 – 29.5^{0}C at RH of 85 – 90% for 4 -7 days before storage but, at temperatures lower than 10^{0}C, roots are susceptible to decay due to chilling injury (Kay, 1973). Sweetpotato genotypes vary widely in their susceptibility to fungal diseases including *Fusarium* and *Rhizopus* species that cause rotting in tropical countries like Bangladesh (Jenkins, 1981), China (Sheng & Wan, 1988; Chen et al., 1990; Feng et al., 1995), India (Ray & Naskar, 2000) and Peru (Cadenas & Icochea, 1994). Varietal differences in dry matter content have also been reported to affect storability. Losses during storage can be considerably reduced by storing only those that are free from damage caused by handling or attack of insects and diseases (Rashid, 1990). Pits covered with grass or baskets commonly resulted in sprouting and spoilage **(**Onwueme, 1978); it was also laborious to dig the pits (Akoroda *et al*., 1992). Sprinkling roots with ash and then covering them with dry vegetation and soil was not very effective as they were susceptible to weevil damage and soft rot. Mpagalile *et al*. (2007) reported fewer losses due to rotting and pest infestation of roots stored for 3 months using an improved house pit (Mjinge) and improved open pit compared to traditional pit storage and Kihenge methods. Desiccation can be minimized by low ambient temperature and oxygen supply, thereby reducing respiration, sprouting, rot and discouraging weevil damage (Akoroda *et al.,* 1992; Woolfe, 1992; Mtunda *et al*., 2001; Rees *et al*., 2001; van Oirschot *et al*., 2007) and maintaining high humidity around the stored roots by covering these with sand, soil or stubble (Rashid, 1990). Exposure of storage roots to direct sunlight before storage appears to lead to excessive loss of moisture causing to tissue breakdown (Ray & Balagopalan, 1997). These methods of storage are only satisfactory for a period of about 2 months.

2.5 The role of the International Potato Center (CIP) in sweetpotato development in sub-Saharan Africa (SSA)

The International Potato Center (CIP) is a member of the Consultative Group for International Agricultural research (CGIAR) with the mandate for sweetpotato, potato and minor Andean crops. CIP's sweetpotato research priorities focus on two main regional areas: SSA and Asia. The sub-Saharan regional office is based in Nairobi, Kenya and, in collaborations with the National Agricultural Research Institutes (NARI) in the East African region, develops and releases new germplasm including orange-fleshed sweetpotato (OFSP). CIP's sweetpotato research and development activities are focused mainly on the generation and phytosanitary improvement, ensuring an adequate supply of planting material at the right time especially in areas normally experiencing longer dry seasons and on the health benefits of orange-fleshed varieties. Lack of sufficient quantity of quality seed in SSA has long been a bottleneck to improved sweetpotato productivity, improved varietal diffusion, and ability to control sweetpotato virus disease and weevil infestation through integrated management approaches. CIP in partnerships with NARIs and selected development partners implemented different projects in the SSA, East African region namely

a) SASHA (Sweetpotato Action Security and Health in Africa)– Partnerships with NARIs for breeding for OFSP, resistance to SPVD and weevils and, with CRS (Catholic Relief Services) as a lead implementing partner in Lake zone of Tanzania, to promote the multiplication and conservation of clean planting material through decentralised vine multipliers, variety evaluation trials and virus-free of planting material
b) FAO implementation of Farmer Field Schools (FFS) in Eastern Uganda, Western Kenya and the Lake Zone of Tanzania regions

c) Harvest Plus, (part of \international Food policy Research Institute (IFPRI) is the major partner in disseminating OFSP varieties

d) CIP in collaboration with NARIs and NGOs piloted the REU (Reaching End-User) project and the DONATA project (Dissemination of New Agricultural Technologies in Africa) in areas of Uganda, Kenya and Tanzania.

e) NARIs have used the results of CIP's pre-breeding programs, resulting in the release by NARIs of several β-carotene (pro-vitamin A)- rich sweetpotato varieties commonly known as OFSP.

f) Sweetpotato Integrated Crop Management and the Sweetpotato Farmer Field School Concept – CIP in collaboration NRI and FAO. The Farmer Field School is based on the principles of learning through experience and takes into consideration the continuous need for well-adapted training and capacity building to achieve meaningful results and links with local farmer innovation systems.

Table 4: Storing roots using different methods (Ray & Ravi, 2005).

Sweetpotato post-harvest losses and causes under different storage methods in the tropics.

Storage method	Storage period	% loss	Causes
Bamboo lined pit under thatched roof	8 weeks	22.1	Weight loss
		82.0	Sprouting
Clamp under thatched roof	8 weeks	22.4	Weight loss
		77.0	Sprouting
Clamp	3 – 5 months	30.0	Weight loss and rotting
Pits in open area/corner of the house and covered with paddy straw	6 months	< 20.0	Weight loss, rotting
Simulated pit condition in laboratory	2 months	50.0	Rotting
Pit with alternate layers of wood ash	1 – 2 months	20 – 40	Weight loss, rotting and sprouting
Heap storage	2 – 4 months	20 – 25	Rotting/weevil
Roots piled on a bench like platform made of bamboo	2 – 4 months	20 – 25	Weight loss/rotting, rodent infestation, weevil
Trench 50 cm deep covered with sand and sheltered by a roof	7 weeks	35	Rotting
		45	Sprouting, weevil
Sand	6 – 7 weeks	< 30.0	Weight loss
Closed cardboard cartoons covered with grass	-	29 – 35	Weight loss
		5 – 44	Sprouting
Cool chamber (double layered brick wall filled in with sand)	5 – 6 weeks	-	Sprouting

Under heap storage, storage period is reduced if weevils are present (Hoa, 1997) and losses of up to 95% were observed in Nigeria (Olorunda, 1979). Sand storage provided a modified atmospheric condition by limiting the supply of oxygen, maintains low temperature as well as a barrier for entry of sweetpotato weevils and roots could be stored for up 45 days without significant loss (Ray *et al*., 2010). Sweetpotato in sand suffered less weight loss than those stored under ambient conditions (Ray *et al*., 1994). Sweetpotato can be best stored at temperatures between 12 and 15^{0}C at 85 to 95% RH without loss of quality for up to one year (Ravi *et al*., 1996).

Studies on the physiological behaviour of roots from different genotypes of the collected germplasm revealed the existence of genetic variation in weight loss and sprouting during storage (Rashid, 1990). The shelf life of roots varies from a few days to few weeks according to the cultivar, conditions prevailing at the time of harvest and during storage (Lewis and Morris, 1956; Wagner *et al*., 1983; Doku, 1989; Kurup and Balagopalan, 1991; Cabanilla, 1996; Acedo *et al*., 1996; Rees *et al*., 1998; Mtunda *et al*., 2001). This indicates that improvement in storability is possible through selection of appropriate genotypes. Even so, the existing options of root storage cannot preserve the roots healthy and alive for long.

Respiration: Respiration and transpiration contribute to loss in weight and alteration of the internal and external appearance of roots (Kushman & Pope, 1972; Winaro, 1982; Picha, 1986; 1987). Most works indicated that respiration was greatest immediately after harvest (Kushman & Pope, 1972; Picha, 1987; 1986; Walter *et al.*, 1989). Because starch is used as a respiratory substrate, the content of starch, the predominant form of carbohydrate in the roots, is decreased during storage (Dempsey *et al*., 1970; Scott *et al*., 1970), decreasing the dry matter content of the roots. Wounding of sweetpotato roots resulted in an increase in both the respiration rate and subsequent weight loss (Jenkins, 1982; Picha, 1986). Respiration increased in sweetpotato roots exposed to a cool temperature of 10°C (Lewis & Morris, 1956; Kushman & Deonier, 1959). All these studies on respiration and consequently moisture loss were conducted in temperate conditions but respiration rates are much greater in the Tropics because of higher temperatures. Cultivars having low dry matter content may have a shorter storage life (Hirose *et al.*, 1984**)** due to maximum rates of respiration and rapid evaporation of moisture through the root skin (Jenkins, 1982). Further loss in moisture leads to a condition known as 'pithiness' in which cavities appear within the tissues (Kushman & Wright, 1969; Picha, 1986). Prolonged moisture losses, as those occurring in tropical conditions, result in collapse of tissues which begins at the distal ends of the roots and may ultimately cause total desiccation, especially in small sized roots (Jenkins, 1982). In Indonesia, piles of roots are usually covered by coconut palm, banana leaves or plastic sheets to prevent desiccation (Watson *et al.*, 1992). Percentage weight loss is sometimes used to evaluate the level of physical damage caused by various sweetpotato harvests and handling methods (Tomlins *et al*., 2000). Roots stored in sand showed the least weight loss (Ray & Balagopalan, 1997).

Sprouting: Delayed harvesting (Ray & Ravi, 2005) and prolonged storage in conditions of high temperature and humidity cause root sprouting (Bourke, 1982; Jana, 1982; Winaro, 1982). In the Tropics, sprouts are generally broken off as they appear (Ray & Ravi, 2005). Sprouting can be suppressed or inhibited by storing the roots at relatively cool temperature (14°C). The other methods for suppressing sprout formation are gamma irradiation and application of growth regulators (Ray & Ravi, 2005) but these seem inappropriate for roots stored for sprouting. Sprouting was 99% reduced when roots were stored in diffused light in a hut made of bamboo (Data & Barcelon, 1985; Icamina, 1985; Data & Eronica, 1987; Data, 1988) but must be very susceptible to weevil damage. During storage, intact tubers form sprouts on the head region and will exert apical dominance which suppresses the formation of sprouts on the other parts of the root but this can be minimized by de-sprouting (Onwueme, 1978).

Respiration and sprouting are key physiological changes in roots that affect successful initiation of development and growth of sprouts into shoots and into sweetpotato vines that are a target source of cuttings for planting. Thus understanding the conditions under which sprouting is suppressed or delayed are important in developing the appropriate method of root storage. Sprout formation can occur in dry soil, dry saw dust, dry shredded newsprint, or even on the shelf but the sprout remains short as sprout elongation is mainly dependent on an external water supply (Onwueme, 1978). Pre-sprouting allows the farmer to plant only roots of proven sprouting capability, as a result the percentage emergence in the field is greater than when fresh roots are directly planted, emergence occurs rapidly and uniformly after planting and rotten ones can be discarded (Onwueme, 1978).

Chapter 3

Materials and Methods

3.1 Description of rainfall trends and farming systems of areas of field study

Rainfall distribution has generally been categorised as: a) High: >1 750 mm *per annum* - 4% of the land area, b) Moderate: 1 000 - 1 750 mm *per annum* - 70% of the land area, and c) Low: <1 000 mm *per annum* - 26% of the land area. Rainfall distribution in southern Uganda is bimodal, allowing two crops annually, and adequate grazing for livestock throughout the year. Around Lake Victoria the annual rainfall averages 1 200 - 1 500 mm and it is well distributed throughout the year. In the north, the two rainy seasons are beginning to merge into one. Dry periods at the end and start of the year have become longer and annual rainfall ranges between 900 - 1 300 mm, restricting the range of crops that can be grown. These conditions are not suitable for bananas but favour extensive livestock production and annual crops. The influence of soils, topography and climate on the farming systems (Plate 3) in Uganda has led to the dividing of the country into seven broad agro-ecological zones (Table 5).

Plate 3. Location of the main study areas in Uganda

On-farm research was conducted in Mukono, Kamuli, Kumi/Bukedea and Soroti districts in Uganda (Plate 3) and the Triple S method was validated in Meatu, Mwanza and Shinyanga regions in Tanzania.

Table 5. Summary of agricultural systems of Uganda (MAAIF, 2011)

Farming system	Districts
Banana/Coffee System	Bundibugyo, parts of Hoima, Kabarole, Mbarara, Bushenyi, Mubende, Luwero, Mukono, Masaka, Iganga, Jinja, Kalangala, Mpigi and Kampala
Banana/Millet/Cotton System	Kamuli, Pallisa, Tororo, parts of Masindi and Luwero
Montane System	Kabale, Kisoro, parts of Rukungiri, Bushenyi, Kasese, Kabarole, Bundibugyo, Mbarara, Mbale and Kapchorwa
Teso systems	Soroti, Kumi/Bukedea, Kaberamaido
Northern System	Gulu, Lira, Apac, Kitgum
Pastoral System	Kotido, Moroto, parts of Mbarara, Ntungamo, Masaka, Ntungamo, Masaka and Rakai
West Nile System	Moyo, Arua and Nebbi

Mukono District follows the banana - coffee system, rainfall (1000 - 1500 mm) is evenly distributed during the year and soils are heavy of medium to high productivity. . The typical total household land holding is 2 - 4 hectares of which less than one hectare is normally cultivated (Namanda *et al*., 2001). Banana is the main food crop and coffee is the main cash crop; root crops and maize are on the increase. Maize is a secondary cash crop and sweetpotato is a secondary food to bananas. Livestock are rare though dairy cattle are gaining prominence (MAAIF, 2011). The natural vegetation is mainly a forest-savannah mosaic. Figure 1a show that Mukono receives generally above-average rainfall throughout the year, with two peaks separated by only short periods of reduced rains around January and July.

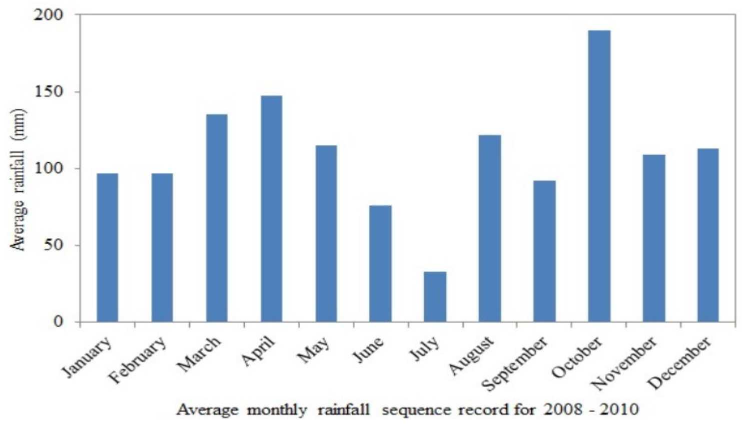


Figure 1a: Average monthly rainfall (mm) for Mukono district (NaCCRI 2010)

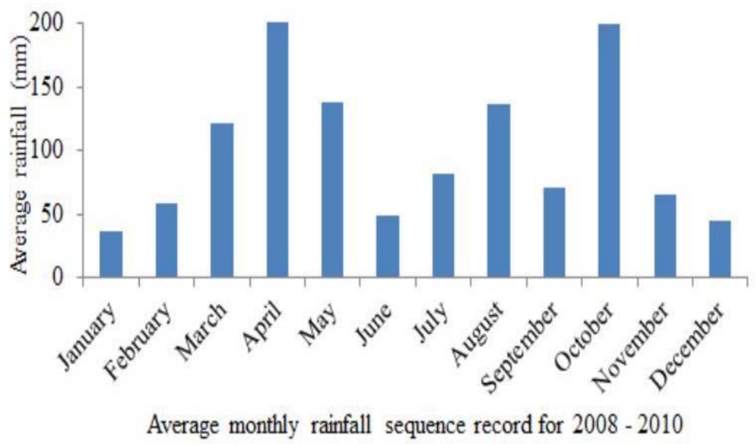


Figure 1b: Average monthly rainfall (mm) Kamuli (NaCCRI 2010)

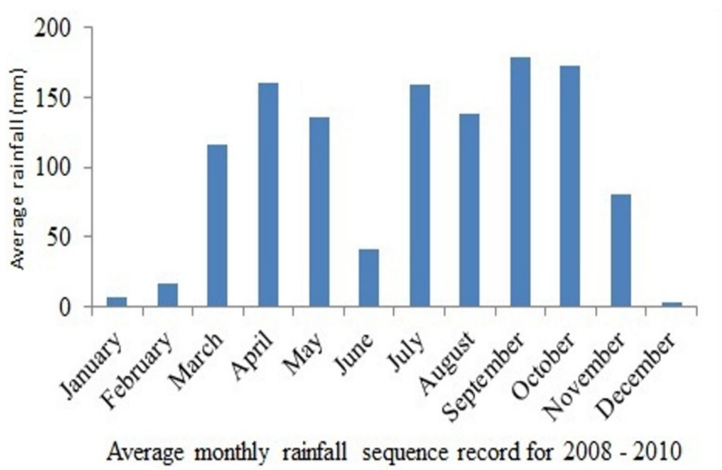


Figure 1c: Average monthly rainfall (mm) for Soroti/Bukedea (NaCCRI 2010)

Kamuli District is in the banana-millet-cotton system, with less stable rainfall than in the banana-coffee system, so there is greater reliance on annual food crops (millet, sorghum, cassava, sweetpotato and maize). In the drier areas, livestock is a main activity. Figure 1b shows that Kamuli experiences 2 dry periods, one from December to February and one from June to September.

Soroti, Kumi and Bukedea districts are all in eastern Uganda and have served as a test bed for many agricultural development initiatives (MAAIF, 2011; Friis-Hansen *et al*., 2004). Soroti and Bukedea are located within the Teso system, an area that has sandy loams of medium to low fertility. The main dry season is longer than in Kamuli, from December to March. The natural vegetation is moist *Combetrum*/*Butyrospermum* and grass savannah; short grassland which is ideal for grazing. The staple foods are cassava, sweetpotato, millet, maize and sorghum; other crops are oil seed crops (groundnuts, simsim and sunflower) and cotton is the major cash crop. Livestock are commonly kept; the soil is light and cultivation by oxen is practiced. The use of crop residues is very common in the Teso system. The average farm size is about 3 hectares. Soroti meteorological data (figure 1c) show its climate is normally characterized by a short dry spell between the two rainy seasons in late June and a long dry season from mid-November through to early March (NaCCRI 2010, Friis-Hansen *et al*., 2004; 2005). Rainfall ranges from 1000 mm to 1200 mm but its reliability is poor, often leading to frequent droughts and floods (Friis-Hansen *et al*., 2004; 2005). Of the three districts, Soroti, the furthest north (Figure 1), experiences the longest dry period of at least 18 weeks (November – mid March), generally with no interrupting rainstorms.

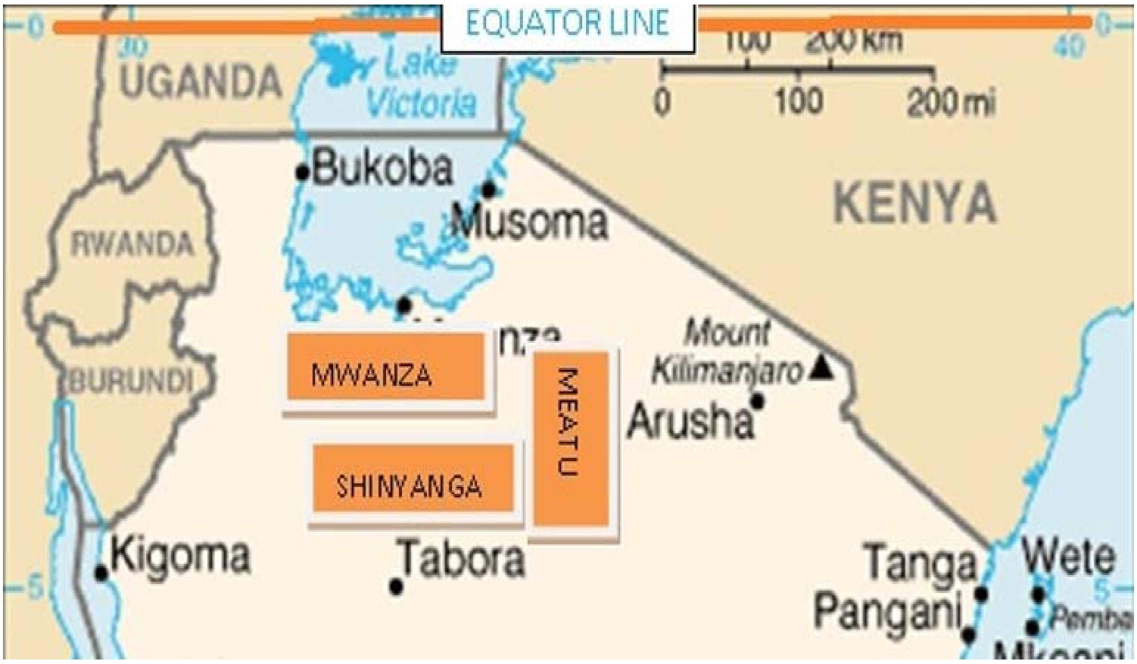


Plate 4. Locations of Mwanza, Shinyanga and Meatu regions in the Lake zone of Tanzania (adapted from a map by the National Bureau of Statistics (NBS), 2007.

Mwanza, Shinyanga and Meatu regions are all located in the Lake Zone of Tanzania, around Lake Victoria in the northern part of Tanzania. They lie between latitude 1^0 30’ and 3^0 0’ south and longitudes 31^0 45’ and 34^0 10’ east. Temperature and rainfall are influenced by their proximity to Lake Victoria, Mwanza region, lying on the coast, having a less harsh dry season than the more inland Shinyanga and Meatu regions. Shinyanga and Meatu regions have clearly distinguished rainy and dry seasons, the rainfall is only 600 - 900 mm per year and the average temperature is about 28^0C. The rainy season usually starts between mid-October and November and ends in the second week of May with a first peak in November, a dry spell which usually occurs in January, and a second peak (the long rains) between February and mid-May. Conversely, the long dry season begins in mid-May and ends in mid-October. The dry season is especially harsh in Shinyanga, with virtually no rain; the soils are hard to cultivate, pastures become very poor, and availability of water for domestic use and livestock become acute.

Maize, cassava and sweetpotato constitute about 70% of all food crops grown in the region. In most years, the regions are unable to feed themselves due to drought. There is plenty of water from the Lake and from ponds along the available numerous river valleys in the region but, currently, irrigation is carried out in only about 6 % of the total irrigatable land.

3.2 Background of the study area and research agenda

During 2000 – 2006, I worked as an International Potato Center (CIP) Research Assistant, leading the implementation of Sweetpotato Farmer Field Schools (SPFFS) in Soroti, in Western Kenya and in Bukoba in the Lake Zone of Tanzania. Through season-long (from seed to harvest) interactive meetings and from various SPFFS, an in-depth understanding of general crop production constraints especially the lack of planting material for early planting was identified (Stathers *et al.,* 2007). For example, in August 2002, 2 FFS groups (Apa Mora and Okungoro) received 2 orange-fleshed varieties namely, Ejumula (sweetpotato virus susceptible variety) and Kakamega from Central region of Uganda but at the onset of 2003 first rains only Apa Mora succeeded to produce and sell planting material at the beginning of rains. Okungoro lost all their seed through desiccation during the dry season and needed to wait for sprouts from underground roots before they could plant. The benefits generated from immediate sales by Apa Mora activated other groups to prepare better for the coming season.

However, during their focus group discussions, it was noted that the rapid multiplication techniques using mini cuttings was not appropriate (Gonzalez, 2006) because it involved watering up to twice per day for the first 5 days after planting (Stathers *et al.,* 2003). Thus, the following two scenarios were opted by different groups of farmers during the immediate multiplication and conservation activities;

a) Modification at Apa Mora scenario: Potential sites were identified, and as part of the preparations for 2004 first season, watering cans were bought to facilitate watering. Instead of using mini 10 cm long cuttings, they doubled the vine cutting length but maintained planting at high density.

b) Modification at Okungoro scenario: Individuals who anticipated the difficulty in watering opted to plant a late crop and leave it unharvested so the roots produced planting material for the coming season.

At the onset of season 2004, there emerged an immediate demand for planting material by FAO for wide scale distribution under the re-settlement programme for displaced people in Northern Uganda. Joint field inspections led by National Agricultural Research Organisation (NARO) scientists instituted and logistically facilitated by FAO verified the quality and quantity of planting material at the various multiplication sites. Multipliers belonging to Okungoro scenario did not have any material ready for supply.

In 2005, I was part of the team sent to Burundi to organise multiplication of planting material using scenario 1. After the fields had been planted, the insurgence re-occurred and watering could not be done, resulting in loss of some beds due to desiccation of the planted mini cuttings. Accordingly I was stimulated to think seriously about improvement of scenario 2 that has minimal risk due to dry spells. A draft proposal was developed and shared with the then CIP Liaison Scientist, Dr. Michael Potts, who encouraged me to transform the ideas into a research study. I made my first presentation during the graduate seminars at Makerere University in 2006 during which various academicians including Dr. Richard Gibson, my first supervisor, made several comments to improve the ideas. The close link to sweetpotato farmers and deep understanding of the farm factors deterring timely availability of sweetpotato planting material as highlighted was perhaps the main factor influencing my future decision to conduct on-farm research rather than on-station.

Studies were conducted including a preliminary field study to understand the factors affecting the traditional system of producing planting material which would form a basis for developing the research questions and designing the research. Information generated in the preliminary study contributed to the development of the questionnaire characterising the existing systems of producing planting material. The findings of the preliminary survey contributed to the design of research experiments on using roots and vine cuttings to produce planting material. These included comparing the productivity of sprouts and irrigated sources of planting material and on-farm trials to validate best bets using roots to produce planting material.

3.3 Preliminary field study

The purpose was to understand the factors affecting the natural generation of vines from sprouting roots and so develop testable hypotheses and protocols for new technologies manipulating production of vines so as to achieve their supply at the beginning of the first rainy season. In May 2007, about a month since the first rains had started, a visit to farmers' fields in Soroti where sweetpotato had been grown the previous season was made. Observations on randomly selected plants sprouting from roots of cultivars Araka, Ejumula and Kakamega were made on their vigour, the number of about 30 cm long cuttings that could be taken from each sample volunteer root was counted and possible causes of any dying or dead shoots investigated. The sampled sprouting roots were uprooted to find out whether there were any below-ground defects affecting the growth of the shoots. The sprouting roots were also examined for signs of damage, weighed, their diameter recorded and any disease on the shoots or roots, especially SPVD, identified.

3.4 Questionnaire on farmers' knowledge of planting practices

Based on observations during the preliminary field study, literature and a personal knowledge of the farming system in Uganda, a questionnaire was developed (Appendix 1) which included mainly 'open' questions in which the respondent was not limited to 'Yes/No' answers and which provided opportunity for farmers to give simple explanations including the advantages and disadvantages of different approaches. The questionnaire was pre-tested at non-target locations in Soroti, Mukono and Kumi during field visits. Initially, this study was to be undertaken only in Soroti, an area with a prolonged dry season where it was presumed to be highly relevant, but the Reaching End-User (REU) Sweetpotato Project (Wamaniala, 2008) needed similar information and had the logistics in terms of funds and a research team to conduct additional studies. This allowed three more districts, Kamuli, Mukono and Kumi, to be included in the study, so allowing findings from areas with other rainfall patterns to be compared.

The study was administered in 2008 during the dry season (Feb –March) when farmers have more spare time and at the farm 'doorstep' by research assistants who had a professional agricultural background and were fluent in the respective local language. A total of 44, 72, 105 and 50 farmers were interviewed from Mukono, Kamuli, and Bukedea and Soroti districts, respectively. This tool was used to provide information for the different chapters of the Results.

Data were analysed using the Chi-squared test in the Statistical Package for Social Scientists (SPSS) and then tabulated for report writing.

3.5 Field experiments on producing and maximizing the use of available planting material

3.5.1 Vine beds using longer cuttings and fertilizer application

The idea was to compare using the recommended mini cuttings (2-3 nodes) against the farmers' preferred vine length of 20 cm (Gonzalez, 2006) for the rapid multiplication technique (RMT). In the 2007 season, three varieties (Araka, Kabode and Kakamega) were used. Mini cuttings (10 cm) advocated by scientists and longer cuttings (20 cm) preferred by farmers of each variety were planted in raised propagation beds 1.2 m wide and 2 m long at a spacing of 20 cm between the rows and 10 cm along the rows and replicated three times in completely randomised block design. During the first week after planting, the beds were irrigated thrice and during subsequent weeks were irrigated twice weekly for 8 more weeks before the first harvest when the main stem length was about 45 cm long of 30 cm long apical vine portions. Harvest was recorded for the 3 middle rows (0.6 m wide x 2 m long) of each plot. Immediately after harvesting, the beds were weeded to loosen to the soil before top dressing with 100g/m^2 of urea fertilizer between the rows and worked into the soil before watering was effected. In 2007 season, there was a shortage of water and watering was missed for a complete week, resulting in some fertilizer treated plants getting scorched by the salt effect. The bed soil surface was covered by a whitish salty layer. Data collection was discontinued and during the subsequent 2008 and 2009 trial seasons, NPK fertilizer was substituted. After raising the beds but before planting the cuttings, 100 g/m^2 of NPK (25:5:5) fertilizer was broadcast on each bed and mixed into the soil using a hand hoe. Then light watering using a watering can was applied to soften the soil before planting the cuttings. The variety Kabode was also dropped in these trials because it was not easy to get the planting material. The treatments were allocated randomly to different plots in randomised block design.

Vine cuttings, each 30 cm long, were also collected from multiplication beds in Soroti and planted in Mukono, Kamuli and Bukedea in other raised beds 1.2m wide x 2 m long. The cuttings were also planted at 20 cm between rows and 10 cm within the row plants using

Kakamega (spreading) and Kabode (semi erect) varieties. NPK (25:5:5) fertilizer was applied to half the plots at a rate of 100g/m^2 in Mukono and Kamuli, the beds were irrigated 17 times (first week thrice and twice per week for the subsequent 7 weeks) using watering cans until the time of harvesting at the onset of the first rains. In Bukedea, the shallow beds were again next to paddy rice in a swamp where channels of flowing water between the beds moistened the soil and water flow blocked whenever watering was not necessary. The 30-cm long cuttings were similarly harvested by the host group at the onset of the rains, counted and recorded.

Findings were discussed with the farmer group members and the cuttings planted by the host farmers for production of storage roots. Only harvest data from the first cut was recorded for this study.

Data were collected on data entry sheets on the survival of planted cuttings, incidence of diseased or pest infested plants and the number of 30-cm cuttings harvested and counted; ANOVA tables were generated using the GenStat programme.

3.5.2 Planting density trial: Effect of using shorter and fewer cuttings for production of storage roots

The trial was planted in Soroti, an area that experiences 4 – 5 months of dry period and the soils are largely sandy. Three varieties were used: cv Kabode, cv Kakamega and cv Tanzania, a yellow-fleshed, semi-spreading, local variety with moderately thick stems. Cuttings of 10 cm, 20 cm or 30 cm lengths were planted on 0.6 m^2 mounds. One, 2 or 3 cutting of equal length were planted at the top of the mound (normal farmer practice) or around the hill (normal farmer practice in other parts of Uganda). The treatments were replicated 3 times and allocated to individual plots in a randomization block design (CRBD). The trial was planted twice under rain-fed conditions, during the second 'short' rains of both 2008 and 2009.

The number of surviving plants in each set of four central mounds was counted in each plot at 6 weeks after planting (WAP). Harvest data was collected from four central mounds: in case of any missing plants on any of the central mounds, up to three replacement mounds were randomly pre-selected before harvest from the surrounding mounds. Yield data on storage roots and foliage were collected at 18 WAP or general physiological maturity. Harvested roots were sorted into marketable and un-marketable ones, counted and weighed. The foliage was weighed. Data were analysed using GenStat.

Plate 5: Vine lengths (cm) planted at different plant densities in the field for root production. NB: the leaves were stripped off for the purpose of taking a photo but the planted cuttings were not stripped.

3.6 Field experiments on producing planting material using roots

Based on the outcomes of the preliminary and survey observations, a model system of producing planting material based on sprouting roots was envisaged which had three key stages, so requiring testing different treatments at each stage:

1. Testing whether cuttings from sprouting roots are as productive as vines obtained from mature plants maintained, for example, in a swamp or in the shade (3.3.1)

2. Producing storage roots perhaps in a specialist crop and thus requiring a sequential planting and harvesting trial to determine the appropriate timings (3.3.2)

3. Storing these roots in different conditions and comparing their sprouting capacity

All trials were done in Soroti in collaboration with SOSPPA. Finally, in collaboration with Lake Zone Agricultural Research and Development Institute (LZARDI), Ukiriguru, the final method was tested and validated in Mwanza, Shinyanga and Meatu regions in 2010.

3.6.1 Comparing the productivity of cuttings produced by sprouting roots and mature plants

In both 2008 and 2009, 30 cm long apical portions were harvested from any stem growth longer than 45 cm growing from roots. These cuttings were then used in a field trial to assess their productivity against cuttings obtained from plants that had been maintained under irrigation throughout the dry season. Trials were planted in April 2008 and 2009 in plots each 10 m long x 10 m wide. Treatments comprised 30 cm cuttings from sprouted roots and 30 cm cuttings from vines from plants of the three varieties maintained under irrigation by SOSPPA; treatments were replicated three times each year.

A record of dead and surviving cuttings was taken two weeks after planting. The trials were harvested in August in both 2008 and 2009 and the total numbers and weights of small, medium and large roots were recorded. Data were analysed using GenStat package.

3.6.2 Sequential seed root production and harvesting

Sequential plantings were made to test the appropriate period for production of seed roots to be sprouted. Three varieties were used: Araka, Ejumula and Kakamega. The varieties were planted for production of seed roots in field plots each 4 m wide x 10 m long at intervals of two months. Three cuttings were planted on mounds ($0.6m^2$) raised in each plot; each treatment was replicated three times in a randomised complete block design. In 2007, plots were planted in June, August and October; in 2008, plots were planted in April, June and August.

Roots were harvested from each sequence at maturity or senescence, whichever came earlier, and sorted into large roots (>10 cm in diameter), medium (5 to 10 cm in diameter) and small (<5 cm in diameter). A record of root counts and weights was taken. The June and August sequences were harvested in mid-December when drought caused the foliage to senesce; the October planting was harvested at the end of January. Harvested roots infested with weevil were separated, counted and weighed.

3.6.3 Storage and sprouting

In 2008, medium (≥ 5 cm - ≤ 10 cm) and small (< 5 cm) diameter clean [especially not weevilled] roots of Araka, Ejumula and Kakamega varieties from the June and August planting dates of the 2007 sequential planting trial were planted immediately after harvesting in plots at varying soil depths of 5 cm, 10 cm, 15cm and 25 cm. Two watering regimes were applied, starting watering either on 10 (10^{th} January) or 5 (10^{th} February) weeks to mid March when the first rains were expected to start. The bed size was 1.2 m wide x 2 m long and treatments were each replicated 3 times. The numbers of sprouts produced by a sample $1m^2$ area of each plot were recorded for the different spacing and the numbers of sprouts/root for the depth of planting were recorded.

There were problems of rotting tubers and inability of shoots to emerge experienced with planting directly in the soil in the 2008 season. Therefore, in 2009, seed roots from the 2008 sequential planting trial were harvested in mid-December, the large, medium and weevilled were discarded and, instead of planting directly in the root beds, the small roots were pre-stored in a pit at 15 cm depth under tree shade for 1 month (Tomlins *et al.*, 2009). One month later the roots were removed from the pits, sorted and counted, counting the healthy and rotten roots per variety and size category. The clean roots [already sprouting] for both small and medium sized roots were all planted at 10 cm depth and watering was started. The bed size was 1.2 m wide x 2 m long and treatments were each replicated 3 times. The numbers of sprouts produced by a sample $1m^2$ area of each plot were recorded for the different spacing and the numbers of sprouts/root planted at 10 cm depth.

There were also separate small replicated (3 times) experiments in 2008 and 2009 in which roots were planted at different spacing of 10 x 10 cm (100 seed roots/m^2), 20 x 10 cm (50 seed roots/m^2) and 20 x 20 cm (25 seed roots/m^2) and at slanting and upright orientations.

In both years, two watering regimes were used: starting at 10 (mid-January) and starting at 5 weeks (mid-February) prior to the expected start of the rains (mid-March). The frequency of watering was twice during the first two weeks of planting and once every week during subsequent growth for 8 consecutive weeks after which watering was withdrawn. The total watering frequency was therefore 12 times for the mid-January planted roots and 7 times for the mid-February planted seed roots watered for a total of 5 weeks consecutively. The numbers of sprouts produced by a sample 1m^2 area of each plot was recorded and analysed by GenStat programme.

3.6.4. Preliminary on-farm testing of the root based techniques

In 2009, a preliminary best practice in producing planting material using beds of sprouting roots had been generated from the results of 2008 season [see Chapter 6]. Beds were raised on smallholder farms in Mukono, Kamuli and Bukedea districts, all Harvest Plus/Reaching End-User (REU) implementation areas and planted using the orange-fleshed varieties Kakamega (spreading) and Kabode (semi erect) (NARO, 2007). The seed roots (≤5 cm in diameter) were from fields planted purposely to ensure production of clean seed roots. Bed size was 1.2 m wide x 2 m long and spacing was 20 cm between the rows and 10 cm within the rows. The beds were planted 10 weeks prior to the expected beginning of first rains and watered. Each of the 3 locations was a replicate. In Mukono and Kamuli, the beds were watered 8 and 6 times using watering cans, respectively, until the time of harvesting the vine cuttings at the onset of the first rains. In Bukedea, the shallow beds were next to paddy rice beds where channels of flowing water between the beds percolated through to moisten the soil. The 30 cm long vine cuttings were harvested from the 3 middle rows of each plot at the beginning of the rains, counted and recorded. After data collection, the material was given to the farmer to plant.

3.6.5 Experiments on using roots stored in different ways to produce planting material in Kumi and Soroti (Uganda)

Preliminary visits were made to two farmer groups, to introduce the idea of using roots to multiply planting material: to Mr Eugene Ekinyu's SOSPPA group in Soroti and Mr Sois's group in Kumi. Possible options of storing the roots were suggested including the known pit method (Tomlins *et al*., 2010), burying the roots in ash and sand (Ray & Ravi, 2005; Mpagalile *et al*., 2007) in buckets and coating roots treated with ash, insecticide and various botanicals in baskets. Collaboration was agreed. The different means of root storage agreed upon for testing at each site are as described in Table 1. Notably, Ekinyu's group wished to include the use of botanical preparations including lantana herbs mixed chilli to control weevils during storage and Sois' group opted to include a local variety, Esapat, which they reported stores for a longer time during the dry season.

3.6.5.1 Storage treatments for the roots

Roots were harvested in Soroti, Uganda on 19th December 2009, when the long dry season had just begun and at the peak of harvests for the season's sweetpotato crop. Cultivar Kakamega (orange-fleshed variety) was from SOSPPA for both sites and cultivar Esapat was from Mr Sois's field. Harvested roots were sorted to remove those that were large, pest infested or had other visible defects.

Table 6: Different means of storing sweetpotato roots tested at Ekinyu's and Sois' farmer groups in Uganda

Ekinyu farmer group	Sois farmer group
Kakamega variety	Kakamega and Esapat varieties
A plastic bowl containing dry sand kept in a roofed shed	A plastic bowl containing dry sand kept in a roofed shed
A plastic bowl containing dry ash kept in a roofed shed	A plastic bowl containing dry ash kept in a roofed shed
A pit in the open covered with 10cm of soil	A pit in the open covered with 10cm of soil
A pit in the open covered with 20cm of soil	A pit in the open covered with 20cm of soil
A pit lined with dry grass/straw under a bush covered with 10cm of soil (recommended)	A pit lined with dry grass/straw under a bush covered with 10cm of soil (recommended)
A plastic mesh basket containing roots treated with Actellic (O-(2-diethylamino-6-methylpyrimidin-4-yl)-O,O-methyl phosphorothioate) dust	A plastic bowl containing roots treated with Actellic dust
A plastic mesh basket containing roots without treatment	A plastic mesh basket containing roots without treatment
A plastic mesh basket containing roots treated with dry lantana (*Lantana Camara*) herbs mixed with chilli	Not tested
A plastic mesh basket containing roots dusted with ash	Not tested
A plastic mesh basket containing roots treated with dry lantana herbs	Not tested

For the bowls containing sand or ash, a layer of cardboard or paper was laid inside the basin before the sand or ash was poured in. This was to absorb any moisture from the roots and allow air to circulate. Then about 15 cm depth of sand/ash was poured at the bottom of the basin before a layer of roots was added. Then a second layer of sand of again 15 cm deep was added to separate the next layer of roots. The third 15 cm layer of sand/ash on top covered everything, and then the container was placed for storage in a building roofed with either grass thatch or iron sheets.

Plate 6: Roots placed in the basin showing the second layer and the paper lining between the basin and sand media. In this case, two varieties were placed in the same basin

For the storage pits, holes were dug to accommodate at least 50 roots and allow for a 10 cm and 20 cm cap, respectively. After placing the roots in the pit, a ruler was used to check that the right thickness of soil would be applied. The pits were covered and the depths of each written on sticks and used at the location of each pit as a label. Similarly a bigger hole was dug under shade provided by the shrubs, lined with dry grass/straw and covered with 10cm of soil (recommended method) (Stathers *et al*, 2007; Tomlins *et al*., 2010). It was easier to lay straw in a slightly bigger pit so 200 roots were kept in this pit.

Other roots were kept in a plastic mesh container (basket). Twenty-five roots were kept in each basket and were: (1) untreated controlled, (2) dusted with ash, (3) dusted with Actellic insecticide (O-(2-diethylamino-6-methylpyrimidin-4-yl)-0,0-methyl phosphorothioate), (4) lantana leaves were added (5) chilli pepper was added. All containers were kept in a roofed shelter.

After 2 months in storage, the group removed the roots and checked for progress in sprouting and removed rotten ones. A record of sprouted, un-sprouted and rotten roots was taken by the farmers but also monitored by me. Roots that had sprouts were de-sprouted and all the non-rotten roots were kept for another 1 month until it was about 1.5 months prior to the beginning of the rains.

3.6.5.2 Assessment of the storage of the roots

Observations on the open and shade covered pits were made after removing the roots from the pits (plates 5a and 5b). Roots kept in bowls containing sand or ash or basket containers with or without dust or botanical applications were carefully poured into a wheelbarrow (plate 5c) and sorted according to status: sprouting, rotting, and pest infestations (plate 5d). Participatory assessments (plates 5e and 5f) of the results were held with the farmer group members to discuss the observed root sprouting differences under the different treatments. The results obtained were compared and discussed with the farmers before selecting the most successful methods of storage.

a) Observing surface the 2 pits in the open

b) Removing stored roots from the pits

c) Removing roots from sand to wheelbarrow

d) Separated ash-treated roots

e) Comparing results from different treatments

Plates 7 a - e: Series of steps during evaluating the different storage methods after 2 months

3.6.5.3 Planting stored roots in irrigated plots

Only roots stored in the ash and sand in bowls and roots stored in the straw-lined pit under a bush were considered satisfactory for planting out. Roots were planted in a garden at a spacing of 1 m between the rows and 0.6 m within the row. Treatments were applied in a factorial design replicated 5 times. A composite fertiliser (NPK 25:5:5) another treatment was added at the rate of 20 g/hole before planting. Spare unplanted roots in either sand or ash at Sois's home were desprouted & replaced in their respective treatments. Roots were planted out at both Eugene and Sois' home gardens but Ekinyu's experiment was accidentally ploughed up and no results could be obtained. At Sois' site, the roots were watered thrice before receiving the first showers of rain. Water was collected from a protected well. A hedge of thorny shrubs was set around the perimeter of the experiment to protect the plants from grazing animals.

Table 7: The different storage and planting treatments applied to roots and tested by planting out at Sois' garden

Treatment number	Root storage	Variety	Fertiliser [NPK] applied to planting hole
1	Ash	Esapat	+
2	Ash	Esapat	-
3	Ash	Kakamega	+
4	Ash	Kakamega	-
5	Sand	Esapat	+
6	Sand	Esapat	-
7	Sand	Kakamega	+
8	Sand	Kakamega	-
9	Pit under bush	Esapat	+
10	Pit under bush	Esapat	-
11	Pit under bush	Kakamega	+
12	Pit under bush	Kakamega	-

On 16th April, before harvesting, the participants subdivided into men and women sub-groups agreed on the length of vine cuttings to use. Thirty centimetre long cuttings were harvested about 8 weeks after planting the root beds and the number of cuttings harvested was analysed.

3.6.5.4 Validating the use of roots to produce planting material in Mwanza, Shinyanga and Meatu (Tanzania)

As a result of the previous trials in Uganda, storing roots in dry sand in a building and then planting them out in a garden and watering till the rains arrived was considered to be by far the best method. Consequently, in May 2010, during a planning meeting of a subcomponent of the the Sweetpotato Action for Security and Health in Africa (SASHA) project (CIP) subcontracted to the Catholic Relief Services (CRS) held in May 2009 in Mwanza, Tanzania, the idea of testing this system of storing and sprouting roots was considered for implementation in the drier areas of the Lake Zone. The system was described and discussed with future research counterparts at LZARDI-Ukiriguru and trials in Mwanza, Shinyanga and Meatu regions were planned to give a transect of increasing length and aridity of the dry season as well as a diverse range of varieties.

A Tanzanian counterpart, Mrs. Rahila Amour, from LZARDI-Ukiriguru was included in the work. During the visit to set up the trials, an extensionist working alongside us in each region identified the farmers to be used. Three farmers in 2 villages separated by at least a distance of 5 km were identified in each of the 3 regions: Mwagala and Ngo'mbe villages in Mwanza region, Hapa and Mwangósha villages in Shinyanga region, and Bulyashi and Mwambiti villages in Meatu region. A total of 18 host farmers were thus involved in testing the root based method. As women predominantly grow the crop in these regions (Kapinga *et al*., 1995), all were women

Each host farmer identified 2 local varieties from her own fields. Sweet potato virus disease (SPVD)-free plants were harvested in May; the roots were sorted to ensure freedom from damage and kept in basins containing sand for storage in her house following the procedure used in Kumi and Soroti. The roots were monitored 2 months later at the end of

July when sprouting roots were de-sprouted; during the fourth week of September, the roots were planted and watered.

A final visit was made in mid-November during the rainy season to monitor the number of cuttings harvested for planting in their fields. Farmers' comments on the practice were recorded and performance data on the root beds including data on pest infestation and the number of cuttings harvested were collected. Farmers' responses were tabulated and harvest data analysed using GenStat. Subsequently follow up field visits in 2011 to participating farmers in Uganda and Tanzania were made to assess the participants' opinion about the applicability of the approach.

CHAPTER 4:

Understanding the characteristics of sweetpotato traditional farming systems in the agro-ecological study areas

4.1 Introduction

The study was conducted in four districts of varying agro-ecologies to examine the factors including average cultivated area and availability of planting material influencing production of sweetpotato under the different agro-ecologies. Farmers' responses provided a general perspective about the usefulness, profitability at household level and magnitude of sweetpotato in the different agro-ecological areas of study. This information was used to provide insights into to how farmers addressed the lack of planting material and limitations involved in obtaining planting material for planting at the onset of rains.

4.2 Materials and Methods

The study was conducted in Mukono, Kamuli, Bukedea and Soroti districts (Sections 3.4 and 3.5). These districts were selected because they represent three different farming systems with varying rainfall patterns and duration of dry periods between the growing seasons (see Chapter 3). A structured questionnaire (see section 3.4) developed on the basis of results from the preliminary field visit and knowledge of sweetpotato was conducted with a total of 271 respondents and results were analysed using the SPSS package. Farmers were asked about the different sources of planting material, portion of land under sweetpotato, cropping calendar and farmers' modes of multiplying and conserving planting material during the dry season. In particular, the effects of being able to plant early were investigated. It was suspected that late availability of planting material was limiting planting time and I therefore investigated the likely impact if this constraint was removed.

4.3 Results

4.3.1 Availability of and demand for sweetpotato planting material

During the survey that was conducted at the on-set of the rains, observations were also taken on farm activities on sweetpotato being by the farmers in view of the rains that had started. Below are photos (Plates 8a & b) captured involving an adaptive approach to plant early following the start of yet unstable rains and precautions taken to ensure that the planted vines do not dry.

Plate 8a: Farmers immediately planting within the days of receiving first rains and covering the planted vines with a film of soil to avoiding being exposed and desiccated

Plate 8b: Uncovering the planted cuttings 3- 4 days after planting using a stick or hands

Table 8: The number of farmers reporting a failure to plant a particular area of land at the beginning of last (2007) first rains due to lack of planting material.

	District				Total
	Mukono	Kamuli	Bukedea	Soroti	
Average normal area (hectares) planted by most farmers	0.25	0.13	0.38	1.55	
# (%) respondents failing to plant normal area from own source	0	21	15	29	65
# (%) of respondents failing to supplement	0	13	28	0	41
# of farmers asked	44	72	105	50	271

No farmers in Mukono reported being unable to plant all the area of sweetpotato they wished to plant (Table 8). In Kamuli, farmers reported planting the smallest plots to avoid loss of planted crop due to severe destruction by mole rats and reported the highest (62%) failing to plant the average normal area. Moving north from Kamuli and Bukedea to Soroti, the proportion of farmers failing to plant increased at the beginning of the planting period, the most (58%) being in Soroti.

Table 9: The numbers of farmers buying planting material for particular areas for the 2007 first rains

Hectares	District				Total
	Mukono	Kamuli	Bukedea	Soroti	
≤ 0.04	0	3	1	3	7
0.04 -0.08	0	1	2	4	7
0.084 - 0.16	0	0	0	1	1
0.164 - 0.2	0	0	2	4	6
0.204 - 0.24	0	0	0	1	1
0.244 - 0.32	0	0	1	2	3
0.324 - 0.4	0	0	5	5	10
0.404 – 0.6	0	0	0	1	1
>0.6	0	0	1	2	3
Total	0	4	12	23	39
No of farmers asked	44	72	105	50	271

The proportion of farmers buying planting material increased steadily from Mukono in the Lake Victoria crescent to the Kamuli in the east to Bukedea in mid-east to Soroti in the north east (Table 9). The proportion of farmers buying planting material to plant more than 0.4 ha was the most in Soroti (6%), more in Bukedea (1%) and no farmer bought planting material in Mukono districts. A number of farmers also bought planting material in Bukedea, probably because farmers are more commercial here, wanting to plant large areas early to sell into nearby Mbale.

Evidently, moving from Mukono, to Kamuli, to Bukedea and Soroti, an increasing proportion bought (P = 0.003) planting material.

Table 10: A comparison of Tables 8 and 9: The number of farmers in Soroti, Bukedea and Kamuli wanting to buy extra sweetpotato planting material and actually buying

Hectares	Wanting to buy				Buying			
	Kamuli	Bukedea	Soroti	Total	Kamuli	Bukedea	Soroti	Total
≤ 0.04	0	0	0	0	3	1	3	7
0.04 – 0.2	34	0	0	34	1	4	9	14
0.204 – 0.4	0	43	0	43	0	6	8	14
➢ 0.4	0	0	29	29	0	1	3	4
Total # of farmers asked	44	105	50	199	44	105	50	199

Very few (about 4 %) of the farmers who planted very small areas (≤ 0.04 ha) in Kamuli, Bukedea and Soroti bought planting material, perhaps because they lacked funds (Table 10). Overall, 53% of the farmers who were interviewed reported that they wanted to buy planting material, and 37 % of the farmers who wanted to buy, bought planting material. In Kamuli, Bukedea and Soroti districts, 12, 28 and 79 % respectively, of the farmers who wanted to, bought planting material. Only 3 % of the farmers in Kamuli who wanted to buy planting material to plant ≤ 0.2 ha were able to buy the planting material which may be attributed to unavailability of planting material. About 50 % of the farmers who bought planting material in Bukedea and Soroti planted more than 0.2 ha.

Table 11: The amount of money (Ug/-) spent by farmers to buy additional planting material

Money spent (Ug/-)	District			Total
	Kamuli	Bukedea	Soroti	
≤1,000	2	1	1	4
1,001 – 5,000	1	2	2	5
5,001 – 10,000	0	4	9	13
10,001 – 20,000	0	1	4	5
20,001 – 30,000	0	1	3	4
30,001 – 40,000	1	1	1	3
40,001 – 50,000	0	1	1	2
50,001 - 60000	0	1	1	2
>60,000	0	0	1	1
Total	4	12	23	39

Most farmers owning small plots reportedly were keen to buy planting material but failed to do so even for their small areas (Table 10). Most farmers spent 5 – 10,000/-, with a similar distribution in both Soroti and neighbouring Bukedea (Table 11). Notably, 75.0, 58.3 and 52.2 percent of the farmers spent less than UGSH 10,000 to buy additional planting material in Kamuli, Bukedea and Soroti districts.

4.3.2 Overall and specific effects of early planting perceived by farmers on sweetpotato production in Mukono, Kamuli, Bukedea and Soroti districts

4.3.2. 1 Overall effects of sweetpotato early planting perceived by farmers in four districts

Increased yields were perceived as the main benefits of sweetpotato early planting, especially in Bukedea and Soroti (Table 12). In Mukono, some farmers [though still very few] considered planting early caused a decrease in yield rather than an increase ($P = 0.001$). In discussions with Mukono farmers, the smaller yield due to early planting was attributed to the senile and diseased quality of planting material available for planting then. The main source of planting material is old fields that survive the desiccation of the short dry season and cuttings from these may have lost 'vigour'.

Table 12: Differences identified by farmers between either being able to plant at the beginning of the rains and having to plant later

Parameter	District				Total
Being able to plant at the beginning of the rains leads to:	Mukono	Kamuli	Bukedea	Soroti	
High/higher yields	3 (7%)	6 (8%)	46 (44%)	39 (78%)	94
Bigger roots	0	0	4	5	9
More roots	0	0	1	2	3
Higher price of roots	0	0	5	1	6
Early harvest	0	0	0	3	3
Less disease on crop	0	0	1	0	1
Easier planting of crop	0	1	0	1	2
Total positive responses	**3**	**7**	**57**	**51**	**118**
Lower yields	9	1	2	0	12
Smaller roots	0	0	1	0	1
More disease on crop	0	0	1	0	1
Total negative responses	**9**	**1**	**4**	**0**	**14**
Different roles of early & late-planted crops	0	0	0	1	1
Benefits depend on rainfall pattern	1	0	0	2	3
Total neutral responses	**1**	**0**	**0**	**3**	**4**
Irrelevant or unclear responses	0	12	0	3	15
Total interviewed	44	72	105	50	271

*Some respondents gave multiple responses

4.3.2.2 Specific pre-harvest benefits of sweetpotato early planting perceived by farmers in four districts

Table 13: Whether the numbers of farmers considering that planting early would make general farm management easier or harder and increase or decrease sweetpotato yield

Early planting makes management [Chi-squared (df 6), P = 0.001]:	District				Total
	Mukono	Kamuli	Bukedea	Soroti	
Easier	2 (5 %)	26 (56 %)	11 (10 %)	43 (86 %)	82
Harder	12 (27 %)	15 (21 %)	56 (53 %)	5 (10 %)	88
Has no effect	30 (68 %)	31 (43 %)	38 (36 %)	2 (5%)	101
Total interviewed	44	72	105	50	271
Effect of early planting on yield [Chi-squared (df 6), P = 0.001):					
Increases it	3	7	57	48	115
Decreases it	16	13	6	1	36
Has no effect	5	4	4	1	14
Total interviewed	44	72	105	50	271

There were big differences between sites (Table 13). Farmers in Kamuli (56%) and Soroti (86%) generally indicated that early planting eased crop management but many farmers in Bukedea (53%) and Mukono (27%) reported harder or no effects on crop management.

Table 14: The numbers of farmers in each district identifying a particular percentage increase or decrease in the yield of early-planted sweetpotato

% increased (or decreased) yield estimate [Chi-squared (df 24), P = 0.000]:	District								Total farmers
	Mukono		Kamuli		Bukedea		Soroti		
	No.	%	No.	%	No.	%	No.	%	
<-50	8	20	6	9	2	0	1	0	17
-50 – -26	4	8	4	4	2	0	0	0	10
-25 – 0	4	10	3	7	2	0	0	0	9
1 – 25	0	0	2	3	0	0	8	16	10
26 – 50	0	0	2	3	21	20	14	28	37
51 – 100	3	7	1	1	25	24	16	32	45
101 – 200	0	0	1	1	5	5	5	10	11
201 – 300	0	0	1	1	5	5	5	10	11
>300	0	0	0	0	1	1	0	0	1
Total interviewed	44		72		105		50		271

Most farmers [across locations] reported increases in yield of up to 300% due to early planting (Table 14). Moving north from Mukono to Soroti, Kamuli and Bukedea, 7%, 10%, 54% and 96 % of farmers reported increases in yield.

Table 15: The average yield increase (%) estimated by farmers from planting sweetpotato early

	District				Mean %
	Mukono	Kamuli	Bukedea	Soroti	
Mean	18	49	82	69	55
SE	8.0	8.0	9.0	7.8	

Bukedea and Soroti had a similarly high percent increase in yield estimated due to early planting (Table 15). Mukono, Kamuli, Bukedea and Soroti reported 36, 18, 6 and 2 percent negative effects of early planting (Table 14).

4.3.2.3 Sweetpotato preservation (Section 3.5)

Table 16: The numbers of households chipping and drying sweetpotato as a means of food preservation in the different districts

Does the household chip and dry sweetpotato [Chi-squared (df 3), P = 0.001]	District				Total
	Mukono	Kamuli	Bukedea	Soroti	
Yes	2 (5%)	17 (23%)	72 (69%)	50 (100%)	141
No	42	55	32	0	129
Total interviewed	44	72	105	50	271

Table 17: The numbers of farmers in different districts considering early planting makes sweetpotato more or less useful for home preservation [chipping and drying]

For home preservation, is early planting:	District				Total
	Mukono	Kamuli	Bukedea	Soroti	
More useful?	1	15	65	49	130
Less useful?	0	1	6	1	8
No effect?	0	0	2	0	2
Total interviewed	44	72	105	50	271

There was a steady increase in the percentage of households drying roots for preservation as one moved north from Mukono [2%] to Kamuli [23%], Bukedea [69%] and Soroti [100%] (Tables 16 & 17), associated with the increasing length of the dry season. In Soroti, all farmers interviewed indicated that sweetpotato slicing and drying is a common practice. Few farmers in Mukono responded to the question as to whether planting early it was more or less useful for this practice (Table 17); most farmers in Bukedea and Soroti districts did and considered it was.

Table 18: The numbers of farmers giving particular explanations why planting early is more or less useful for home preservation

Explanations	District				Total
	Mukono	Kamuli	Bukedea	Soroti	
Beneficial					
Easy to dry chips	0	2	11	21	34
Surplus roots for preservation	0	1	3	8	12
Total	0	3	14	29	46
Not beneficial					
Busy with other workload	0	0	6	1	7
No surplus food	0	0	6	1	7
Hard to dry in rainy season	0	0	4	1	5
Total	0	0	16	3	19
Neutral	0	0	3	2	5
Total interviewed	44	72	105	50	271

No farmer interviewed in Mukono and very few farmers in Kamuli responded to this question: they do not chip and dry sweetpotato. There is a nearby market for sales of fresh roots in Kampala etc and the short dry season means periods of food scarcity are few and short. Interestingly, only in Soroti did more farmers here overwhelmingly give answers indicating that it was beneficial to plant early for sweetpotato preservation (Table 18) – whereas in Table 15 it was also farmers in Bukedea. It is drier in Soroti and the rainy season is shorter so there may be more opportunities to dry. Also, the presence of many other short duration crops in Bukedea means farmers have a busy workload during the rainy season.

4.4 Discussion

Moving north from Mukono to Kamuli and Bukedea to Soroti, the dry period gradually becomes longer. Figures 1a – 1c show that Mukono experiences poorly defined dry spell of about one month characterised by reduced rains, Kamuli receives two months of dry periods, Bukedea and Soroti experience at least four months with generally no storms. Overall, there was a lack of planting material in areas that experience prolonged dry season whereas there was no lack in areas which experience a short dry season (Table 8). Farmers in areas with a prolonged dry season reported a failure to plant as they wanted to, especially for small farmers planting small plots for home consumption. Thus, the farmers who were more willing to pay for the vines were those who planted bigger plots possibly because they would get money to recompense them when they sold and because they were richer. In Soroti, 79 percent of the farmers who wanted to, bought planting material, which may be attributed to unavailability of planting material and the majority of these planted ≥ 0.04 ha which may indicate the need to sell roots (Table 10) if you are going to buy planting material.

Moving from Mukono to Kamuli, Bukedea and then Soroti, more farmers bought ($P = 0.003$) and the plot size planted using purchased planting material increased (Table 9), probably because farmers are more commercial here, wanting to plant large areas early to sell at high prices in nearby Mbale. Very few (about 5 %) of the farmers with smaller than the average planting area planted by farmers in Kamuli, Bukedea and Soroti bought sweetpotato planting material (Table 10), perhaps because they lacked funds (Table 11) or it was not viable due to the small size of plots and absence of sales.

Greater yields and bigger roots (Table 12) were perceived as the main benefits of sweetpotato early planting, especially in Bukedea and Soroti but a few farmers in Mukono considered planting early caused a decrease in yield than an increase (P = 0.001). In discussions with Mukono farmers, the smaller yield due to early planting was attributed to the senile and diseased of planting material available for planting then. The main source of planting material is old fields that survive the desiccation of the short dry season and cuttings from these may have lost the ability to grow more vigorously.

In Bukedea and Soroti, areas characterised by a long dry season, early planting resulted in harder crop management in Bukedea and easier in Soroti. The reason for it being easy to manage in Soroti may be because farmers there have access to a lot of oxen for ploughing and cassava, the other main crop, there requires less labour. The majority of the farmers there reported a pronounced root yield increase ranging from 25 % to 300 %. Selling in Bukedea to Mbale (25 km) and Soroti to Kampala (400 km) for income was reported. Profitability of an early planted crop in Bukedea and Soroti districts was a function of increased yields and high selling prices of roots (Table 12). Slicing and drying for preservation were also reported to benefit from early planting in Soroti, where the shortness of the rainy season may mean even an early planted crop is still at optimum maturity and with little weevil damage by the time the dry season start. Elsewhere, it seemed less valuable, partly because chipping and drying occurs more rarely, or not at all in Mukono, and partly because it is more difficult if the crop matures before the rainy season ends or when other crops are maturing.

Generally, increase in yield would be achieved in areas with a long dry season if farmers planted early and the yield would be more useful for home consumption, for preservation and for sale. However, planting early is normally constrained by lack or high cost of planting material. Conserving more planting material in the swamps would provide a solution but it is questionable that this could be achieved, partly because of lack of money but also for environmental reasons. There are laws restricting the use of swamps for agricultural purposes. Making cuttings from sprouting ground keeper roots to provide an early source of planting material seemed likely to be the better way forward. This provided logical basis for the development of the Triple “S” concept.

CHAPTER 5:

Optimizing production in valley bottoms and use of the resulting planting material

5.1 Introduction

Growing a crop during the dry season in swampy land provides vines for planting material at the beginning of rains which is a common practice around Lake Kyoga in Uganda and the shores of Lake Victoria in Tanzania (Namanda *et al*., 2011). If there was no dry season, sweetpotato would be planted at any time because the sweetpotato crop only desiccates during prolonged dry periods (Yanggen & Nagujja, 2006; Gibson, 2009; Namanda *et al*., 2011). Thus, the capacity to conserve and multiply planting material during prolonged dry season is limited to areas where water supply is not interrupted particularly areas without limited ownership of wetlands, especially for the relatively poorer members of society. The ability of members of the general community to divert existing water resources for irrigation may also be limited by household rights to water, livestock having priority, and laws conserving natural water resources. Such competition for water (Namanda *et al*., 2011) will increasingly require efforts to maximise production of sweetpotato planting material using the minimum of natural wetlands or irrigation and to make best use of the planting material that is available. One option for sweetpotato planting material involves increasing its production by enhancing soil fertility to improve vegetative growth (Villordon & Franklin, 2007). Another is to extend the use of the limited planting material available by using shorter cuttings and reducing planting densities (Aldrich, 1963). However, neither of these should compromise the storage root yield (Kay, 1973; NRI, 1987; Mwanga & Wanyera, 1987). Investigations were made on farmer preferred length of cutting used for planting using the questionnaire (3.5) , farmer responses on question 8 (Appendix 1); comparison of 10 and 20-

cm long cuttings planted in watered beds under two different nutrient regimes; and varied plant densities and vine lengths planted to produce storage roots.

5.2 Materials and Methods

Data on shortage of planting material and farmer based interventions were imported from the questionnaire on farmers' knowledge on planting material (Section 3.5).

The trial vine beds (Section 3.7.1) planted using mini cuttings (2-3 nodes) to produce planting material was compared with the farmers' preferred vine length of 20 cm (4 – 6 nodes) for the rapid multiplication technique (RMT) in the 2007 season, using 3 varieties (Araka, Kabode and Kakamega), top dressing with urea fertiliser as another level of treatment. In 2008 and 2009 trial seasons, urea was substituted with a pre-planting NPK (25:5:5) fertilizer at 100 g/m^2. Data were collected on data entry sheets on the survival of planted cuttings, incidence of diseased or pest infested plants and the number of 30-cm cuttings harvested; ANOVA tables were generated using the GenStat programme.

Information was also extracted from the questionnaire on farmers' knowledge on planting material (3.5), farmer responses on question 8 (Appendix 1).

An additional trial was planted in Soroti to investigate effects of varying plant densities and using different vine lengths (Section 3.7.2) on producing roots of the 3 different varieties during the second 'short' rains of 2008 and 2009. Harvested roots were sorted into marketable and un-marketable storage roots, counted and weighed. Data on weight of foliage per plot were also collected. Data were analysed using GenStat.

5.3 Results

5.3.1 Optimizing the available planting material through using of shorter stem lengths and lower plant densities for production of roots (Section 3.6.1)

Table 19: The numbers of farmers using particular lengths of vine to plant their crop in Mukono, Kamuli, Bukedea and Soroti

Length of cuttings (cm)	District				Total
	Mukono	Kamuli	Bukedea	Soroti	
15	0	0	5	3	8
20	0	1	25	4	30
25	2	1	21	10	34
Total < 30	2	2	51	17	72
% overall total respondents using <30 cm					28.3
30	32	56	39	29	156
% overall total respondents using 30 cm					61.5
35	0	1	0	2	3
45	7	11	1	0	19
60	3	1	0	0	4
Total > 30	10	13	1	2	26
% overall total respondents					10.2
# of farmers asked	44	72	105	50	271

Farmers used a wide range of vine lengths across the different sweetpotato growing districts in Uganda but the majority (61.5%) used the recommended 30 cm long cuttings (Table 19). The use of shorter cuttings was associated with a lack of planting material in areas where the dry season was longer. Presumably those using shorter lengths were mostly successful; some farmers seemed likely to be using excessive lengths. Relatively more farmers in Mukono and Kamuli areas used cuttings longer than 30 cm than in Soroti and Bukedea (P = 0.001). About 50 percent of the farmers in Bukedea use short cuttings (15 -25 cm), rather more than in Soroti (P = 0.035).

Table 20: The numbers of farmers in Bukedea and Soroti using particular lengths of cuttings for vines obtained from mature plants maintained in wetlands and from sprouting ground keepers (roots that were accidentally left in the soil)

Length of cuttings (cm)	Cuttings from wetland crop			Cuttings from sprouting ground keepers		
	Mukono	Kamuli	Total	Bukedea	Soroti	Total
15 – 25	3	7	10	56	20	76
25	1	10	11	9	12	21
≤30	40	31	71	32	17	49
# of farmers asked	44	72	116	105	50	155

Farmers in Mukono and Kamuli rarely take cuttings from sprouting roots so results for only Bukedea and Soroti are compared. Most (90%) of farmers in Mukono plant 30 cm long cuttings from wetland crop compared to only 34% in Soroti from sprouts of roots in previous fields (Table 20).

A total of 72 farmers (28 %) used shorter cuttings than the recommended (Table 19) but 68 (95 %) of the 72 farmers were farmers from Bukedea and Soroti districts where cuttings are often sourced from sprouting groundkeepers. A greater proportion of shorter cuttings were taken from sprouts from ground keeper roots than cuttings from vines in both Bukedea and Soroti (P= 0.001).

5.3.2 Producing planting material using longer cuttings and fertilizer application (Section 3.6.2)

Cuttings 10 and 20 cm long were compared for production of 30 cm long vines of planting material for planting to produce storage roots. Urea or NPK fertiliser were used during seasons 2007, and 2008 and 2009 on Araka, Kabode and Kakamega varieties.

Table 21a: Effect of urea application on the number of 30 cm cuttings harvested per 1.2 m^2 for successive harvests in season 2007

Variety	Fertilizer regime		Average
	No fertilizer	Urea	
Araka	67	83	75
Kabode	47	45	46
Kakamega	104	69	86
Average	72	65	

Table 21b: Effect of vine length on the number of 30 cm cuttings harvested per 1.2 m^2 for successive harvests in season 2007

Variety	Vine length (cm)		Average
	20	10	
Araka	70	79	74
Kabode	37	55	46
Kakamega	76	97	86
Average	61	77	

Urea application resulted in less average number of cuttings harvested notably due to the scorching effect on the plants. Kakamega variety produced more cuttings without fertiliser than Kabode and Araka varieties (Table 21a). Planting longer cuttings increased the number of cuttings harvested (P<0.001) (Table 21).

Table 21c: Analysis of variance of the number of 30 cm long cuttings harvested from three varieties planted using 10 cm and 20 cm long under urea and no fertiliser application during season 2007

Source of variation	d.f.	s.s.	m.s.	v.r.	F.pr
Variety	2	10373.2	5186.6	13.33	<.001
Vine length (cm)	1	56.3	56.3	0.14	0.707
Nutrient regime	1	434.0	434.0	1.12	0.302
Variety x vine length	2	5310.5	2655.2	6.83	0.005
Variety x nutrient regime	2	33935.4	1967.7	5.06	0.016
Vine length x nutrient regime	1	34.0	34.0	0.09	0.770
Variety x vine length x nutrient regime	2	3908.7	1954.4	5.02	0.016
Residual	22	8558.2	389.0		

Top dressing with urea produced fewer cuttings than plots not fertilized due to its burning the plants after the first harvest (Table 21a & b). 20 cm long cuttings produced no more harvested cuttings than 10 cm mini cuttings. Kakamega variety produced more cuttings probably because of its spreading growth habit. Generally, Kabode variety produced the least number of cuttings possibly because of its semi-erect and less branching growth habit. There were significant (P= 0.01) varietal effects but there were no effects of vine length or fertilizer.

Table 22a: Number of cuttings produced per 1.2 m^2 for three successive harvest using two vine lengths under NPK fertilizer at planting time on two varieties of sweetpotato in 2009

Harvest lot	Vine length (cm)		Average	$Lsd_{0.05}$
	10	20		
1	15.7	31.9	23.7	10.15
2	121.1	177.6	149.4	19.05
3	117.8	140.0	128.9	NS
Total # cuttings	254.6	349.5	429.4	45.9

Table 22b: Average number of cuttings produced per 1.2 m^2 for three successive harvests with and without NPK at planting time on three varieties of sweetpotato in 2009

Harvest lot	Soil fertility amendment regime		Average	$Lsd_{0.05}$
	None	NPK		
1	11.7	35.9	23.8	10.15
2	107.2	191.7	149.5	19.05
3	78.8	179.0	128.9	38.25
Total cuttings	197.7	406.6	302.2	45.9

Table 22c: Analysis of variance table (ANOVA) for total number of cuttings produced per 1.2 m^2 planted using two levels of vine lengths and NPK application on two different varieties in 2009

Source of variation	d.f.	S.S.	M.S.	V.R	F.Pr.
Rep Stratum	2	7373	3686	0.61	
Variety	1	138890	138890	22.87	< 0.001
Vine length (cm)	1	108110	108110	17.81	< 0.001
NPK application	1	524172	524172	86.33	< 0.001
Season	1	3605	3605	0.59	0.447
Variety x vine length	1	16354	16354	2.69	0.111
Vine length x NPK application	1	1825	1825	0.30	0.588
Variety x season	1	24120	24120	3.97	0.055
Vine length x season	1	560	560	0.09	0.763
NPK application x season	1	520	520	0.09	0.772

Planting longer cuttings significantly increased the number of cuttings harvested (P <0. 001) only during the first cutting, thereafter there was no significant effect of vine length on the number of cuttings harvested (Table 22a). Pre-planting fertiliser (NPK 25:5:5) application doubled the yield of cuttings (Table 22b). Differences in variety growth habits especially trailing character significantly (P<0.001) affected the number of cuttings produced. Kakamega that is more spreading than Ejumula produced more cuttings. Variety, vine length and fertilizer application increased (P<0.001) effects on the number of cuttings harvested (Table 22c).

Overall, pre-planting application of NPK fertilizer greatly increased the numbers of cuttings produced per unit area, roughly doubling the yield of cuttings; post-planting application of urea did not. Pre-planting NPK fertilizer was advantageous in that it did not result into the burning effect to plants under conditions of limited water supply. Planting longer cuttings produced more cuttings, but not commensurately so. Depending on whether planting material or irrigated land is in more limited supply, there seem to be opportunities to identify appropriate choices of cutting length to maximise cutting yield with the available planting material.

Plate 9: Effect of pre-planting fertiliser application on sweetpotato crop vigour and vegetative growth rate

5.3.3 Reducing the cutting lengths and plant densities of planted cuttings to produce roots using different varieties

The study examined both how to increase the production of planting material and how to increase the area plant coverage by planting the limited available material. All trials were done in Soroti district, an area with long dry season in collaboration with the farmers for two successive seasons in 2008 and 2009.

Table 23: The survival (%) of cuttings (3 wks after planting) and root yield (kg/4m^2) of three sweetpotato varieties planted using 3 vine lengths and 5 planting arrangements during 2008 and 2009

Parameter	Treatment	% vine survival	P [variance ratio]	Lsd 0.05 =	Root yield (kg/4m^2)	P [variance ratio]	Lsd 0.05 =
Season	2008	72.9	< 0.001	5.21	1.5		
	2009	60.5			1.2	< 0.007	0.2
Variety	Kabode	67.9			1.1		
	Kakamega	65.0	0.642	NS	1.2	< 0.001	0.3
	Tanzania	67.3			1.7		
Vine length (cm)	10	47.4			1.0		
	20	75.7	< 0.001	6.38	1.5	< 0.001	0.3
	30	77.0			1.6		
Plant density per m^2 and placement	Single at top	73.4			1.1		
	Two cuttings at top	72.1			1.7		
	Three cuttings at top	66.5	< 0.001	8.24	1.6	0.009	0.4
	Two cuttings on sides	64.4			1.2		
	Three cuttings on sides	57.2			1.2		

Vine cuttings lengths 20 cm and 30 cm had similarly greater yields because of greater percent vine survival (Table 23); 10 cm cuttings did not survive so well or produce such high root yield but not proportionately [a 20 cm and a 30 cm cutting both produced only 1.6x as much yield as a 10 cm cutting, not 2x or 3x] because of delayed establishment of planted 10 cm long cuttings. Greater planting densities similarly did not produce proportionately greater yields, two cuttings at the side or at the top having similar yields to 3 cuttings at the side or top respectively and a single at the top producing only about 35% less than 2 or 3 cuttings. Cuttings planted at the top survived and produced more root yield than those planted on the sides of mounds

5.4 Discussion

Generally the majority of the farmers in all agro-ecologies preferred to use the recommended 30-cm long cuttings for the ware crop. The proportion of farmers in Mukono and Kamuli who planted longer than 30 cm cuttings was more than those who planted a cutting less than 30 cm long cuttings. The reverse was true in Bukedea and Soroti where, although the 30 cm cutting was preferred, more respondents planted 30 cm and below possibly because they wanted to utilize whatever planting material was available to plant a bigger area. The use of shorter cuttings was probably associated with lack of planting material in these areas where there is a longer dry season. This therefore seems a rational response by farmers to maximise on the limited planting material available, especially since using 20 cm long cuttings instead of 30 cm long did not affect significantly ($P<0.009$) either the survival of the cuttings or the storage root yield. Even using only two 10 cm cuttings makes sense if cultivated land is not limiting in that they only yielded 1.6 times less, rather than 2 times less – but this is probably not the case. Pre-planting fertilizer (NPK 25:5:5) at the rate of 100 g/m^2 is preferred to a top dressing fertilizer (urea) because the latter can easily burn the plants, especially if watering is inadequate, as it is likely to be in the dry season. Application of a pre-planting fertilizer mixed into the soil at planting time roughly doubled ($P<0.001$) the number of cuttings harvested. Farmers confirmed the significant benefit of applying pre-planting NPK fertiliser to produce planting material (Plate 9).

Relevant to previous chapters, doubling the length of cuttings for the production of planting material increased the number of cuttings produced especially during the first round of vine harvests probably due to much easier establishment and larger plants. However, the increase in the number of cuttings produced was not commensurately so. Irrigated land may often be in more limited supply than vines, especially at the beginning of the dry season when farmers are planting the off-season crop so it may be logical to use increased cutting length to ease the burden of watering as well as maximise cutting yield. A 100g of fertilizer applied to the bed of $1.2m^2$ produced 209 more cuttings; the cost of fertilizer application was UgSh. 180 (100 gm) and the extra production of cuttings was worth UgSh. 2,090 so it is clearly profitable to do so.

Also, reducing the number of cuttings from 3 to 2 cuttings per mound did not affect the storage root yield. It therefore seems that there are options for farmers both for doubling the production of cuttings for planting with just using fertilizer and at least reducing the number of cuttings planted in the main root production crop by a third.

CHAPTER 6:

The use of sprouting roots as a means of obtaining early planting material

6.1 Introduction

Sweetpotato is commonly propagated through vine cuttings (Nedunchezhiyan & Ray, 2010) as obtaining planting material direct from mature crops is the easiest and cheapest means and general practice throughout the Tropics (Gibson, 2009). The using of roots for direct planting is not recommended as it results in very poor yields (Onwueme, 1978), thus, the need to produce vegetative planting material. Areas with prolonged dry periods experience common shortages of planting material (Dunbar, 1969) arising from complete desiccation of the aboveground plant parts during prolonged dry periods (FAO,1994) and special means have to be made in order to obtain planting material at the beginning of the rainy season (Namanda *et al*., 2011). Farmers failed to adopt the rapid multiplication techniques that were devised by NARO, NRI and CIP (Mwanbene *et al*., 1994; Kapinga *et al*., 1995; 1998) and Swaziland (Nsibande & McGeoch, 1999) because the method involves excessive care (González, 2006; Yanggen & Nagujja, 2006).

Volunteer plants sprouting from groundkeeper roots are a popular source of planting material in areas that experience prolonged dry periods (Gibson, 2009; Namanda *et al*., 2011). Sweetpotato roots appear to provide a natural mechanism for continuity and survival as they go dormant at the beginning of physiological maturity (maturity point during which period the roots show no intrinsic or bud growth but retain the potential for future growth) (FAO 1997). Although this works in areas characterised by longer dry periods, shoots to produce planting material only emerge after the beginning of the rains (Onwueme, 1978; Namanda *et al*., 2011), inevitably resulting in late delivery of planting material. This results in delayed planting until at least 4 to 6 weeks after the onset of the rains. Various studies have demonstrated that sweetpotato crops require at least 2 months of adequate soil moisture in order to produce good yields (Onwueme, 1978; Woolfe, 1992). Also, sweetpotato, despite being an early maturing crop, fails in its role as a life saver during the periods of severe food shortages that commonly occur before the main cereal harvest because the crop is planted late. This study explores the manipulation of root sprouting to enable production of planting material for timely planting.

6.2 Materials and Methods

A reconnaissance field visit in mid April 2007, almost 4 weeks after the onset of the rains, was conducted to diagnose and identify factors associated with traditional sprouting roots in previous sweetpotato fields in Soroti, an area with a prolonged dry season (Section 3.4). A questionnaire was administered to understand and characterise the traditional methods of producing planting material (Section 3.4). On-farm research trials compared roots obtained from sequential planting trials, compared different planting depths for the roots and compared irrigated plants and sprouts from roots as sources of planting material for crops producing the main root crop.

Data were collected on varieties, average vine lengths attained since shoot emergence, sprouting root sizes and factors affecting growth of sprouts including pests and diseases.

6.3 Results

6.3.1 Current system of using sprouting groundkeeper roots to produce planting material

The preliminary field visit (as the rains had already started) focused on describing the extent to which the available growing shoots could be sourced for planting material (Section 3.4). The shoots were examined for readiness for harvesting; observations included measuring vine length (cm), the diameter of parent roots (cm), pest and disease infestations, and identification of varieties.

Table 24: The average number of 30 cm long sprouts obtained from a sample of 20 sprouting roots of Ejumula, Araka and Kakamega in Soroti during May 2007

	Ejumula		Araka		Kakamega	
	#	%	#	%	#	%
# ≥ 30 cm long sprouts	61	11.4	98	14.6	68	10.7
# < 30 cm long sprouts	463	81.1	474	85.4	566	90.3
Total	534	100	672	100	634	100
Average # shoots per root (Total N = 20)	26.7		33.6		31.7	

Each root had an average of around 30 sprouts but most of the shoots were too short for harvesting (Table 24) although it was already May, well after the onset of the rains in late March/early April. The ratio of shoots at least 30 cm long: < 30-cm long shoots was 1:5 for Araka variety and 1:8 for Ejumula and Kakamega varieties. Some roots were sprouting vigorously, producing many stems (Plate 10), whilst other roots were affected by pests and disease (Table 26, Plates 13 and 14).

Table 25: Average weight of roots per plant according to category size for each of the 3 varieties sampled in Soroti, North Eastern Uganda during April-May 2007 period

Root samples (Total N = 20)	Ejumula	Araka	Kakamega
	Average weight (g)/ root	Average weight (g)/ root	Average weight (g)/ root
Root diameter (> 10 cm)	232	618	176
Root diameter (≤ 10 ≥ 5 cm)	96	388	55
Root diameter (< 5 cm)	30	120	30

Most of the roots were small sized (Table 33), probably undiscovered or discarded because they were damaged during harvest.

Table 26: Pest infestations and SPVD symptoms

Variety	% weevil root infestation	% SPVD infected sprouting shoots
Araka	97	3
Ejumula	95	4
Kakamega	94	2

Weevils were causing massive damage to some roots and the sprouts of some plants; especially attacked around the shoot bases (Table 26). Millipedes were also damaging (Plate 13).

Plate 10: Roots sprouting vigorously at the start of the rainy season.

Plate 10 shows the potential of roots to produce planting material at the beginning of the season but the sprouts are still too short for planting even though it was already May and there is weevil damage to the roots.

Plate 11: Emergence of shoots from storage roots and underground stems

a) Left: Shoots emerge readily from a root disconnected from the underground stems.
b) Right: No roots emerge directly from the roots but emerging instead from the still-attached underground stem.

Plate 12: Millipedes(*Scaphiostreptus parilis*) destroying emerging shoots close to the soil surface

Plate 13: Magnitude of weevil damage of groundkeeper roots

Most of the groundkeeper roots are damaged or destroyed by weevils and then rot – see the numerous small holes marking the position of their burrows.

6.3.1.1 General issues emerging from the initial observations were that:

- Sprouting volunteer roots are a potential source of ample planting material
- Natural sprouting is too late and emergence of sprouts prior to the start of rains is required needs to be manipulated to enable early planting

- Pests need to be controlled to avoid damage to emerging shoots
- Most of the sprouts emerged from the end of the root previously connected to the planted stem (underground stem) or, if still present, from the stem itself
- Both small and large roots sprouted
- Damage by weevils resulted in rotten roots and delayed and reduced shoot emergence

6.3.2 Survey to investigate the farmers' choice of where to source planting material (Section 3.5)

6.3.2.1 Relative preference for cuttings from sprouting root and cuttings from growing plants in different agro-ecologies and reasons given (Section 3.5)

The following observations in Table 27 seemed particularly noteworthy:

- The top two comments, it 'Allows vines to mature' and it 'Allows vines to increase in length' may result from the wording of the question to be 'in their fields'. They may not relate to situations in which the roots sprout in harvested fields away from their homes and may be considered common property
- The easy availability of the vines seemed a common feature of the next three comments.
- The low response rate to the use of cuttings from sprouted roots in Mukono and Kamuli was because they have ample alternative planting material from their surviving crops.
- It seems significant that only two farmers suggested sprouting roots provide early planting material

Table 27: The numbers of farmers identifying specific advantages associated with cuttings from roots sprouting in their fields

Advantage	District				Total
	Mukono	Kamuli	Bukedea	Soroti	
Allows vines to mature	1	0	19	35	55
Allows vines to increase in length	0	0	12	2	14
Easily available	0	1	6	2	9
Many plants grow, hence many vines	0	0	5	4	9
Reliable source of vines	0	0	7	0	7
Allows vines to recover from dry season	0	0	5	1	6
Plants from vines give good yields	1	0	4	0	5
Vines are cheap	0	0	4	0	4
Provide early planting material	0	0	1	1	2
Require little rain	0	0	2	0	2
Total responding	2	1	65	45	113
Total asked	44	72	105	50	271

Table 28: The numbers of farmers identifying specific disadvantages of obtaining cuttings from roots sprouting in their fields

Disadvantages	District				Total
	Mukono	Kamuli	Bukedea	Soroti	
Vines have to mature hence delayed planting	0	0	38	0	38
Destroyed by animals	1	0	4	15	20
Cut by other people	0	0	3	3	6
Pests and diseases	1	0	4	1	6
Poor yields sometimes	0	0	5	0	5
Easily dries up	0	0	3	0	3
Take long to mature	0	0	2	0	2
Not easy to get vines	0	0	1	0	1
Vines are old hence delayed planting	0	0	1	0	1
Total responding	2	0	61	19	82
Total asked	44	72	105	50	271

The following observations in Table 28 seemed particularly noteworthy:

- Reliance on these cuttings involved acceptance of delayed planting
- Destruction of sprouts by animals was a major problem and was greater in Soroti than Bukedea, perhaps because they have larger herds of cattle.

- Ownership of vines in open fields may be unclear because harvesting by other people was a problem
- Pests and diseases are confirmed as a problem

Table 29: The numbers of farmers specifying they prefer cuttings from growing plants or from sprouting roots

Farmer thinks cuttings from [Chi-Square (df 3), P = 0.000]:	District				Total
	Mukono	Kamuli	Bukedea	Soroti	
Growing plants are better	44	71	88	38	241
Sprouting roots are better	0	1	15	12	28
Total responding	44	72	103	50	269
Total asked	44	72	105	50	271

Farmers preferred cuttings from growing plants across agro-ecologies (Table 29) so there is clearly a need to research whether cuttings from sprouting roots are in some way inadequate. There seem to be two possible explanations for cuttings from sprouting roots being judged inferior:

- They are inferior physiologically – perhaps their lack of maturity
- They carry a heavier burden of pests, e.g., weevil eggs & larvae, or diseases, perhaps viruses.

6.3.2.2 Special farmer practices for obtaining sweetpotato planting material for early planting at the onset of rains (Section 3.5)

Table 30: The numbers of farmers that purposely planted a late crop for producing sprouts from roots when it rained

a) Last year

Number of farmers that [Chi-Square (df 3), P = 0.001]:	District				Total
	Mukono	Kamuli	Bukedea	Soroti	
Purposely planted a late crop	2	2	53	27	84
Did not purposely plant a late crop	42	70	51	22	185
Total responding	44	72	104	49	269
Total asked	44	72	105	50	271

b) Usually

Number of farmers that [Chi-Square (df 3), P = 0.001]:	District				Total
	Mukono	Kamuli	Bukedea	Soroti	
Usually plant a late crop for producing sprouts	4	0	51	42	97
Usually do not plant a late crop for producing sprouts	40	69	53	7	169
Total responding	44	69	104	49	266
Total asked	44	72	105	50	271

Generally only farmers in areas with long dry seasons (Bukedea and Soroti) planted a late crop for producing planting material from sprouting roots.

Table 31: The numbers of farmers that left an area of sweetpotato unharvested for producing sprouts from roots when it rained

a) Last dry season

Number of farmers that [Chi-Square (df 3), P = 0.007]:	District				Total
	Mukono	Kamuli	Bukedea	Soroti	
Left an area of crop unharvested	16	22	58	21	117
Did not leave an area of crop unharvested	28	50	46	29	153
Total responding	44	72	104	50	270
Total asked	44	72	105	50	271

b) Usually

Number of farmers that [Chi-Square (df 3), P = 0.001]:	District				Total
	Mukono	Kamuli	Bukedea	Soroti	
Usually leave an area of crop unharvested	0	21	28	40	89
Usually do not leave an area of crop unharvested	44	48	76	9	177
Total responding	44	69	104	49	266
Total asked	44	72	105	50	271

Some farmers do appear to leave an area of unharvested crop to sprout for planting material, especially in Soroti and Bukedea.

6.3.2.3 The yield of cuttings farmers perceived they obtained from roots sprouting in the field (Section 3.5)

Table 32: The number of times farmers in each district collected cuttings from roots sprouting in their fields

Number of times cuttings were collected [Chi-Square (df 3), P = 0.000]:	Districts				Total
	Mukono	Kamuli	Bukedea	Soroti	
Once	2	0	29	7	38
Twice	0	1	31	9	41
Thrice	0	0	5	18	23
Four times	0	0	1	2	3
Five times	0	0	0	8	8
Six times	0	0	0	1	1
Total responding	2	1	66	45	114
Total asked	44	72	105	50	271

More than 90 percent of the farmers in Bukedea collected cuttings only once or twice whereas most farmers in Soroti collected cuttings thrice or even more often (P = 0.000); the later rounds must provide very late planting material. Table 32 is consistent with farmers in

Soroti (longer dry season) being the most short of cuttings. The majority of the farmers in Kamuli and Mukono did not respond probably because they rarely use sprouts.

6.3.2.4 Time of planting and length of cuttings harvested for planting in the different agro-ecologies (Section 3.5)

Table 33: The number of weeks after the start of the cropping season that farmers in each district could collect cuttings from roots sprouting in their fields

After how many weeks?	District				Total
	Mukono	Kamuli	Bukedea	Soroti	
1	0	0	1	2	3
2	0	1	5	19	25
3	1	0	3	18	22
4	1	0	22	7	30
5	0	0	2	0	2
6	0	0	3	0	3
7	0	0	1	0	1
8	0	0	10	0	10
>8	0	0	2	0	2
Total responding	2	1	49	46	98
Total asked	44	72	105	50	271

Generally harvesting cuttings started 2-4 weeks after the rains have started (Table 33) but farmers in Soroti indicated that they started harvesting cuttings earlier than farmers in Bukedea [or perhaps their cropping season for sweetpotato started later than in Bukedea]. As before, few farmers in Mukono and Kamuli responded to this question.

Table 34: The lengths of cuttings farmers in different districts specified they harvested from roots sprouting in their fields

Length of cutting (cm) [Chi-Square (df 3), P = 0.206]:	District				Total
	Mukono	Kamuli	Bukedea	Soroti	
15	0	0	13	5	18
20	1	0	43	15	59
25	0	1	9	12	22
30	0	4	30	14	48
35	0	0	0	3	3
40	0	0	1	0	1
45	0	0	1	0	1
Total responding	1	5	97	49	152
Total asked	44	72	105	50	271

Planting of short cuttings (≤20 cm) is practised in Bukedea and Soroti, probably because they were in dire need of planting material (Table 34). Farmers in Kamuli and Mukono rarely responded.

Chi Square showed no significant differences but there were too many non-respondents in Mukono and Kamuli.

6.3.3 On-farm research trials on using roots to produce planting material (Section 3.7)

Irrigated and sprout sources of planting material were compared for production of storage roots. Characterising sprouting shoots during field diagnostics on farmers' fields and secondary information provided a basis for identifying the treatments to test. They included when to produce the seed roots (sequential trial) and varying the depths of planting, spacing and watering regimes in order to produce cuttings for planting at the onset of the rains.

6.3.3.1 Survival and yield of irrigated and sprout sourced planting material

Cuttings for production of storage roots were sourced from irrigated field in the swamp and from sprouting volunteer plants and used in a replicated yield trial in 2007 and 2008 **(Section 3.7.1)**.

Table 35a: Percent survival of planted cuttings of three different varieties planted using 20 and 30-cm long cuttings and from two sources during seasons 2007 and 2008

Source of cuttings	Variety	Vine length (cm)/Season				Average
		20		30		
		2007	2008	2007	2008	
Sprouting roots	Araka	37	73.7	45.3	80	59
	Ejumula	48.7	88.3	52	80.7	67
	Kakamega	45	92.7	50	87.3	69
	Average	44	85	49	83	65
Mature vines from plants maintained in a swamp	Araka	43	82.7	50.7	95	68
	Ejumula	41.3	94	52	100	72
	Kakamega	50	95.7	50.7	97.3	73
	Average	45	91	51	97	71

b: Analysis of variance

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r**	**F pr.**
Season	1	31584.22	31584.22	411.98	<0.001
Source	1	660.06	660.06	8.61	0.005
Variety	2	805.08	402.54	5.25	0.009
Vine length	1	288.00	288.00	3.76	0.059ns
Season x Source	1	382.72	382.72	4.99	0.030
Season x Source.Var x Vine_length	2	1.69	0.85	0.01	0.989ns

ns = not significant

Cuttings of mature vines taken from plants maintained in a swamp survived better than cuttings taken from sprouting roots (Table 35). There were also significant (P = 0.001) differences between survival in 2007 and 2008 caused by drought in 2007 but the survival of 20cm and 30cm cuttings in both years was similar (P = 0.059), suggesting that the use of 30cm cuttings may be wasteful. Generally, cuttings of Araka, a local variety, had the poorest survival.

6.3.3.2 The sequential planting of cuttings to produce roots for sprouting

Planting of clean vine cuttings was done at 3 equal planting intervals of 2 months for 2 successive growing years to produce seed roots for planting in beds (Section 3.7.2). The aim was to identify the most appropriate time for production of seed roots.

Table 36: Number and weight of roots of different diameters generated by plots of Araka White, Kakamega and Ejumula planted in April, June and August planting sequences or June, August and October in 2007 and 2008*

*Results for varieties and years are combined because there were no significant

Parameter	Month				P [Variance ratio]	SED	LSD 5%
	April	June	August	October			
	Numbers of roots**						
<5 cm diam	14.2	14.3	22.8	11.3	<.001	2.04	4.15
5 – 10 cm diam	15.5	17.4	10.6	2.6	<.001	1.84	3.73
>10 cm	13.3	17.4	12.7	0.7	<.001	1.15	2.33
Weevil damaged	4.3	2.6	3.3	3.5	0.438	1.03	2.09
Total	48.0	51.8	47.9	17.3	<.001	4.16	8.45
	Weight of roots (kg)**						
<5 cm diam	1.05	0.61	0.73	0.40	<.001	0.117	0.238
5 – 10 cm diam	2.97	1.48	0.90	0.17	<.001	0.266	0.541
>10 cm	7.64	5.55	2.78	0.64	<0.001	0.627	1.274
Weevil damaged	1.8	0.39	0.43	0.24	0.018	0.462	0.939
Total	13.46	8.03	4.84	1.45	<.001	0.947	1.924

(P>0.05) differences between years or varieties for all categories apart from those which were weevil damaged. For these, there were significant (P = 0.014) differences between varieties, Ejumula having significantly fewer affected roots. **Plot area harvested was 2 x 2 m (4m^2) or 4 heaps (mounds) per plot.

The August planting generated most roots <5 cm diameter, which were considered to be the most suitable for keeping over the dry season for sprouting. There were fewer medium-sized (5 – 10 cm diameter) at this time (Table 36). However, the April planting generated by far the greatest weight of roots, with total weight declining steadily with later planting, confirming the economic value of early planting for root production. The April planted crop had a yield twice that of the crop planted in June, thrice that of the August planting and more than six times that of the very late planted October crop.

Although the August planting had most small roots, the April planting still produced quite a few and seems likely to produce enough to keep for sprouting as well as producing the most yield. There was little difference between April, June and August plantings in terms of total numbers of roots produced. Weevils didn’t seem to get much worse with early planting, which was a little surprisingly since their populations were expected to expand with time.

6.3.3.3 Results from the root bed trial

Seed roots were planted in the root beds at different depths (cm), spacing, watering regimes and using varieties with differing growth habits **(Section 3.7.3)**. The numbers of vine cuttings each regime produced was recorded.

Table 37a: The number of 30 cm long cuttings harvested per root and percent shoot emergence of Kakamega roots planted at varying root depths during season 2008

Depth (cm)	June				August			
	10 week		5 weeks		10 week		5 weeks	
	Cuttings/ root	% shoot emergence	Cuttings/ root	% shoot emergence	Cuttings/ root	% shoot emergence	Cuttings/ root	% shoot emergence
5	1.62	2.50	0	0	5.31	74.26	0.47	7.78
10	4.31	35.74	0	0	9.87	74.07	7.26	45.46
15	0.99	12.31	0	0	5.63	58.33	2.81	36.48
25	0	0.65	0	0	0.11	2.41	0	2.31

c) Table 37b: Analysis of variance

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Sequence	1	677.260	677.260	94.36	<.001
Depth	3	1057.374	352.458	49.11	<.001
Watering_regime	1	337.035	337.035	46.96	<.001
Sequence.Depth	3	389.864	129.955	18.11	<.001
Sequence.Watering_regime	1	13.500	13.500	1.88	0.171
Depth.Watering_regime	3	131.898	43.966	6.13	<.001
Sequence.Depth.Watering_regime	3	131.898	43.966	6.13	<.001

The time of producing seed roots, depth of planting and time of initial watering significantly ($P< 0.05$) affected the number of cuttings produced at the time planting

The low emergence and survival of sprout shoots planted at 5 cm depth (Table 37) was due to loss of seed roots as a result them drying up (The roots were described by the farmers as 'cooked') and weevils attacking at the surface. Seed roots planted at 25 cm depth resulted into most of the sprout shoots failing to emerge above the ground due to an inability to penetrate the thick soil coverage above the roots, causing the sprouts to coil (Plate 17) generally confirming the importance of planting depth in survival of seed roots and generation of planting material.

Plate 14: Pest damage at 5 cm deep (Shallow planting). The emerging sprouts are readily vulnerable to pest damage

Plate 15: Seed roots planted at shallow soil depth (5 cm) easily destroyed by heat and pests around the soil surface; also, the main tuber has been attacked by weevils and rotted

Plate 16: At deeper seed root planting the sprouts coil in their struggle to break through the thick soil cover to get to the surface

Plate 17: Rotten mother root planted at deeper soil level

Table 38a: Number of 30 cm long cuttings harvested per root and percent shoot emergence of Kakamega roots planted at varying spacing during seasons 2008 and 2009

Spacing (cm)	2009	
	Cuttings per root	% emergence
10 x 10	12.2	87.8
20 x 10	16.0	86.3
20 x 20	19.0	86.7

There was a progressive increase in the numbers of cuttings produced by roots as they were planted at a wider spacing (Table 46). This suggests that, if roots are in short supply, it would be better to plant them widely separated than closely together in 'traditional' propagation bed.

Table 38b: Analysis of variance

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Sequence	2	192.721	96.361	10.14	<.001
Variety		789.410	394.705	41.53	<.001
Watering_regime	1	574.934	574.934	60.49	<.001
Sequence.Watering_regime	2	123.664	61.832	6.51	0.004
Sequence.variety	4	143.274	35.819	3.77	0.012
Watering regime. Variety	2	5.481	2.741	0.29	0.751
Sequence.Watering_regime.variety	4	34.501	8.625	0.91	0.471

Table 39: Effect of planting date for production of the roots and watering regime on the number of 30-cm long cuttings harvested/ $1m^2$ produced from pre-sprouted seed roots at the beginning of first season 2009

Variety	Planting date			Watering regime	
	April	June	August	mid Jan	Mid Feb
Araka	85.7	99.2	94.5	115.3	59.9
Ejumula	97.7	104.2	105.5	133.5	72.0
Kakamega	135.2	115.3	115.7	150.2	85.9
Average	106.2	106.2	105.2	133.0	72.6
Least significant differences (P = 0.05) between means	$Lsd_{0.05} = 13.10$			$Lsd_{0.05} = 10.59$	

It was confirmed by the 2009 results that watering from mid-January resulted in much more production of vines for early planting than watering from mid-February for all varieties and in all sequences of seed root production. Once again, the date the crop supplying the roots was planted made little difference to number of cuttings they produced. Overall, the long prostrate stems of cv Kakamega produced more (P = 0.004) cuttings than either Araka or Ejumula – but this tends to be true whatever strategy is adopted for producing cuttings.

Table 40a: Root yield (kgs/2 m^2) of three different varieties of sweetpotato planted using 20 and 30 cm cuttings from sprouting roots and from irrigated plants during 2007 and 2008 seasons

Season	Variety	Root yield kg/2m^2			
		20 cm cuttings	30 cm cuttings	20 cm cuttings	30 cm cuttings
		Sprouting roots		Irrigated plants	
2007	Araka	3.23	7.53	5.13	4.03
	Ejumula	3.63	4.5	1.7	2.67
	Kakamega	4.1	4.8	4.13	3.73
Average		3.7	5.61	3.7	3.5
2008	Araka	4.53	4.63	3.23	5.2
	Ejumula	3.5	5.4	5.43	2.97
	Kakamega	5.57	5	4.2	6.53
Average		4.5	5.0	4.3	4.9

Table 40b: Analysis of variance

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r**	**F pr.**
Season	1	6.125	6.125	1.68	0.201
Source	1	6.969	6.969	1.91	0.174
Variety	2	16.053	8.027	2.20	0.122
Vine length	1	9.245	9.245	2.53	0.118
Season.Source.Var.Vine_length	2	27.503	13.752	3.77	0.030*

*Significant at P<0.05

The following two seem to be the key findings from Table 40:

- The source of planting material did not affect the root yield (P > 0.05)
- Longer cuttings (30 cm) did not yield more than 20 cm cuttings (P > 0.05), confirming previous results on their survival and confirming that the use of long cuttings is a waste of planting material

6.4 Discussion

Generally sprouting groundkeeper roots (volunteer plants) irrespective of root size are a potential source of planting material but early emergence of sprouts prior to the start of rains is prerequisite for early planting. Emergence of sprout shoots in previous sweetpotato fields, the main source of planting material for late planting, is greatly hampered by pest and diseases infestations including weevils and millipedes besides destruction of groundkeeper roots through rotting.

Farmers' comments such as "take long to mature" indicate that, for roots to produce planting material early, growth from the sprouting roots must be initiated prior to the normal planting time of the main crop. A few farmers appreciated that cuttings from sprouting roots are a good source of planting material, despite their preference for cuttings taken from irrigated crops. Positive comments made about cuttings from sprouting roots included "easily available", "many vines produced", "reliable", "vine recovery" , cheap and survival under minimum rains as reasons why they use such cuttings. The common problems are late availability for planting, destruction by animals, theft, pests and diseases (Plate 14). Evidence from the preliminary study agrees with farmers that weevils and millipedes cause massive damage to sprouting shoots, weevil larvae attacking the roots and the shoot bases. Besides destruction of sprouts by grazing animals, ownership of vines in open fields seemed unclear because harvesting by other people was a problem. In spite of the problems outlined, the numerous sprouting shoots from volunteers suggested that roots are a potential source of planting material in areas with long dry seasons.

Only farmers from areas with long dry seasons planted a late crop for producing planting material from sprouting roots and left an area of un-harvested crop to sprout for planting material. Farmers in Soroti reported collecting cuttings at least thrice from sprouting roots but only once or twice in Bukedea. Planting short cuttings (≤20 cm) harvested from sprouts is more practised in Bukedea and Soroti probably because they need to save on the available planting material to plant large areas. The overall lack of response to the question on relative preference for root sprouting and cuttings from growing plants by farmers in areas with short dry seasons compared to long dry seasons was consistent with them seldom using such material. Planting a late crop or leaving an area of normally-planted sweetpotato un-harvested for producing sprouts from roots still does not address the issue of production of planting material for planting *at the beginning of* the rains. Thus, there was still a need to develop a protocol that will enable cuttings from root sprouts to mature at the start of the rains and avoid the loss of four weeks of planting time.

The following questions then emerged:

a) When should the crop for producing roots that will produce planting material be planted?

b) When should these roots themselves be planted and should they be watered?

c) How should they be planted?

d) Is the planting material from these roots good?

Thus, there was a need to investigate the effect of the identified factors in producing planting material using roots.

The sequential study to investigate when seed roots should be produced showed little difference between April & June plantings for producing seed roots (Table 35). The August planting produced most roots <5cm diameter suitable for keeping over the dry season for sprouting but also had very few medium-sized [5 – 10 cm diameter] roots for sale. Early planting ($P<0.001$) benefited storage root yield, emphasising its value. The April planted crop had a yield twice that of plots planted in June, thrice the August planting and more than 6 times the crop planted in October (Table 35).

The sprouting root trials indicated that sprouts planted at a shallow depth of 5 cm resulted into low emergence due to poor survival (drying up, rotting and weevil damage) of planted seed roots and high early weevil attack at the surface (Plate 14). Conversely, seed roots planted at deeper (25 cm) soil depths failed to emerge above the ground due to depth of above the roots (Plate 17), and this resulted in rotting of the seed root. There was a difference between planting at 10 cm and 15 cm soil depth ($P<0.001$) and these resulted in the highest survival and emergence of planted roots and vigorous shoot growth. Doubling the density of seed roots planted did not ($P= 0.001$) increase the number of cuttings per unit area of bed but the spacing of 20 cm between rows and 10 cm within the row (50 roots/m^2) produced more cuttings per planted root. Overall, irrigated root beds resulted in production of vines from early plantings of both the June and August sequences of seed root production. Starting to water the root beds at 10 weeks prior to the expected time of harvesting resulted in more harvestable shoots than watering 5 weeks prior (Table 37). Cv Kakamega produced more ($P = 0.004$) cuttings than either Araka or Ejumula because it is produces long vegetative stems (Table 39).

The experimental results comparing the performance of the irrigated and sprout sources of planting material showed that cuttings from plants maintained in a swamp survived better than cuttings from sprouting roots but the yield of plots planted with cuttings from sprouting roots was still similar to ones planted with cuttings from irrigated plants (Table 35). Possibly the plants from cuttings from sprouting roots are actually more vigorous (physiologically younger?) and so the survivors compensated for the poor plant stand. Longer cuttings (30 cm) did not yield more than 20 cm cuttings ($P > 0.05$), suggesting that the use of 30 cm cuttings is a waste of planting material (Table 40).

Chapter 7:

The survival of roots of different sweetpotato varieties using different storage methods and testing the Triple S method of producing planting material in Uganda and Tanzania

7.1 Introduction

In the previous trials (Chapter 6) on producing planting material using seed roots, they were stored in-ground immediately after harvesting in prepared seed beds in a replica of natural field conditions, though with pre-determined depths of planting and varied spacing. Few shoots emerged in the first trial season 2007/2008; especially roots planted close to the surface (Plate 18) were either destroyed by pests or dried up before emergence. Others that were planted deeper had become rotten (Plate 17) or the sprouts failed to emerge above the ground. During subsequent trial season 2008/2009, modifications were made to pre-store the seed roots in a soil pit under tree shade at depth of 15 cm for at least 3 weeks before planting the multiplication seed beds. This improved the emergence in the subsequent season. However, the trial was conducted in Soroti, an area where the farmers could access adequate watering because the sites were located towards the shore of an inland lake or swamps with reliable watering source so there was no need to store the roots for long.

The key to a successful method, especially for areas with a long dry season, appeared to be identifying a means of storing the roots prior to planting them out. Trials using methods that had already been shown to prolong survival when stored included sand and covered pits, especially in the shade. Other treatments were identified by host farmers and scientists; these were trialled in Soroti and Kumi areas in 2009/2010 season. In both areas, dry sand was identified as the most viable method because it cost nothing and stored roots remained intact without shrivelling and with no destruction by pests including rats. At one trial site, many vines were generated to the satisfaction of the host farmer ground. This was so successful that the trial was immediately tested for applicability in the Lake Zone of Tanzania, an area with a longer dry season than generally occurs in Uganda.

7.2 Method

Various methods (Section 3.7) of seed root storage were identified and trialled with host farmers. Seed roots were examined for survival under the different storage methods and data collected by counting and recording sprouted and un-sprouted roots and computation of percent live and dead roots. Sand was the most successful storage medium and was tested in Mwanza, Shinyanga and Meatu regions in Tanzania (Section 3.7.4.4), areas with long dry periods.

7.3 Results

7.3.1 Experiments on using roots stored in different ways to produce planting material with farmer groups in Kumi and Soroti (Uganda) (Section 3.7.4)

Experiments were done with Mr Ekinyu’s group (SOSPPA) in Soroti and with Mr Sois’ group in Kumi districts. The roots were provided by the group and stored in a single replicate at each site in various ways as described below (Tables 41 & 42).

Table 41: The various methods of root storage and a summary of general initial observations at 2 months after storage in Soroti and Kumi

Method of storage	**Key observation**	**Comments**
Open pit	Shoots had emerged above the soil surface in the shallow (10 cm) soil cover pit storage.	Top soil layer was thin, the chamber was moist and favoured sprout growth aboveground
	No sprout shoots emerged above the soil surface in the thicker (20 cm) soil cover pit storage. But all roots had sprouted when pit was opened	Thick soil cover suppressed emergence of sprouts to the surface but lots grew coiled up in the pit.
Pit under shade	All roots had sprouted	Sprouting was vigorous
Plastic mesh basket with pesticide	Few sprouted shoots, roots dried up with minimal weevil damage	Pesticide did not completely prevent weevils and it was costly and dangerous
Control plastic mesh basket	Generally most roots dried up and were weevil infested	
Lantana herbs mixed with chilli in plastic mesh basket	Roots dried up with high weevil infestation	Poor method and generally rejected
Ash dust in plastic mesh basket	Limited sprouting, dried roots and high weevil infested roots	Poor method and generally rejected
Lantana in plastic mesh basket	Dried roots, weevil infested and rat damaged	Poor method and generally rejected
Ash in plastic bowl	Very few roots sprouted.	Ash ‘burnt’ the roots
Sand in plastic mesh bowl	Both Kakamega and Esapat varieties had short sprouts and some had not sprouted. Neither weevil nor rat damage	Sprouting was very slow because sand was dry. Sand appeared to stop the weevils and rats attacking the roots

Table 42: The survival of roots of cv Kakamega stored under different conditions at Ekinyu's site, February 2010

Treatment	Sprouting	Un-sprouted	% alive roots	Dead
A pit in the open covered with 10cm of soil	21	0	44	27 (rotten)
A pit in the open covered with 20cm of soil	12	0	24	38 rotten)
A pit lined with dry grass/straw under a bush covered with 10cm of soil (recommended)	161	0	81	39 (rotten)
A plastic mesh basket containing roots treated with Actellic dust	9	5	33	29 (dried)
Roots kept in plastic mesh basket without treatment	3	0	6	48 dried (36 + weevil damage)
A plastic mesh basket containing roots treated with dry lantana herbs mixed with chilli	0	0	0	25 (dried & eaten by rats)
A plastic mesh basket containing roots dusted with ash	0	0	0	25
A plastic mesh basket containing roots and lantana herbs	0	0	00	25
A plastic bowl containing dry sand kept in a roofed shed	37	0	95	2 (weevil)
A plastic bowl containing dry ash kept in a roofed shed	6	24	68	14 (rotten)

At Ekinyu's site (Table 41), roots kept in the bowl containing sand had the most surviving 2 months after harvesting. Roots stored in sand had just initiated sprouting after 2 months of storage, there was no rat damage and roots were still turgid. No roots had emerged above the soil surface in the pits covered with a 20 cm soil layer above the roots but the roots had sprouted vigorously. Sprouts had emerged from the pit covered with 10 cm of soil. Most of the roots kept in the pit lined with straw had also sprouted but there was no shoot emergence above the soil surface. Very few roots stored in ash had sprouts but most of the roots were dehydrated and, dusted in the basket, did not prevent weevil infestation. Roots kept in a basket without pesticide applied were dehydrated and infested with weevils. Although the roots kept in a basket with insecticidal dust were generally free from pests, chemical use is not only costly but also a health hazard to the farmers. Also the roots dried up. Storage in open-mesh baskets was poor as the roots dried up and, unless protected by Actellic, were damaged by weevils, borers and rats. All roots untreated or treated with *Lantana camara* by itself or mixed with chilli or dusted with ash were pest infested and some were eaten by rats.

Table 43: The survival of roots of cvs Kakamega and Esapat stored under different conditions at Sois' site, February 2010

Variety	**Kakamega**			**Esapat**		
Treatment	Sprouting	Un-sprouted	Dead	Sprouting	Un-sprouted	Dead
A pit in the open covered with 10cm of soil	50	0	0	44	0	6
A pit in the open covered with 20cm of soil	47	0	3 rotten	33	0	17 rotten
A pit lined with dry grass/straw under a bush covered with 10cm of soil (recommended)	89	7	5 rotten	87	8	5
A plastic bowl containing dry sand kept in a roofed shed	44	0	6	28	16	6
A plastic bowl containing dry ash kept in a roofed shed	6	13	6	9	32	9
A plastic bowl containing roots treated with Actellic dust	3	0	22	15	6	4
Roots kept in basket without treatment	0	0	25	7	7	11

Kakamega kept in the pits survived better than Esapat (a local variety). Otherwise, results were very similar to those at Ekinyu's site, sand providing a medium in which the roots produced only short sprouts but the roots remained turgid (Table 43). Rotting of roots during storage resulted wet and dirty newsprint cushion (Plate 19) below.

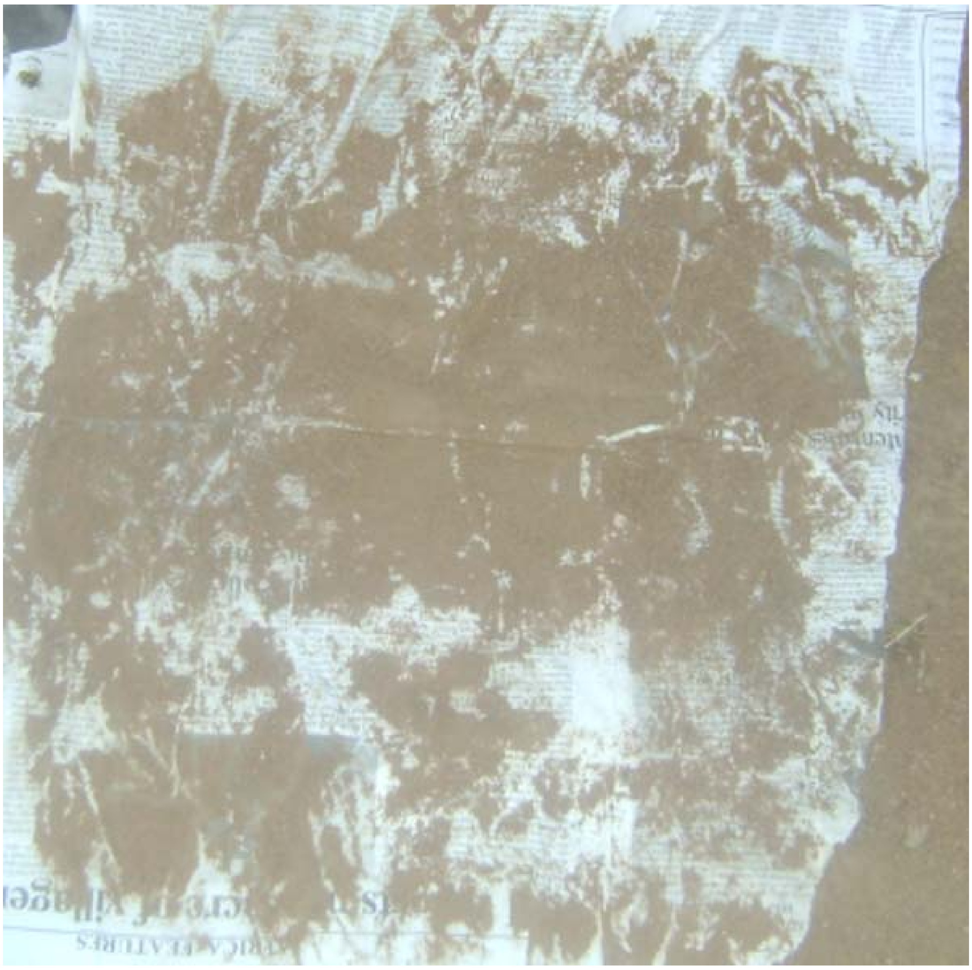


Plate 18: Newsprint cushion wet and contaminated due to rotten seed roots during storage in a plastic bowl containing dry sand kept in a roofed shed

7.3.1.1 Summary of the results on storage for Kumi and Soroti root trial

Generally, farmers at both Eugene's and Mr Sois' considered that the roots stored in sand were in excellent condition and that this was the best treatment by far. There was also no damage by weevils or rats [common at both farms]. Storage in ash seemed to cause excessive water loss. Only the roots stored in sand, ash or in the pit under a bush and covered with 10 cm of soil were considered worth growing on. Storage in open-mesh baskets, even with Actellic, was poor as the roots dried up and, unless protected by Actellic (Pirimiphos-methyl), were damaged by weevils, borers and rats.

Plate 19: Mr. Sois showing the excellent storage of roots after 2 months in sand

a) Shoots growing through 10 cm soil cover b) Roots under 20 cm soil cover

c) Roots in pit under shade d) Roots dusted with ash

e) Untreated roots kept in basket f) A basket of untreated roots

g) Kakamega in sand h) Esapat in sand

Plate 20: The results of different on-farm storage conditions for sweetpotato seed roots in Soroti and Kumi

7.3.2 Assessment of sprouting and production of cuttings from Soroti and Kumi

Table 44: The number of sprouts and subsequent cuttings available from cv Kakamega

What assessed	Root germination*	Number of cuttings available/plant		
When assessed	17/03/2010	16/04/2010 [8wks after planting]		14/05/2010 [11 wks after planting
Who assessed	Researcher	Men farmers	Women farmers	Men farmers
Ash	0.4	6.9	7.1	33.6
Pit	1.2	13.6	15.0	97.6
Sand	1.6	39.6	39.6	164.8
+ Fertiliser	0.7	19.2	16.4	90.3
No fertiliser	1.4	20.8	24.7	107.1

*0 = no plant; 1 = the root had sprouted; 2 = the root was sprouting vigorously

As in root storage, sprouting and cutting production of Kakamega roots kept in sand was good; roots kept in the pit were satisfactory but roots kept in ash sprouted poorly. Sprouting of Esapat was poor generally and many of those that sprouted had SPVD. Consequently, this treatment was not included in Table 44. Adding fertilizer was of no benefit, but too much may have been applied. Sprouting of Kakamega was very vigorous (Plate 21 below), often providing an average exceeding 100 cuttings/plant.

Plate 21: Vigorously growing sweetpotato vines from roots 2 months after planting

7.3.3 Validating the use of roots to produce planting material in Mwanza, Shinyanga and Meatu (Tanzania)

7.3.3.1 General initial responses to the watered root-bed concept

The idea of duplicating the method of storing roots in sand then planting in root beds was introduced to farmers in Mwanza, Shinyanga and Meatu regions in the Lake Zone of Tanzania during the end of harvesting season in May 2010. Visual photo Powerpoint slides showing the procedure and what the farmers in Kumi had achieved were provided to supply exciting evidence and conviction. The method seemed very cheap to the farmers because the basins were provided (and were cheap anyway), sand was free and roots were available since the harvesting season was just being concluded. The dry season had started, roots remaining in the fields were being damaged, the method was simple and it did not require particular skills to apply. Farmers recalled that the traditional method of waiting for sprouts to emerge after the rains had started resulted into delayed planting and, even so, planting material was not easy to get. Farmers from drier areas such as Meatu normally travelled long distances to buy expensive planting material. Generally, the applicability of root storage in sand and sprouting before planting in root beds concept was readily appreciated as a realistic, resource and time saving method of conserving and multiplying early planting material of sweetpotato, particularly in Meatu and Shinyanga regions.

7.3.3.2 Results of storage of roots in different regions

Table 45: Performance of planted sweetpotato seed roots in different villages in the different regions in Tanzania

Parameter	Mwanza villages		Shinyanga villages		Meatu villages	
	Mwagala	Ngo’mbe 4	Hapa	Mwangósha	Bulyashi	Mwambiti
% emergence of planted roots	70.0	54.2	93.3	93.3	95.8	88.3
% Weevil infestation	10.3	8.7	0	0	0	0
% SPVD	12.3	31.2	1.2	0	1.2	0
# cuttings harvested /root irrigated	14.7	17.3	31.5	49.8	51.7	48.2

A third of roots were lost during storage in sand in Mwanza whereas only 7% and 15% were lost in Meatu and Shinyanga respectively. This was attributed to difference in storage conditions and generally more enthusiasm and therefore more care taken in Meatu and Shinyanga. It was also observed that sunlight was shining through the door and window directly on the basins inside some of the houses in Mwanza and causing increased heating of basins. Overall, sand storage method resulted in about 80% root survival after about 4 months, when they were planted out in their gardens. Farmers reported that the sand in bowl was better than the traditional method because roots left in the field are normally lost due to high weevil infestation and rotting.

Table 46a: Farmers' general evaluation of the practice in Mwagala and Ngo'mbe villages in Mwanza region

<table>
<tr><td>Host farmer</td><td>Farmers' comments</td><td>General observations</td></tr>
<tr><td colspan="3" align="center">Mwagala village</td></tr>
<tr><td>Farmer 1</td><td>- Sought to be given opportunity to visit other farmers using this method in Uganda
- Watered only twice because her site was fertile and ever moist
- Acknowledged planting next to old field spreading pests to the new beds</td><td>- No fence but no animal destruction of the plants because she was isolated at the end of the village</td></tr>
<tr><td>Farmer 2</td><td>- Plant growth checked due to lack of watering for more than 2 weeks
- Generally questioned why she was watering roots when she could get vines from her crop in the swamp
- She needed money to pay someone to water
- However she agreed that roots generate more shoots for planting material</td><td>- Generally seemed not interested</td></tr>
<tr><td>Farmer 3</td><td>- She had prepared plot for planting cuttings
- Watering was easy for her because the children could collect the water</td><td>- Pests and SPVD infected plants were evident in her plot.</td></tr>
<tr><td colspan="3" align="center">Ngo'mbe village, Mwanza</td></tr>
<tr><td>Farmers 1, 2 and 3</td><td>Practice was very good</td><td>The 3 host farmer had planted their beds at a single site for ease of watering and monitoring. Fencing had been erected</td></tr>
</table>

The farmer's comments including "watering root beds was not a problem" was generally taken to imply that the practice was undemanding in terms of irrigation possibly in comparison with other irrigated plots. The other farmers generally appreciated that watering roots generated a lot of planting material, and confirmed that that it was easy to manage because they could even engage children to do the watering. Two host farmers expected to be given some money for participating in the trial, possibly because of the influence of being close to the urban centre in Mwanza and lack of serious vision to own the activity. It could have also been that the lack of planting material is not as serious as drier areas of Meatu and Shinyanga where planting material is completely desiccated during the dry season.

Table 46b: Farmers' general evaluation of the practice in Hapa village, Shinyanga region.

	Farmers' comments	General observations
Farmer 1	- planting roots to produces planting material does not require a lot of labour - Ensures that planting material is available - Have been buying vines expensively between TZ 5,000 – 8,000 per bag of about 1,200 cuttings each during the first rains. - Her husband and children had given her support in erecting the fence around the root beds.	- A copy of the protocol on using roots to produce planting was requested by her husband so that he could train other farmers
Farmer 2	- Generally impressed with the approach. - Regretted not doubling the roots. - Missed watering because she had delivered a month after she had planted the beds - Found the vines had been harvested as if animals had grazed	- There was suspicion that her vines could have been stolen by neighbours because she was not able to go to the field herself.
Farmer 3	- Farmer not available during the visit	- The water source had dried but the vines had established and coverage well spread - She reportedly preparing the field for planting the vines - Had left the beds not weeded but weeding would have exposed the vines to withering due to lack of watering

The extension staff reported that the practice was relevant especially for farmers who have been buying planting material from distant village (Mwangósha). However, he noted that some participants expected facilitation which he could not provide. Notably Hapa village is semi urban, less than 2 km from old Shinyanga town. There was actually no evidence of a need to facilitate them to participate in the trial as reported by the extension worker in the area. Instead the farmers reported getting support from the families to water and erect the hedge around the plots, and regretted not doubling the size of root beds. They had already prepared their fields to plant so as to gain from increased yield of early planted crop and to avoid further stealing of the planting material by other farmers. The beginning of rains had relieved the famer from possible drying of her plants in the bed because her source of water had dried prior to the start of rains. The request for the protocol was taken as a positive indicator.

Table 46c: Farmers' general evaluation of the practice in Mwangósha village, Shinyanga region.

Host farmer	Farmers' comments	General observations
Farmers 1, 2, 3 and volunteer farmer (who had kept her roots in a broken pot)	- vines available at the time of planting - supported each other in watering and monitoring - practice useful in generating vines early - field already prepared for planting cuttings - method is cheaper than the their common practice of watering a late planted crop in may and then leave to dry up later - have been depending on sprouts from underground stems and roots which emerge as soon as the rain starts	- beds fenced and organic manure applied - beds located at the same sites - popularly known community for conserving planting material during the dry season

Reportedly this area is the main source of planting material especially after the prolonged dry periods. Traditionally a late crop is planted in May close to the swamps, watered twice if there were no late showers of rain and left to grow. As the dry season advances, the crop normally withers but underground stems and possibly small roots survive and sprout at the onset of the first rains. They confirmed the reports from the regional offices during the courtesy call that Mwangósha village was a hub for sourcing sweetpotato planting material during the first rain season. The evidence of planting a late crop, volunteer farmers trying the practice, enhanced hedges around the root beds and general excitement during the introduction of the practice were indications of how important the community considered the production of planting material.

Table 47a: Farmers' general evaluation of the practice in Bulyashi village in Meatu region

Host farmer	Farmer's comments	General observations
Farmer 1	- Hoped to use the method again next season but use double rows at the spacing of 0.6 m x 0.6 m instead of 0.3 m x 1m because the sprouts had spread widely - Her family including the daughter and elder son helped water the beds which were located adjacent to his vegetable and rice beds - He piped the water using a treadle pump	- She was a single parent but had managed to educate her children through cultivation of sweetpotato - Field already prepared for planting cuttings
Farmer 2 and 3	Appreciated that the method is good but instead of 0.3 m x 1 m used, she will 0.3 m x 0.5 m so that there is quick soil coverage	- The farmers had 2 other varieties grown from sprouted roots. They must have collected the roots and kept them after we had left.

In Table 47a, the farmers generally preferred a closer spacing possibly to reduce on the area watered. General involvement of the family to irrigate and manage the root beds was possibly an indication of how the family valued the root beds. It could also be an indication of increasing ownership among family members. Setting the root beds next to beds of other vegetables crops for collective management could have been a strategy to reduce labour costs on watering and protection. The single mother farmer reported that she had managed to support her family including paying educational fees of her children through sale of sweetpotato products, mainly dried chips. Obtaining more than 120 cuttings from a single root at harvesting during the first cut had convinced the farmer and her family that the practice had worked well for them. The already prepared field for planting after 3 days since the first showers of rain were received was confirmation of the need to plant as early as possible.

Plate 22: Vigorously growing irrigated sweetpotato vines in Bulyashi village, Meatu region. Green islands in the generally dry region

Plate 23: Green sweetpotato plots surrounded by dry grass in Meatu

Table 47b: Farmers' general evaluation of the practice in Mwambiti village, Meatu region

Host farmer	Farmer's comments	General observations
Farmer 1 and 2 (Peninah Elias and Susan Masanja)	- Practice very applicable because it not does not need frequent watering - Earlier sprout shoots had been eaten by animals but had repaired the fence. Estimated to have lost about 700 cuttings due to animals	Although shoots in their beds had earlier been eaten by livestock, she continued watering and second growth was vigorously growing
Farmer 3	- Rodhes Gwese was very excited with the approach - Had kept other roots aside which she used to expand the plot - Realized that the roots we had kept were not enough - Also cut the first shoots when they were about 25 cm and replanted another multiplication plot	Technically she was the best practice farmer. – Use innovative watering by pouring water in a hole created between neighbouring plants and had adjusted the spacing to 0.3 m x 0.6 m so the watering is not widely spread. - She had reinforced fence with local thorny shrubs (see in the photo) which the animals could not easily penetrate

In Table 47b, farmers indicated that the root based technique for producing planting material was appropriate and not difficult to irrigate. Considering that Meatu experiences drier conditions than the other areas, and farmers collected water from below the thick sand deposits in the riverbed, the comment " not very stressful to irrigate" was possibly relative in comparison to other watered beds or irrigating sweetpotato vine cuttings. Innovative practices including pouring water in created depressions between neighbouring plants was basically to minimize on possible loss of water through sprinkling. Reinforcing hedge with thorny shrubs around the root beds was to prevent the animals getting access to the 'green island' of vines (Plate 24). Notably some farmer had their planting material eaten by the animals in cases where the protection was not enhanced.

Plate 24: Conservation beds protected with thick thorny hedge in Mwambiti village Meatu. Farmers review the security precautions around the bed.

Table 48 Quantitative data validating the effectiveness of the Triple S method in Tanzania

Region	Mwanza		Shinyanga		Meatu	
Village (No of farmers x No of cvs)	Mwagala (3 x 2)	Ngo'mbe (3 x 2)	Hapa (3 x 2)	Mwangósha (3 x 2)	Bulyashi (3 x 2)	Mwambiti (3 x 2)
Average number of shoots preserved in sand ± SD	32 ± 4.6	34 ± 5.7	36 ± 6.3	30 ± 5.8	31 ± 7.4	31 ± 9.2
Average number of shoots surviving in sand to plant ± SD	22 ± 7.5 (56%)	14.7 ± 8.7 (35%)	27 ± 11.3 (76%)	21 ± 7.1 (71%)	28 ± 7.4 (91%)	28 ± 7.9 (88%)
Average number of shoots emerging from soil ± SD	17.5 ± 7.9 (80%)	14.7 ± 8.7 (100%)	26 ± 11.4 (93%)	20 ± 7.2 (93%)	17 ± 5.9 (61%)	16 ± 11.4 (57%)*
% Weevil infestation	8	9	0	0	0	0
% SPVD	7	22	0	0	0	0
No of cuttings harvested /surviving shoot ± SD	6 ± 4.2	9 ± 3.5	31 ± 22.3	57 ± 20.7	45 ± 39.0	25 ± 2.0

7.3.3.3 Validating the Triple S method in different villages and regions in Tanzania

Two years after being taught the Triple S method, farmers asked about the Triple S method generally considered it provided them with ample and secure planting material at the right time for the rains, demanded less water and less frequent watering than cuttings kept through the entire dry season and it was convenient and safe being close to the home. There were also few problems with pests and diseases on the sprouting vines and the cuttings yielded well

(Tables 47a - b). Another benefit was that farmers could make more money; one Ugandan farmer sold his 2011 crop for the equivalent of US$900 [a 'fortune' in Kumi where most farmers live on a few dollars a day] as a result of being able to harvest early, before others could harvest and before the main cereal harvest came on the market. In Tanzania, farmers were interviewed who had adopted the method after copying the few farmers who had been taught. In one village in Meatu District, though only 3 farmers had originally been trained, after one year, at least a further 20 were apparently practicing it, just by copying the original farmer validators. Even so, watering was still a burden, a few roots rotted whilst stored and roots were not safe from animals and children either in store or when planted out, gardens needing to be fenced.

7.4 Discussion

Generally, farmers at both Mr Ekinyu's and Mr Sois' considered that the roots stored in sand were in excellent condition and that this was the best storage treatment by far (Ray *et al.*, 2010). Sprout elongation was reduced and weevil and rat damage did not occur. The reasons why roots stored best in sand could be that it provided a) dry yet not desiccating environment, b) an aerobic environment because gaseous exchange of CO_2 and O_2 occurred readily, and c) a fairly constant and appropriate [cool] temperature [the bowl was kept in shaded but open buildings in which overnight cooling would have been substantial (Lewis & Morris, 1956; Kushman & Deonier, 1959).

Generally, root storage in sand also performed well across the regions in Tanzania. Roots were successfully stored until the time of planting out, there were few losses due to pest and disease, and root emergence of planted roots was above 90 percent in most locations. Variation in root storage by different varieties occurred in Tanzania, consistent with results observed in Kumi. In Mwanza, the variety Polista sprouted later than other varieties. The method seemed very cheap, sand was free and roots were available since the harvesting season was just being concluded. The dry season had started, roots remaining in the fields were being damaged, and the method was simple and did not require particular skills to apply. Generally, farmers recalled that the traditional method of waiting for sprouts to emerge after the rains had started resulted into delayed planting and even so planting material was not easy to get. Farmers from drier areas such as Meatu normally travelled long distances to buy expensive planting material. Farmers in Meatu, who had no access to improved watering equipment, avoided complete bed irrigation and instead applied water in central soil depressions between planted roots. Generally, the applicability of root storage in sand and sprouting before planting in root beds concept was conceived as an early planting-enabling, realistic, resource and time saving method of conserving and multiplying sweetpotato, particularly in Meatu and Shinyanga regions. The percent root survival and number of cuttings harvested/m2 was less in Mwanza than in Meatu and Shinyanga. This was attributed to weevil infestation from nearby fields. SPVD was also present in many roots, but probably most of all, due to lack of seriousness of the farmer in the area.

Farmers in Mwang'osha village in Shinyanga region added manure to their beds before planting the roots. They seemed to acknowledge that poor soil fertility could affect the performance of the planted roots.

Infection of sprouting roots with sweetpotato virus disease (SPVD) was a problem in Kumi in the variety Esapat and in Mwanza. Mwanza appears to have high prevalence of SPVD than Meatu and Shinyanga which experience a harsher dry spell than Mwanza. This is consistent with Uganda where areas with longer dry spells have lower SPVD infection rates. Maybe, in areas with high SPVD infection rates, the parent plants should be screened before storing and the sprouting roots screened before planting in the beds by observing the sprouts before planting. The roots that did sprout and were free of SPVD produced lots of cuttings [about 150/plant] so farmers don't actually need to keep many roots – in this sense, it is very efficient!

The farmer's expressions including "watering root beds was not a problem" was generally interpreted as implying that the practice was less demanding in terms of irrigation, possibly in comparison with irrigating cuttings.

The farmers generally indicated a preference for closer spacing in Tanzania as opposed to Kumi in Uganda, possibly because of the need to reduce the area watered since the areas were drier than Kumi in Uganda. General involvement of the family to irrigate and manage the multiplication beds was in common with the results obtained in Uganda. Possibly it was an indication of how the family valued the usefulness of obtaining planting material during the season following the prolonged dry season. It could have also been an indication of increasing ownership among family members because planting material would expensive. Innovative practices included watering in depressions created between neighbouring plants to minimize on possible loss of water through sprinkling. Reinforcing dried hedge protection with thorny shrubs around the root beds prevented animals getting access to the attractive green islands of vines. Setting the root beds next to beds of other vegetables crops (Plate 23) was particularly common in Meatu where the conditions were harsher and could have been a strategy for reducing labour costs on watering and protection. Some cases farmers had to construct thick thorny hedge around the beds to ward off livestock (Plates 25). Generally the attention and management of the root beds was more critical in Meatu than other areas because water sources were very difficult. The practice, however, actually seemed most successful there, possibly because planting material was most scarce here and because sweetpotato was very important for food and income. Obtaining more than 120 cuttings from a single root at harvesting seemed convincing to the farmer and her family that the practice had worked well for them. The already prepared field for planting after 3 days since the first showers of rain were received was confirmation of the need to plant as early as possible.

Generally storage in sand in a basin proved a reliable method for storage of sweetpotato roots for seed. Irrigated root beds successfully provide farmer with planting material at the planting time. Across the regions, the method was acceptable especially in the drier areas of Meatu and Shinyanga. Farmers volunteering to participate in future trials, collective family participation especially in Meatu, expression of stakeholders to lobby for funds to support the practice and requests to have the protocol disseminated are some of the many positive indicators.

CHAPTER 8:

Conclusions and recommendations

8.1 General discussion

8.1.1 Lack of planting material

There was a lack of planting material at the beginning of the rains in areas that experienced prolonged dry spells (Soroti, Bukedea) whereas there was no lack in areas which experienced a short dry spell (Mukono). Similarly, Dunbar (1969) reported that common shortages of planting material are caused by prolonged dry seasons in Uganda. Results suggest that lack of planting material at the onset of the rainy season immediately following the prolonged dry period (Friis-Hansen *et al*., 2004; 5) is critical as it resulted in about 50% of the farmers failing to plant the area they wished to. The results agreed with Bashaasha *et al*. (1995), Gibson (2009) and Namanda *et al*. (2011) that there is a lack of planting material in areas with prolonged dry periods due to the desiccation of the aboveground vegetation. Farmers largely rely on sprouting roots from the previous season's cropped fields (Akoroda *et al*., 1992; Yanggen & Nagujja, 2006; Gibson., 2009; Namanda *et al*., 2011) which are late and result into delayed planting (Franklin (1988) and consequently low yields (Akoroda *et al* 1992).

8.1.2 Effects of ease planting

The work confirms Bashaasha *et al*. (1995) that farmers prefer to plant early at the onset of rains in March if lack of planting material is not a problem (Plates 8a & b, and Tables 8 – 18). The method of early planting demonstrated by farmers could be regarded as an adaptation to ensure that early planting of sweetpotato is done. This leads to attain the benefits including increased yields and higher prices of early harvested crop (Table 12) also reported by Kay (1973), NRI (1987), Rockstrom & de Rouw, (1997), Stathers *et al*., (2005), Heyd & Qaim (2006), Low, (2009) and Namanda *et al*., (2011). Sweetpotato is widely grown by small farmers and is a key supplementary crop to cereal crops including maize and millet (Bashaasha & Mwanga, 1992; Bashaasha *et al.,* 1995; Mwanga & Wanyera, 1987) as well as a seasonal staple during periods when supplies of most other foods stuffs including cereals like maize and millet (FAOSTAT 2008; 2010; MAAIF 2011) are exhausted (Hall *et al*., 1998) and, unlike sweetpotato, cannot mature (Kay, 1973; NRI, 1987; Kay, 1987; Woolfe 1992). Notably the more important role of sweetpotato in the drier eastern and northern regions than in the other regions in Uganda (Khatana *et al*., 1999; Scott *et al*., MAAIF 2011) compared to cereal crops in Uganda (FAOSTAT 2008; 2010) was confirmed (highlighted in Table 3c).

Late planting results in delayed harvests. Harvesting then occurs later than the periodic peak of severe food shortages. Consequently, the advantage of sweetpotato as an early maturing crop (Onwueme, 1978) largely fails to be realised. The advantage of sweetpotato as a food security crop has been rendered less useful due to an ineffective seed system (Onwueme, 1978; Akoroda *et al* 1992; Setimela *et al*., 2004; Gibson, 2009) failing to supply planting material in a timely fashion.

Other weaknesses revealed by this study included farmers' failure to plant the maximum crop area through irrational planting of the available scarce planting material such as the extravagant use of long cuttings and high planting density. Planting at populations reduced to two cuttings per mound showed no significant decrease in root yield which confirmed (Aldrich 1963) that planting material can be manipulated in areas where it is scarce. Planting 20 cm cuttings rather than 30 cm cuttings had no significant effect on yield.

8.1.3 Benefits of early planting

The majority (78%) of the respondents from areas with prolonged dry periods, especially, Soroti and Bukedea (Table 12), perceived greater yields and bigger roots as the main benefits of early planting. The findings corroborated reports from Kay (1973), NRI (1987), Franklin (1988) and Woolfe (1992) that early planting increased storage root initiation and bulking (key parameters influencing final root yield) due to the plants receiving adequate soil moisture. The majority of the farmers reported a pronounced root yield increase ranging from 25 % to 300 % (Tables 12 & 14). The majority reported a >200% increase in profit associated with early planting, with the biggest increase in Soroti followed by Bukedea. Profitability of an early planted crop in Bukedea and Soroti districts is a function of both better yields and prices (Heyd & Qaim, 2006). Besides, farmers considered that planting early created an early crop that was useful for home consumption, and sold readily to urban centres at better prices than a late planted crop. However, reports from Mukono, an area with short dry seasons, indicated the early planting resulted in more difficult crop management and reduced yields due to senility of planting material and greater management costs, especially land preparation.

8.1.4 Length of cuttings

Surveys showed that most farmers in areas characterised by longer dry periods tended to use ≤30-cm long cuttings and the main source of planting material was sprouts from ground keeper roots whereas those in shorter dry seasons tend to use ≥30-cm long cuttings. The two largely distinct farmer options of vine lengths for planting material were within the ranges reported by Shanmugavelu *et al*. (1972), Kay (1973) and Nair (2006) who reported an optimum vine length of 20 – 40-cm long, and 30-cm long recommended by Stathers *et al*. (2007). Farmers who rely on cuttings from sprouting roots may be poorer and less able to access planting material (Onwueme, 1978) in other ways. So, maximizing the available planting material by using shorter cuttings and manipulating plant densities (Aldrich, 1963) over the range from 25,000 to 125,000 plants/ha (where there was relatively little difference in overall yields) (Kay, 1973; NRI, 1987; Mwanga & Wanyera, 1987) should be particularly beneficial to these farmers.

Considering that the rapid multiplication technique (RMT) devised by NARO, NRI and CIP was not adopted by farmers due to frequent watering and other intensive care (Gonzalez, 2006; Yanggen & Nagujja, 2006), it is probably worthwhile planting 20 cm cuttings even though they did not yield twice as many cuttings as 10 cm ones. Application of a pre-planting fertilizer mixed into the soil at planting time roughly doubled ($P<0.001$) the number of cuttings harvested using RMT. Pre-planting fertilizer (NPK 25:5:5) at the rate of 100 g/m^2 is preferred to a top dressing fertilizer (urea) because the latter can easily burn the plants, especially if watering is inadequate, as it is likely to be in the dry season. The results agreed with Franklin (1988) that application of nitrogen fertiliser application improved the source of cuttings; complete fertiliser is recommended for plant beds (Jonathan, 1998).

8.1.5 The Triple S method

Conserving planting material in swamps tends to conflict with environmental concerns and laws restricting the use of swamps for agricultural purposes. Although making cuttings from sprouting ground keepers delayed planting, it seemed likely to be the better way forward for an early source of sweetpotato planting material in areas with prolonged dry periods. The Triple S method developed during the study is a simple and cheap way to store roots during the dry season and then minimal watering of root beds to produce planting material for early planting. Generally storage in sand in a basin proved a reliable method for storage of sweetpotato roots for seed. Irrigated root beds sufficiently provide farmers with planting material at the required planting time. Across the regions, the method was acceptable especially in the drier regions of Meatu and Shinyanga. In these regions, sweetpotato is generally cultivated by small and medium scale farmers and as such the Triple S method is relatively simple, cheap and applicable for the majority of these farmers. Sand is easily available and keeps the roots free from pests including rodents. Farmers volunteering to participate in future trials, collective family participation especially in Meatu, expression of stakeholders to lobby for funds to support the practice and requests to have the protocol disseminated are some of the many positive indicators. Storage of roots in sand and later establishing minimally irrigated root beds provides an opportunity to timely access to enough clean sweetpotato cuttings for early planting in areas with prolonged dry periods.

In Tanzania, sand was confirmed as a reliable medium for storage of sweetpotato roots, weevils did not damage the roots in the sand and numbers of weevils in the gardens may also have been reduced by a long dry season as none were evident in the validation trials in Shinyanga and Meatu districts. There were some complaints about the cost of the basins and digging a pit in the floor of the house and adding the sand and roots may be a practical solution (Mpagalile *et al*., 2007). Infection of sprouting roots with SPVD was a problem in Mwanza (as well as in Kumi, Uganda, in cv Esapat). The long dry season in Meatu and Shinyanga may also help to control the whiteflies that spread this disease (Gibson, 2009) but elsewhere there will be a need to carefully select the parent plant. In Tanzania, farmers were especially enthusiastic about the method, seeing that it provided a method of solving their chronic shortage of planting material. Obtaining sometimes more than 50 cuttings from a single root convinced the farmers and their families that the practice worked.

In summary, this thesis has identified a chronic shortage of planting material that farmers suffer at the beginning of the rainy season in eastern Uganda and developed several different approaches (using fertilizer to increase production of cuttings, planting fewer and shorter cuttings, and using the Triple S method) to address it. A combination of some or all of the different approaches to alleviating it should enable farmers to achieve greater production earlier in the season, increasing their food supplies at a particularly crucial time and/or increasing their profitability. Further studies have already emerged including investigations in storage approaches of roots for generating planting material, investigation on the possible transmission of sweetpotato virus disease to sprouting shoots, and further studies on the application of fertiliser on production of planting material and rationale of using the available limited planting material have been identified.

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Appendices

Questionnaires

1. Farmers' practice on sources of sweetpotato planting material questionnaire

District: Sub-county: Parish: LC1:

Farmer's name: Farmer's age: Gender:

Farmer's level of education Number of households members at home:

Total area: Sweet Potato area: OFSP area:

What is the most important crop for you?

What is the second most important crop for you?

Now I would like to talk with you about sweet potatoes and specifically the sweet potato that you grow during the first season (March –August)

What are the differences between sweetpotato crop you are able to plant at the beginning of the rains [because you have got planting material] and those that planting material had to be delayed?

a) For management of sweetpotato and your other crops, does planting material at the beginning of the rains

i) Have no effect ( )

ii) Cause difficulties ( ) or is easier ( )? Explain choice

b) Productivity of sweetpotato. Does planting at the beginning of the rains

(i) Have no effect on yield

(ii) Increases it ( ); or

(iii) Decreases it ( ).

If ii or iii, ask farmer by how much

c) Usefulness for home consumption. Does planting material at the beginning of the rains make a sweetpotato crop?

(i) Less useful ( ),

(ii) More useful ( ) or has no effect on usefulness ( ) to you for home consumption.

If i or ii, ask why.

d) Usefulness for home preservation. Do you dry sweetpotato to preserve it Yes ( ) No ( ).

If yes, Does planting at the beginning of the rains make a sweetpotato crop (i) less useful ( ), (ii) more useful ( ) or has no effect to you on home preservation. If I or ii, ask why

e) Profitability if sold. Do you sell sweetpotato Yes ( ), NO ( ).

If yes, does planting at the beginning of the rains make a sweetpotato crop?

(i) Less profitable (   ),

(ii) More profitable (   ), or

(iii) Has no effect on profitability (   ),

If I or ii, ask farmer by how much per acre ……….

2a) If 1a no, at the beginning of last year's (2007) first rains, did you supplement

Yes (   )   No (   )

(If 2a No, go to 3a)

2b) If 2a yes, how did you supplement?

2c) Is this the usual way you do it?

2d) If no, was extra planting too expensive (   ) or not available to buy locally (   ) (tick choice)

3a) At the beginning of last year's (2007) first rains, What area/how many mounds did you fail to plant?

3b) Is this the usual amount?

4a) If you bought for last year's (2007) first rains, for what area/for how many mounds?

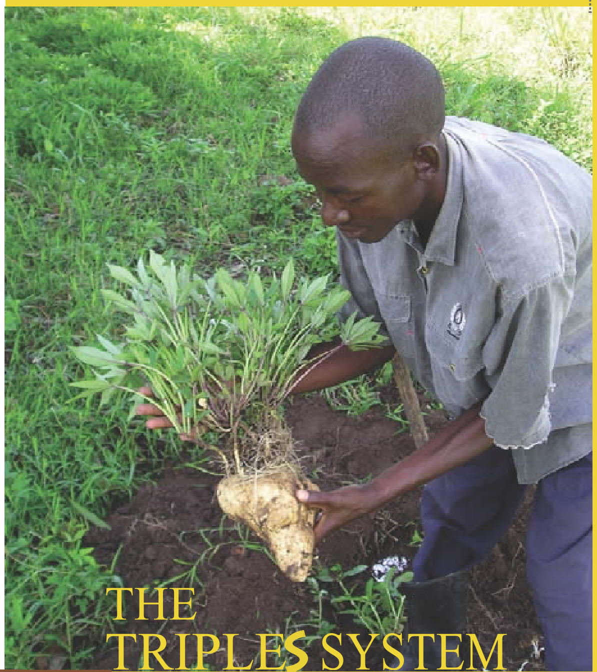
4b) If so, what did it cost? UGSH …………..

5a) At the beginning of last year's (2007) first rains, from what source did you get planting material of your own? (after registering the sources, please ask the farmer to rank the sources according to the importance of each source for the farmer)

Source	Rank

5b) Is this your usual sources of your own planting material?

Yes (   )   No (   )



THE TRIPLE S SYSTEM

[Storage in Sand and Sprouting]

provides planting material from storage roots in areas with a long dry season

In such areas, farmers often obtain sweetpotato planting material from roots which have been overlooked during harvest and sprout when it rains. However:

1. The roots sprout only when it rains and planting material only becomes available some weeks afterwards
2. The roots may sprout in distant fields, unprotected from grazing animals and thieves.

To solve these problems, researchers and farmers have developed a system of conserving planting material whereby storage roots are stored in sand and then planted out and watered before the arrival of the rains. This way, they have sprouted and produced large amounts of planting material in time for the arrival of the rains.

THE TRIPLE S SYSTEM

STORAGE IN SAND AND SPROUTING

CENTRO INTERNACIONAL DE LA PAPA • CIP •

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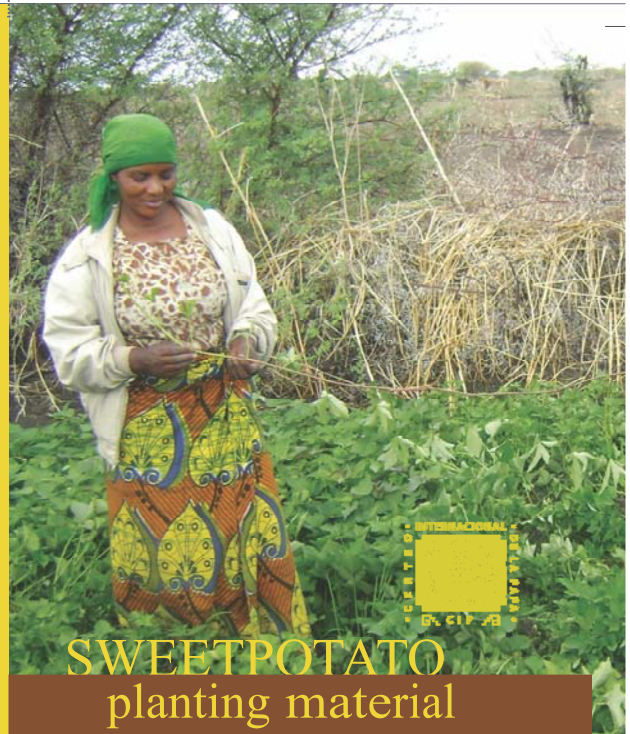

SWEETPOTATO planting material

THE TRIPLE S SYSTEM

Storage Sand Sprouting

The sand covers the roots [by about 5cms].

1

At the end of the rainy season, farmers get small to medium-sized sweetpotato storage roots, carefully selecting roots that are from healthy plants and are undamaged, particularly free from weevil damage.

2

The roots are kept in dry sand [swept from around the house or a road] in a container until 6 - 8 wks from the expected start of the rains.

Take care that the sand is cool [not hot from having been in the sun]. Maybe two or more layers of roots can be kept in the same container.

3

The container of sand and roots is kept in a cool dry, place, until about 6 - 8 wks before the start of the rains, perhaps in the house or in a roofed hut, but safe from the children or chickens that may like to nest in it.

The roots sprout but generally the sprouts remain quite short. [If the dry season is very long, it may be necessary to remove the sprouts midway during the dry season and allow them to re-grow].

4

About 6 - 8 wks before the start of the rains, the sprouting roots are planted in a garden near the home. The whole of the root and sprouts are buried, unless they are very long. They are planted at ~0.5 x 0.5m and in a slight depression [to help watering]. The soil needs to be fertile and the area fenced against grazing animals. The roots are watered at planting and then every 3 or 4 days.

5

By the time the rains come, the roots will have sprouted vigorously and it is possible to cut large amounts of planting material.

Just 40 roots can generate about 1,500 cuttings.

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Sweetpotato Seed Systems in Uganda, Tanzania, and Rwanda

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Sweetpotato Seed Systems in Uganda, Tanzania, and Rwanda

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Surveys were made of the seed systems used in Uganda, Tanzania, and Rwanda and to investigate the reasons underlying them. Along the equator in Uganda, where rainy seasons are evenly spaced and occur twice a year, vine cuttings from mature plants only are used as planting material. Where there is a long dry season, the seed system includes a diversity of means of conservation: the passive production of volunteer plants from groundkeeper roots sprouting when the rains come; small-scale propagation of plants in the shade or backyard production using waste domestic water; and relatively large-scale propagation in wetlands or irrigated land. The last is the only means of obtaining sufficient quantity for sales, but is also the most expensive. Volunteers only produce planting material one or two months after the start of the rains and tend to be regarded as common property; nevertheless, they are an important source of planting material for poorer farmers. Although farmers perceive multiple benefits from planting early, planting material is in short supply at the beginning of the rains and mainly larger scale farmers gain these benefits. Farmers select carefully to avoid using plants with symptoms of virus disease as planting material and may also remove any diseased plants from crops.

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KEYWORDS Africa, volunteers, virus infection, propagation, planting material

Seed systems have several purposes and effective seed systems provide the different categories of farmers with planting material 1) in sufficient quantities, 2) at the right time, 3) of an appropriate physiological state, vigor, and health, 4) of superior genotypes appropriate to the farmer's purposes, and 5) at an affordable price. To maintain superiority of genotypes and health, there may need to be capacity within seed systems for dissemination of new cultivars and pathogen-free stocks. Sweetpotato is propagated through vine cuttings. In Tanzania, Uganda, and Rwanda, planting material originates almost entirely within the farming community (Ndamagé 1990; Bashaasha et al. 1995; Kapinga, Andrade, et al. 1995), with only occasional formal distributions for disaster relief (Kapinga, Andrade, et al. 2005) and of new varieties (Kapinga et al. 2000).

Viruses have been reported as damaging in all three countries (Carey et al. 1998; Tairo et al. 2004; Njeru et al. 2008) and an International Potato Center (CIP) survey in 2005 reported that "virus management, seed quality and supply systems" were the highest priority for future research and development against all other listed sweetpotato technologies for 91 respondents from them and 31 other developing countries (Fuglie 2007). Farmers select against infection with the severe disease, *Sweet potato virus disease* (SPVD), caused by the synergism of *Sweet potato chlorotic stunt virus* (SPCSV) on sweet potato feathery mottle virus (SPFMV; Gibson et al. 1998). However, they cannot select against infection with symptomless viruses, notably SPFMV when infecting alone.

Sweetpotato seed systems in East Africa fall into two categories: along the equator where two evenly spaced rainy seasons occur at and after the equinoxes; and away from the equator, where the dry seasons are asymmetric, there is a prolonged dry season and special measures are necessary to survive it (Gibson et al. 2009). Uganda is the only country of the three discussed that has such an area along the equator; on either side of it, all three countries have areas where there is a prolonged dry season. A "hunger gap," whereby severe food shortages occur when the grain harvest is exhausted in the late dry season and early part of the rainy season before the harvest of the new season's crop, is common to such areas. In such areas, sweetpotato is potentially an early source of fresh food. However, traditional vine sources usually fail to provide sufficient planting material at the onset of the rains, delaying planting, preventing the crop from satisfying demand, and limiting its role as a famine relief crop (e.g., in northern Uganda, sweetpotato root prices increase from December with the start of the dry season through to June when harvesting starts; Hall et al. 1998). Shortages of planting material have been reported from Uganda (Dunbar 1969) and Tanzania (Mwanbene et al. 1994; Kapinga et al. 1995, 1998) and calls made for community-based nurseries (Kapinga et al. 1998), later evolving into a call for a decentralized farmer-based seed multiplication system (Kapinga, Tumwegamire, et al. 2005) to address the problem.

This article looks at various aspects of the different seed systems utilized in the three East African countries, with the particular aim of understanding how better to provide planting material following the long dry season. The lack of a major formal sector also creates particular difficulties in understanding how to disseminate new cultivars and stock free from disease, particularly asymptomatic viruses, in this clonally propagated crop.

METHOD

The results were obtained from questionnaire-based surveys in:

- Uganda of 271 farmers in Soroti, Kamuli, Bukedea, and Mukono districts in 2008;
- Rwanda of 434 farmers in the east, west, north, and south Rwanda and Kigali town in 2009;
- Tanzania of 126 farmers in Mara and Mwanza districts in 2010;

and other more informal observations conducted in the three countries from 2005 to the present. The surveys involved sweetpotato farmers—mostly women and mostly small-scale—who grow the bulk of the crop in all three countries. Farmers were selected for interview at random from lists provided by local extensionists. Farmers were asked about the sizes of their holdings, how much land was planted to sweetpotato, their sales, as well as how they obtained planting material in a series of relatively open questions to which they could provide extensive replies. Some chose not to answer certain questions. Table 1 is developed from observations in Soroti District Uganda made in 2007; Tables 2 and 3 are from a general survey of sweetpotato farmers in the Lake Zone of Tanzania in 2010; Tables 4 and 6-8 are from a general survey of sweetpotato farmers in Uganda in 2008; and Table 5 is from observations made in the Lake Zone of Tanzania in 2005.

RESULTS

Some eight different methods were observed to be a part of the seed system, each practiced to differing extents in different parts of Tanzania, Uganda, and Rwanda.

TABLE 1 Weight, Average Number of Sprouts and Weevil Infestations of 20 Volunteer Plants from Groundkeeper Roots of Each of Three Cultivars in Fields in Soroti, Uganda

Cultivar	Weight range (gm) of roots	Average number of sprouts/root	% root infestation by weevil
Araka	120-618	33.6	96.9
Ejumula	30-232	26.7	94.6
Kakamega	30-176	31.7	94.4

TABLE 2 Criteria for the Identification of Vines for Multiplication (from Tanzania Survey)

Criteria for identification of planting material	Number of farmers giving opinion
Healthy/disease-free/well developed/with good leaf formation/green leaves/plants or vines	44
Pest free vines	10
Get production history/observe roots produced/High yielding plants	8
Attractive plants	4
<2 farmers giving a particular opinion	11
Total	77

TABLE 3 Treatments Applied to Ensure Planting Material is of Good Quality (from Tanzania Survey)

Treatments	Frequency
Weeding	60
Roguing	11
Irrigating during drought	10
Timely planting	9
Inspecting the fields	9
Store in a cool place (postharvest treatment)	8
<2 giving a particular opinion or don't know	18
Total	125

- *Farmers use vines collected from fields of growing crops* as their source of planting material at some point in the cropping cycle everywhere. Close to the equator, where there is no prolonged dry season, this may be the only source throughout the year. Where there is a prolonged dry season, it is also the source of planting material during the rains as crops established from other sources become mature. Apical portions of vines are preferably taken from young/mature crops, to benefit from their physiological youth (Martin 1984) as well as freedom from pests, especially weevils, which infest mainly the stem bases. Vines are selected for a healthy appearance, particularly freedom from SPVD [as in other means of planting material production]. Generally, vines are given to neighbors freely.

TABLE 4 Characteristics of the Three Common Sources of Sweetpotato Planting Material in Areas With Long Dry Seasons in Uganda

Management activity	Conserving in the valley bottom/swamp	Volunteer plants	Conserving plants under shade
Fence	Yes	No	No
Month of planting	Dec-Jan	Not relevant	Oct-Dec
Average area (ha)	0.6	Not relevant	< $10m^2$
Irrigated	Yes	No	No
Expected harvesting month	March	May	April
Total cost (Ug/-)/ha	925,237*	0	0
Quantity harvested/ha	605 bags	Not relevant	A few m^2
Average farm gate price/bag (100 kg maize bag)	10,000	[7,300] [Not sold]	[8,750] [Not sold]
Total income	6,050,000	Not relevant	Not relevant
Gross margin	5,124,763	Not relevant	Not relevant
Common varieties	Kakamega,* Vita A,* Kabode,* and Araka	Araka and Osukut	Araka and Osukut

Rate of exchange: 1,900 Ug /- = $1 US in 2009.
*Kakamega, Vita A, and Kabode are released varieties; Araka and Osukut are local landraces.

- *Volunteer plants* growing from unharvested roots provide a major source of cuttings in more-or-less all areas in which the dry season has become sufficiently harsh to prevent crops surviving with foliage. Usually, it is small buried roots that have been overlooked during the harvest or larger damaged ones that have been rejected that produce shoots when the rains arrive. It is a passive means of production; nevertheless, large amounts of vines are produced in this way. They are a free source of cuttings and are particularly popular amongst poorer farmers. The process, however, requires that the land is not planted or closely grazed. Because they occur naturally and by chance, they may be considered to be "common property," free for all. This may result in them being harvested prematurely even by the owner—in case another person harvests them. Another disadvantage is that they grow aboveground only once the rains occur and so are always late. They are also often severely infested by weevils (Table 1).
- *Growing a crop during the dry season in swampy land* usually provides a dual purpose crop, providing roots at a time when there are shortages of food and also vines for planting material at the beginning of the rains. This is common practice around the shores of Lake Victoria in Tanzania, of Lake Kyoga in Uganda and in the valley bottoms in Rwanda. In Tanzania, rice paddy fields are sometimes used, the sweetpotato surviving on the residual moisture. The system reaches its peak in Rwanda, crops being planted in large beds in valley bottoms at the start of the dry season in May and June, harvested in October and November and their vines used to plant the main crop on the valley sides. This practice, which has traditionally helped assure food security in Rwanda, is being undermined by the spread

TABLE 5 Responses by Interviewees in the Lake Zone of Tanzania Indicating the Extent to Which Access to Planting Material is a Constraint at the Start of the Rains

District and number of interviewees		Availability of planting material is a problem?					For planting material, do you:	
		No	Small	Main	Limits planting area	Delays planting time	Buy	Sell
Shinyanga	8	3	1	4	7	5	4	3
Meatu	9	0	1	8	9	9	8	3
Mwanza	1	0	0	1	–	–	1	0
Total	18	3	2	13	16	14	13	6

TABLE 6 The Numbers of Farmers in Two Districts in Uganda Giving Particular Explanations Why Planting Early Creates a More Useful Yield

	Districts in Uganda		
Advantages	Bukedea	Soroti	Total
Provides food [when other sources are running out]	55	36	91
Enables dual benefits: can sell as well as eat	26	1	27
Early maturity of crop	12	4	16
High yield	2	8	10
Helpful for food preservation	3	1	4
Better for sales [good early-season market]	1	1	2
Fits well with cassava	0	2	2
Total indicating advantages*	99	53	152
Total indicating disadvantages	0	0	0

TABLE 7 The Amount of Money (Ug/-) Spent by Ugandan Farmers to Buy Additional Planting Material

	District		
Money spent (Ug/-)*	Bukedea	Soroti	Total
≤1,000	1	1	2
1,001-5,000	3	2	5
5,001-10,000	7	9	16
10,001-20,000	3	4	7
20,001-30,000	2	4	6
30,001-40,000	2	1	3
40,001-50,000	1	1	2
50,001-60000	1	1	2
>60,000	0	1	1
Total	20	24	44

* \$1.0US = 1,700/- Ugandan in April 2008.

TABLE 8 A Comparison of the Number of Farmers in Soroti and Bukedea Wanting to Buy Extra Sweetpotato Planting Material But Not Doing So and Those Actually Buying

Hectares	Wanting to buy	Buying
≤ 0.04	39	6
0.04-0.2	43	16
0.21-0.4	21	14
>0.4	3	4
Total	106	40

of large irrigation schemes designated for growing rice, beans, maize, and potatoes instead in these valley bottoms, with sweetpotato often banned from such land. Elsewhere, although there are laws against the cultivation of wetlands, these often seem to be broken. Crops grown in wetlands are at risk of being eaten by grazing wild or domestic animals because they may be the only young vegetation around and sited far from homesteads. They are consequently often fenced, usually with thorn. These crops, as with others grown specifically for seed, are carefully planted with healthy-looking and pest (mainly weevils) -free vines; planting material may even be positively selected based on the root formation of the parent plant (Table 2). The crop is valuable and is weeded regularly, inspected and rogued for off types and diseased plants especially SPVD (Table 3).

- *Irrigating a crop during the dry season* from a river, waterhole [often in a dried-up river bed] or lake is widespread, particularly in Tanzania. The crop is often hand watered, for example, by buckets. In Tanzania, watering is done on average every other day from May to September inclusive, reaching a peak of almost every day in July, and for 3 ± 2.5 hours a day. It is done primarily by women and young girls; in one location in Shinyanga Tanzania, 22 women and older girls were busy watering but, although several men and older boys were present, none were watering. As with growing a crop in swamps, both roots for eating and vines available in time for the rains are produced. Irrigating allows the crop to be grown close to, but not in, wetlands, thus, avoiding laws on the cultivation of actual wetland. A petrol or diesel powered pump may be used, especially if it is an NGO. Again, these crops are carefully planted with healthy-looking and pest (mainly weevils) -free vines and planting material may even be positively selected based on the root formation of the parent plant (Table 2). The crop is valuable and is weeded regularly, watered, inspected and rogued for off-types and diseased plants especially SPVD (Table 3).The Ugandan Soroti Sweetpotato Producers Association (SOSPPA) provides an example of a large-scale farmers' association equipped with a pump used to irrigate several hectares of land.
- *Growing plants in the shade* occurs in areas with only a moderately prolonged dry season. Often, the shade is provided by bananas, as in the Kagera region of Tanzania and in Rakai and neighboring districts in Uganda, but coffee, avocados, and such are also used and also sometimes cassava or the dried-up stalks of harvested maize and millet. In very prolonged dry seasons, shade vegetation either does not survive or loses its leaves, so this method cannot be used. Generally, only small amounts of vines are produced by individual homesteads; storage roots are generally not produced because of shading. Usefully, vines are available for the start of the rainy season.
- *Plants grown in the backyard* and watered from waste water from the house, or downstream of village pumps, are common in dry areas of Uganda and Tanzania. Because only small amounts of water are generally available, only small amounts of vines are produced; the crop generally does not produce storage roots. However, almost anyone can do it and crops are generally easy to protect against grazing animals. Vines are also

produced in time for the rainy season. They are, however, often affected by weevils.

- *Planting a crop, often late, for production of vines from the roots* is occasionally done but generally results in crops badly affected by weevils.
- *Use of trash vines* growing from vines discarded during harvest is rare.

In all systems, even when vines are purchased, it is usually farmers who select and cut the vines. This allows them to avoid collecting vines from plants that are affected by virus, especially SPVD. Generally the apical 30 cm of the vine only is taken; this reduces the likelihood of transferring weevils and may be important in ensuring that the vine is physiologically young. In Rwanda, there is a particular problem with erinose, caused by *Aceria* spp mites. Although the parent plants form normal storage roots, the vines are unsuitable for planting as they fail to root well.

Seed systems consist of more than one means of propagation except in the areas of Uganda close to the equator, where continuous production is practiced. Thus, in Tanzania in an area where there is a prolonged dry season, planting material is conserved during the dry season by a variety of means including volunteer plants growing from groundkeeper root, growing in swampy land or by watering. This planting material is then used to establish the initial crop at the beginning of the rainy season and from which vines are taken to establish further crops (Figure 1). The cycle is completed by vines from these crops establishing the conservation crop or providing groundkeeper roots.

The main constraints to seed production are drought, pests, and diseases (Figure 2). The management and outcomes of three common means of maintaining planting material were compared (Table 4) in Uganda. Generally, conserving in wetlands or irrigating requires considerable inputs, including a sturdy fence to protect it, land preparation and weeding during the growing season. Land preparation is often expensive because the land may not be used during the wet season and is colonized by coarse grasses and other vegetation. However, this method results in planting material being available at the beginning of the planting season in March, to be sold at considerable profit. Large-scale planting is mostly to modern varieties, aiming to sell most of the vines to nongovernmental organizations (NGOs) or international relief operations. In Tanzania, it is also done privately by quite small-scale farmers, for example, in Shinyanga District, Tanzania, generating $90-140 US per year from the sale of vines alone. Most sales are then to other farmers and of local varieties. Planting in the shade requires no costly inputs but is done on a very small scale, suitable for the requirements of the homestead only. Relying on volunteers also requires no inputs and may achieve a greater output of vines than production in the shade but the vines are available much later and are also not saleable.

Farmers in all three countries confirmed that shortages of planting material at the beginning of the rains were a major constraint. In Rwanda, nearly

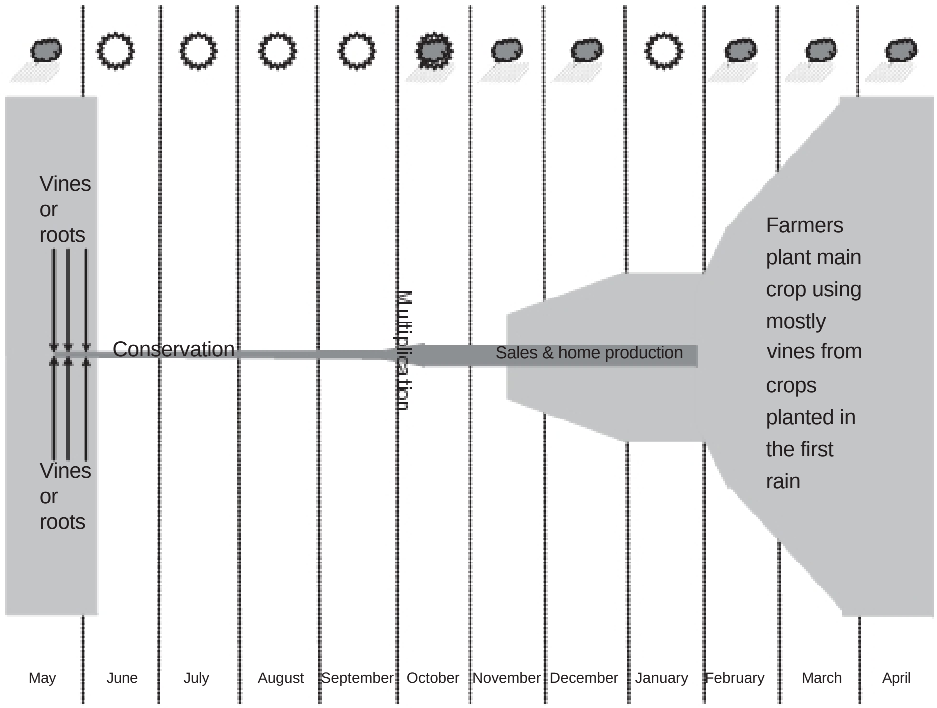

FIGURE 1 The seed system in areas with prolonged dry season in the Lake Zone of Tanzania. (*Note:* The conservation, sales, and initial multiplication of vines are exaggerated in order to be better seen.)

half of the 434 farmers interviewed disagreed with the statement that "supply of planting material is easily available," nearly 40% disagreeing strongly. In the Lake Zone of Tanzania, farmers in Shinyanga and nearby districts confirmed lack of planting material as the main problem in production, both delaying planting time and limiting the area planted (Table 5). The farmers who did not complain of shortages of planting material in Shinyanga grew it in the swamps and were all sellers of planting material. Most farmers bought planting material; the concept of getting it free from their neighbors was unrealistic and some traveled long distances and incurred considerable costs to obtain planting material. In parts of neighboring Meatu district, farmers paid the equivalent of $6 US travelling 50 km and buying a bundle of cuttings filling a 100 kg maize/fertilizer bag, planting perhaps 10-15 ridges each 10-20 m long (as described by purchasers). In Rwanda, a large bundle of vines cost about $2 US. Most farmers in northeastern Uganda thought they would plant about twice as much and about one month earlier if planting material was readily available. Farmers obtained numerous benefits from early supplies of planting material, particularly an early source of food for the family and early, high value sales (Table 6). Ugandan farmers mostly spent

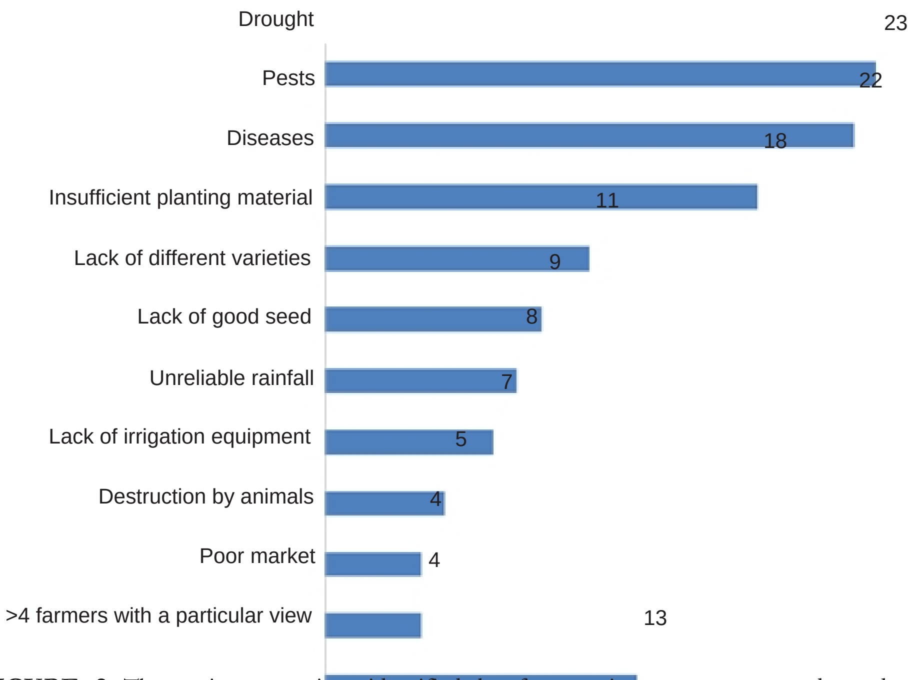

FIGURE 2 The main constraints identified by farmers in sweetpotato seed production. Numbers after each column are the number of farmers responding (color figure available online).

between 5,000 and 10,000 Ugandan shillings (Ug/-) ($3-6 US) on purchasing planting material, although quite a few spent up to 30,000 Ug/- ($18 US) (Table 7). Interestingly, many more farmers wanted to buy than actually bought; since it was mainly farmers owning large areas of sweetpotato that actually bought (Table 8), it seems likely it was lack of funds that prevented purchase by smaller-scale farmers. A similar situation occurred in Rwanda; there the farmers who did not buy relied on vines from sprouting roots and on neighbors to supply them freely when their early-planted crops from bought vines had matured.

DISCUSSION

The sweetpotato seed system varies from country to country and from region to region within each country but there are commonalities across agro-ecological zones. Uganda is the only country with an area running along the equator and which, therefore, has an area with no prolonged dry season. This is the only region for which the seed system involves only the use of vines from growing crops, vines being taken from a mature crop to establish a new crop which, when mature, is itself used as a source of vines and so on. Elsewhere, there is at least a moderate, and in parts of northern and northeastern Uganda and in Tanzania and Rwanda, a prolonged, dry season and a diversity of means such as growing in the shade, in swamps, and use of sprouting roots is used to maintain planting material until the rains return. Growing crops in swampy areas and/or watering is the only current mechanism which produces large enough quantities for sale. Watering by buckets is used mostly in private enterprise small-scale farming, with the planting material sold to farmers. Mechanically-powered irrigation is restricted to large-scale production of vines, often by NGOs, which are important in secondary multiplication of vines in both Tanzania and Uganda (Kapinga, Tumwegamire, et al. 2005). In all areas, once the rainy season is established and mature crops are available, farmers start to use vines from their own crops as their main source lack of planting material (Figure 1). The use of sprouting roots suffers from two major disadvantages: that the vines from the sprouting roots may be seen as common property and that the vines grow in response to the rains and so always occur *after* the rains. Despite this diversity of mechanisms, the overwhelming situation at the beginning of the rainy season in all three countries is one of scarcity of planting material. In Rwanda, scarcity has mostly been created artificially by government forbidding most sweetpotato from the valley bottoms during the dry season, although in the drier east of the country, scarcity occurs because of the dry season. In Tanzania and Uganda, scarcity of vines due to the dry season (Bashaasha et al. 1995; Kapinga et al. 1995, 1998) means that the farmers are unable to plant enough land with resultant food shortages and high prices.

The seed systems for sweetpotato do not by themselves provide a means by which virus infection is avoided as the crop is always propagated vegetatively. Some viral diseases, such as SPVD, are severe, clearly very damaging and visual inspection provides an effective means by which farmers can select against them. Others such as SPFMV and sweet potato mild mottle virus (SPMMV) are generally symptomless when infecting alone. Surprising, the planting material of many landraces seems largely virus free. Thus, when cuttings were obtained from asymptomatic field plants—such as farmers would normally use as planting material (Bashaasha et al. 1995)—and are tested for virus infection by grafting to the indicator plant *Ipomoea setosa*, 85% indexed as virus free and the infected 15% all had SPFMV alone (Gibson et al. 1997). In Tanzania, 38 (52%) of 73 symptomless plants collected from crops were sero-negative for viruses (Tairo et al. 2004) and in Kenya, 477 (75%) of 638 asymptomatic plants collected from crops throughout Kenya were both sero-negative for viruses and found to be virus free when indexed on *I. setosa* (Ateka et al. 2004). In all cases, the main virus infecting the asymptomatic plants was SPFMV alone. It has been shown that some cultivars possess a mechanism by which SPFMV can be eliminated

(Aritua et al. 1998), probably through an RNA silencing mechanism (Kreuze et al. 2005). This appears to be a valuable way by which planting material of landraces is maintained relatively free from such diseases.

Improved seed systems have a proven track record in raising productivity of clonal crops, for example, the adoption of CIP sweetpotato seed technology (virus testing and large scale production of virus-free planting material) in the Shandong province of China in the period 1988-1998 in >80% of the production area of the province, increased average yield by ~30% (Fuglie et al. 1999; Gao et al. 2000). Whether something similar needs to or can be done for small-scale farmers in Africa and whether it will be decentralized and based on farmers' seed systems (Kapinga, Tumwegamire, et al. 2005) or involve commercial producers remains to be seen. The provision of planting material of appropriate varieties is also a key intervention, sometimes to rehabilitate farming systems following natural disasters such as drought, civil unrest, or conflict and to assist the return of displaced persons (Kapinga, Andrade, et al. 2005). Distribution may be of the indiscriminate "truck and chuck" form but it is hoped that this detailed description of the informal systems of farmers will help these interventions to be integrated with them and so also have longer-term benefits.

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Developing and Validating the Triple S Method (<u>S</u>and <u>S</u>torage and <u>S</u>prouting) of Producing Sweetpotato Planting Material for Areas in Africa with a Long Dry Season

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Ugandan farmers preferred vine cuttings from sweetpotato plants maintained during the dry season in a swamp or by irrigation as planting material rather than cuttings from volunteer plants growing from unharvested roots. The latter were late and weevil-infested, though readily available. To improve their earliness, roots planted 5, 10, 15 or 25 cm below ground at the start of the dry season were watered from 5 or 10 weeks before the start of the rains. Only those planted 10 cm deep emerged satisfactorily; those watered for 10 weeks produced more vines. To improve survival, roots were stored under various conditions before planting and watering: roots stored in dry sand in a roofed building survived especially well and sprouted prolifically, producing many cuttings. This method of producing cuttings was validated by farmers in the harsher Lake Zone of Tanzania. As well as providing farmers with ample early and healthy planting material for little and infrequent watering, it also provided convenience and ownership.

KEYWORDS sprouting roots, volunteer plants, long dry season, arid, vine cuttings

INTRODUCTION

Sweetpotato is normally propagated by vine cuttings. Obtaining these direct from a mature crop is easy, cheap and practiced in Africa wherever cropping is year-round. However, where there is a long dry season, the vines die and lack of planting material is then the main production constraint (Gibson et al., 2009; Namanda et al., 2011) as reported, for example, in north and north-eastern Uganda (Bashaasha et al., 1995; Yanggen & Nagujja, 2006) and the Lake Zone of Tanzania (Kapinga et al., 1995). Farmers may then conserve plants in swamps and irrigated land so vines are maintained or use vines from plants that grow from unharvested roots when it eventually rains (Gibson et al., 2009). The latter is a cheap source of planting material but has at least three major problems:

- The roots sprout only once the rains have begun so planting has to be delayed until vines are long enough to be cut. This results in the subsequent crop yielding after the main cereal harvest rather than before, so after the time when food is most needed by families and after the time when market prices are high (Akoroda et al., 1992; Hall et. al., 1998).
- The cuttings are often infested by weevils, the main pest of the crop (Smit & Van Huis, 1999), surviving the dry season on the parent root.
- After harvest, fields in many areas are traditionally grazed by domestic animals belonging to villagers, including volunteer sweetpotato plants (Namanda et al., 2011).

Climate change is also increasing the extent and variability of the duration of the dry season, the time of onset of the rains and their intensity throughout Africa (Boko et al., 2007), exacerbating problems associated with supply of planting material leading to a need to 'climate-proof' the provision of planting material.

It was considered from the outset that increased use of wetlands was unsustainable in East Africa for legal and environmental reasons (Bakibinga-Ibembe1et al., 2011) and from competition from other crops so preference was for innovation(s) to the process by which unharvested roots produce volunteer plants and hence vine cuttings. This would mimic the way farmers in the temperate and sub-tropical world store sweet potato roots during the cold season in barns or cellars and then plant them out in spring in heated nursery beds: under such conditions, they sprout prolifically and cuttings, so-called ‘slips’, can be harvested within 1 – 2 mths to use as planting material (Deonier & Kushman, 1960; general ref: http://extension.missouri.edu/p/G6368 Accessed 20 March, 2012). Roots are not normally stored in the tropics (Wolfe, 1992) as they sprout quickly and are attacked by weevils (Smit & Van Huis, 1999) and disease (Ames et al., 1996); even when stored in pits in the ground (Tomlins et al., 2007), it is usually for no more than a few weeks (reviewed: Ray & Ravi, 2005). In a rare report, farmers in India are described storing roots during the dry season in pits in the ground, planting them out late in the dry season near a water source, watering them and making cuttings from the resulting plants (Arya & Khatana, 1999). Storage of roots in sand is also a traditional technique in India (Ray & Ravi, 2005), confirmed experimentally in Tanzania (Mpagalilie et al., 2007). An additional inspiration for us was Mr Sois, a farmer and trader who heads a small farmer group just outside Kumi town, NE Uganda. He transplanted roots which he found sprouting in fields at the onset of the first rains to his garden, generating about 130 cuttings from each root after ratooning and harvesting perhaps three times. This solved the problem of volunteer plant ownership but not the problem of lateness.

MATERIALS & METHODS

Climate and Site Description

There are two rainy seasons in Uganda, the first from around late March to June and the second from late July to early November. However, away from the Equator and towards the north, the first rainy season starts and ends later and the second starts and ends earlier. As a result, the dry season between the first and second rains is short and, more importantly for this research, the dry season between the end of the second and the start of the first rains is long, too long generally for sweetpotato crops to survive. Bukedea District is in north-eastern Uganda and this dry season lasts about 17 weeks [till mid-March], with occasional storms because of its close proximity to the eastern highlands. Soroti and Kumi districts are further north and this dry season lasts at least 18 weeks (November – mid March), generally with no rainstorms at all. In Tanzania, being on the other side of the Equator and Shinyanga, Meatu and Mwanza regions being further from it, the seasons are reversed and the main dry season longer, from the end of May till November. Only Mwanza Region may have intervening storms, as a result of the adjacent Lake Victoria.

The Survey in Uganda

Based on observations during a preliminary survey, previous literature and a personal knowledge of the farming system in Uganda, a questionnaire was developed with mainly 'open' questions about sweetpotato planting material, particularly the use of vines from volunteer plants, providing opportunity for farmers to give explanations including their advantages and disadvantages. The study was done in 2008 by research assistants fluent in the local language and with a professional agricultural background, during the dry season (Feb –March) when farmers have more spare time. A total of 105 and 50 farmers from Bukedea and Soroti districts, respectively, were interviewed. Data were analysed using SPSS.

On-farm field experiments in Uganda testing how well roots survived the dry season and how well cuttings from sprouting roots performed

All experiments were done at Abuket village in Soroti District with the Soroti Sweetpotato Producers Association (SOSSPA), led by Mr Ekinyu.

Survival of roots planted at different depths: In 2008, medium sized (5 - 10 cm diameter) undamaged, especially not weevilled, roots of cv Kakamega from crops planted in June and August were planted immediately after harvesting (early January) in plots at soil depths of 5, 10, 15 and 25 cm. Two watering regimes were applied to plots: watering either 10 (from 10th January) or 5 (from 10th February) weeks prior to mid-March when the first rains were expected. Each plot was 1.2 x 2 m and the treatments were each replicated 3 times. The numbers of vine cuttings produced by roots planted at each depth were recorded.

Survival and productivity of cuttings: In 2008 and 2009, 30 cm long cutting were harvested from sprouting roots of cvs Araka, Ejumula and Kakamega. Trials were planted each year in April to compare their survival and productivity with 30 cm cuttings obtained from plants that had been maintained under irrigation throughout the dry season. Plots were 10 x 10 m; treatments were replicated three times each year. A count of surviving cuttings was made two weeks after planting. Plots were harvested in August and the total numbers and weights of small, medium and large roots were recorded.

Group testing of different methods of root storage during the dry season in Uganda

The experiment was done with Mr Ekinyu's group and with a farmer group in Olupe village, Kumi District led by Mr Sois. Roots were harvested on 19th December 2009, when the long dry season had just begun, and sorted to remove those that were pest infested or had other visible defects. Cv Kakamega, a Kenyan orange-fleshed landrace, was used by Mr Ekinyu's group; cvs Kakamega and Esapat, a local white-fleshed landrace, were used by Mr Sois' group. Methods tested for storing the roots included pit storage, ash and sand in basins and treating roots with ash dust, Actellic insecticide (20 g/kg of pirimiphos-methyl as a dust) and various botanicals (Table 1). For the storage pits, holes were dug in open ground sufficiently deep to be filled with at least 50 roots plus a cap of either 10 cm or a 20 cm of soil. The recommended method is a hole dug under shade, lined with dry grass and capped with 10 cm of soil (Stathers *et al*, 2005). It was easier to lay grass in a big pit so 200 roots were kept in this pit. The basins, approximately 1 m diameter and 40 cm deep, had about 15 cm of sand/ash was poured into the bottom; 40 roots were added and then more sand or ash so that a 15 cm layer of sand or ash covered the roots. For the baskets, 25 roots were placed in each and were: (1) untreated [control], (2) dusted with ash, (3) dusted with Actellic, (4) *Lantana* spp (probably *L. camara* L.) leaves were added, or (5) chilli pepper was added. All containers (basins/ baskets) were kept in a roofed building with open windows.

After 2 mths storage, each group checked the roots for survival, any long sprouts were removed from surviving roots and rotten roots were discarded. The roots were then kept for another 1 month until it was about 1.5 months prior to the beginning of the rains when farmers assessed the different treatments. Roots from the most successful methods of storage were selected for planting out: roots stored in ash and sand in basins and roots stored in the grass-lined pit under a bush were selected. These roots were planted in a garden near each group leader's house at a spacing of 1 m between rows and 0.6 m within a row on 23rd or 24th February, 2010; a root from each treatment was planted in a factorial design replicated 10 times. Unfortunately, the experiment at Mr Ekinyu's site was accidentally ploughed up. At Mr Sois' site, the roots were watered thrice before receiving the first showers of rain. The numbers of cuttings each sprouting root could provide were counted by farmers on 16th April 2010 and on 14 May 2010.

Validation in Tanzania of storing roots in sand, then planting out and watering them

Storing roots in dry sand and then planting them out in a garden and watering till the rains arrived gave by far the most cuttings/root in Uganda. The seasons are reversed in Tanzania, on the other side of the Equator, and, in June 2010, three farmers in each of 2 villages were identified in each of 3 regions by a local extension worker - in Mwagala and Ngo'mbe villages in Mwanza Region, in Hapa and Mwangósha villages in Shinyanga Region, and in Bulyashi and Mwambiti villages in Meatu Region - making a total of 18 farmers. The farmers were all women as they grow most sweetpotato. Each farmer identified 2 local varieties from her own fields. Healthy-looking plants were harvested and undamaged roots were selected for storage in basins containing sand in her house following the procedure used in Kumi and Soroti (Fig 1). The roots were checked and sprouts removed from roots at the end of July; during the last week of September, the surviving roots, now re-sprouted, were counted, planted at about 30 cm spacing and watered. Watering was continued by the farmers and a final visit made in mid-November at the start of the rainy season for harvesting of cuttings (Fig 2). Farmers' comments on the practice were recorded and the numbers of cuttings harvested and data on pest and virus infestation were collected.

Assessment by farmers of the Triple S method

A short questionnaire (Tables 10 & 11) was used to assess the main benefits obtained by farmers from adopting the Triple S method. The interviews were done in Uganda (13 farmers) on August 2011 and in Tanzania (20 farmers) during mid-February 2012 with farmers who had participated in the original testing (Uganda) or validation (Tanzania) of the method or who had been taught by the farmers (5 Tanzanian farmers).

Statistical analysis

Results of all field trials were analyzed using GenStat version 7.

RESULTS

The survey in Uganda

In both districts, most farmers (80%) considered that cuttings obtained from vines of watered mature plants were superior to cuttings obtained from volunteer plants from sprouting roots (Table 2). When asked what were the disadvantages of cuttings obtained from volunteer plants, most indicated problems associated with the immaturity of the vines causing them to be planted later than cuttings obtained from vines of mature plants, and with damage by grazing animals (Table 3). They were also affected by pests and diseases and sometimes provided a poor yield. The two most common responses about their advantages, 'Allows vines to mature' and 'Allows vines to increase in length', were more observations on the need to wait until vines had become older; other responses centred mainly on the easy availability of vines due to many volunteers growing (Table 4). Most farmers said they took ≤30 cm cuttings 1 – 3 times from the volunteer plants, mostly starting 2 – 4 weeks after the start of the cropping season.

On-farm field experiments in Uganda testing how well roots survived the dry season and how well cuttings from sprouting roots performed

Most emergence of shoots occurred from roots planted 10 cm deep (*P*<0.001) (Table 5); roots planted deeper (15 and 25 cm) emerged poorly, the shoots being unable to force their way through to the soil surface, instead coiling; planting roots shallower (5 cm) led to what the farmers involved in the trial referred to as 'cooked roots', in which the roots became blackened and rotten – probably because the roots were so close to the soil surface that they became overheated in the intense sunshine and died. Watering the roots for 10 wks prior to the start of the rainy season resulted in many more cuttings than watering plots for only 5 wks (*P*<0.001). Roots produced from a June-planted crop produced more 30 cm cuttings than roots from an August-planted crop; roots from an August-planted crop which were only watered for 5 wks produced no cuttings ($P<0.001$).

There was a small but significant ($P = 0.05$) difference between the survival of cuttings from sprouting roots and from irrigated plants, those from irrigated plants surviving better (Table 6). There were also differences in the survival of the vines of the different varieties ($P = 0.009$), cv Kakamega surviving better but vine length (20 *v* 30 cm) had no significant ($P = 0.059$) effect on survival. Yields of plots planted with either source of cuttings, with different lengths or different varieties (Table 7) were statistically similar ($P>0.05$), though average plot yields planted with cuttings from sprouting roots were actually greater than average plot yields planted with cuttings from mature plants (despite the latter's better survival).

Group testing of different methods of root storage during the dry season in Uganda

Most of the roots that were buried in the ground in pits survived: those in pits that were covered with 10 cm of soil generally sprouted prolifically aboveground; those in pits that were covered with 20 cm of soil did not emerge aboveground, the sprouts instead forming a mass of coils in the pit; those that were in a pit lined with grass and located under a bush were generally perceived to be best preserved, with less rotting and shorter shoots, few of which emerged aboveground. The roots kept in sand in a shed seemed very well preserved, with short shoots and little rotting; the shoots kept in ash had fewer and even shorter shoots but the roots seemed dehydrated though mainly still alive. The roots that were kept in open-meshed plastic baskets were generally shriveled. Untreated roots and ones dusted with ash or with various botanicals were also damaged by weevils; the ones treated with Actellic insecticide had no weevil damage.

The roots kept in sand, the roots kept in ash and the roots kept in a pit lined with grass and located under a bush were selected as the best preserved and were planted out in February 2008. At the surviving trial planted at Mr Sois' site (Kumi), few plants of cv Esapat grew and those that did were affected by sweet potato virus disease (SPVD) (Gibson et al., 1998); it appears that this stock of roots came from SPVD-affected plants and a lesson learnt was the need to ensure parent plants were disease-free. Consequently, Table 8 shows the results at Mr Sois' home for cv Kakamega only. The germination and production of shoots by the roots preserved in sand were far better that those of roots preserved in either ash or in a pit lined with grass; in April, just 8 wks after planting out, the roots preserved in sand had produced the equivalent of an average of 40 cuttings/plant and after 11 weeks (May) had produced an equivalent of an average of 164 cuttings/plant.

Validation in Tanzania of storing roots in sand, then planting out and watering them (The Triple S method)

Most roots stored in sand by the 18 farmers survived to be planted out (Table 9), especially those stored by the villagers in Meatu and Shinyanga regions. There was also better germination of the roots in Meatu and Shinyanga villages, possibly because few of the roots were affected by SPVD. Production of cuttings was also excellent in Shinyanga and Meatu (Fig 2), averaging around 50/root whereas in Mwanza villages it was only 15 – 17. The farmers in Shinyanga and Meatu districts, located far from Lake Victoria, were extremely enthusiastic about the new method, seeing it as a method by which they could easily obtain ample planting material. Most farmers in Mwanza district were generally less enthusiastic, probably because they are located close to Lake Victoria and could get vines from sweetpotato conserved along the shoreline.

Assessment by farmers of the Triple S method

The farmers asked about the Triple S method generally considered it provided them with ample and secure planting material at the right time for the rains (Fig 2), demanded less water and less frequent watering than cuttings kept through the entire dry season and it was convenient and safe being close to the home. There were also few problems with pests and diseases on the sprouting vines and the cuttings yielded well (Table 10). Another benefit was that farmers could make more money; one Ugandan farmer sold his 2011 crop for the equivalent of US$900 [a 'fortune' in Kumi where most farmers live on a few dollars a day] as a result of being able to harvest early, before others could harvest and before the main cereal harvest came on the market. In Tanzania, farmers were interviewed who had adopted the method after copying the few farmers who had been taught. In one village in Meatu District, though only 3 farmers had originally been trained, after one year, at least a further 20 were apparently practicing it, just by copying the original farmer validators. Even so, watering was still a burden, a few roots rotted whilst stored and roots were not safe from animals and children either in store or when planted out, gardens needing to be fenced.

These responses were largely reiterated in the responses to the specific questions (Table 11). In addition, most farmers disagreed with the statement that few varieties could be conserved in this manner, indicating that all varieties could be grown in this manner, and most disagreed that a large amount of manure had to be added, pointing out that, although some did have to be applied, it was little. Farmers considered that they obtained about 91±16 vines/root.

DISCUSSION

This paper describes the evolution of a protocol by which farmers could obtain sweetpotato planting material in ample quantities at the start of the rainy season. Although farmers generally preferred cuttings from vines from mature plants conserved in irrigated or swampy areas to those from volunteer plants (Table 2), there were positive comments about cuttings from volunteer plants such as “easily available”, “many vines produced” and “reliable” (Table 4), emphasizing they are cheap and easy to obtain. A few farmers also mentioned that they yielded well, confirmed in experiments (Table 7). The disadvantages of obtaining cuttings from volunteer plants sprouting from roots were mainly that cuttings became available only late in the planting season, there were difficulties in protecting them from grazing animals and from other people harvesting them and they were often infested with weevils (Table 3). Late planted crops generate a smaller yield because of the shorter growing season and, unlike early planted crops, yield after most cereals, so the harvest achieves only low prices and does not assist in famine relief (Akoroda et al., 1992; Hall et. al., 1998).

In addressing these disadvantages, the following main questions emerged:

- Were the vine cuttings from shoots from roots as good as planting material as those from mature plants?
- How should the crop from which the roots are obtained be grown?
- How should the roots be kept during the dry season?
- When should the roots be planted out and watered so that vines are available at planting time?

The vine cuttings from shoots from roots yielded at least as well as those from mature plants (Table 7); the cuttings individually may even be higher yielding, perhaps because they are physiologically very young (Martin, 1984), as fewer cuttings survived to create this similar yield (Table 6). Roots from the June-planted crop produced more shoots than the roots from crops planted late in August (Table 5) as well as the June crop producing more roots including the relatively small roots which can be conserved for sprouting yet which are less saleable or otherwise useful. Consequently, normal planting time was adequate for the crop producing the roots.

At first it was assumed that the roots should be planted immediately after harvest in their final location in the soil, simulating the survival of groundkeeper roots. Roots were therefore planted at different depths (Table 6) at the start of the dry season. The optimum depth was 10 cm: more shallowly resulted in the roots dying apparently from heat stress; more deeply resulted in the shoots being unable to emerge. However, even planting at 10 cm depth was unsatisfactory because of losses from the vagaries of the weather, pests and diseases. It was therefore decided to conserve the roots in a more protected environment. Although conserving them in pits (Tomlins et al., 2007) was satisfactory, storing them in sand (Ray & Ravi, 2005) in a shed or in the home proved even better. It also seemed proof against weevils and rats, so the roots and succeeding plants largely escaped damage.

The number of cuttings produced increased with the number of weeks the crop was watered (Table 5); this is logical but watering for many weeks costs time and effort, especially when the crop is sprouting vigorously, so a compromise may be necessary depending on ease of access to water and value of the early planting material – and these will vary from farmer to farmer. It seems likely that many farmers would wish to arrange for crops to be entering this vigorously growing phase when the rains are just beginning so that planting material is available a week or so afterwards, when the main cereal crops have been planted.

In the temperate zone, roots are planted densely in a nursery bed to sprout (http://extension.missouri.edu/p/G6368 accessed 20 March, 2012). However, Mr Sois' preference for planting them at a wide spacing and watering individual roots may be more appropriate for Africa, where stored roots are a valuable commodity and a wide spacing allows the resulting plants to perform to their maximum (Table 8). He also planted the roots in a garden next to his home and protected it by a thick thorn fence, establishing ownership.

In Tanzania, sand was confirmed as a reliable medium for storage of sweetpotato roots (Table 9). Weevils did not damage the roots in the sand and numbers of weevils in the gardens may also have been reduced by a long dry season as none were evident in the validation trials in Shinyanga and Meatu districts. There were some complaints about the cost of the basins and digging a pit in the floor of the house and adding the sand and roots may be a practical solution (Mpagalile et al., 2007). Infection of sprouting roots with SPVD was a problem in Mwanza (as well as in Kumi, Uganda, in cv Esapat). The long dry season in Meatu and Shinyanga may also help to control the whiteflies that spread this disease (Gibson et al., 1998) but elsewhere there will be a need to carefully select the parent plant. Here, farmers were especially enthusiastic about the method, seeing that it provided a method solving their chronic shortage of planting material. Obtaining sometimes more than 50 cuttings from a single root convinced the farmers and their families that the practice worked.

As a first step to disseminate the practice more widely, a brochure has been produced – see http://sweetpotatoknowledge.org/seedsystem/seed-propagation/TRIPLE%20S%20SYSTEM%20ENGLISH.pdf# (accessed 20 March 2012). Because **s**toring in **s**and and **s**prouting is the actual innovation, it has been called the Triple S method. Farmers in Uganda and Tanzania confirmed its efficacy, obtaining ample healthy planting material early in the rainy season, financial reward but also ownership and control of their planting material. As a result, this practice appears to be the solution to the chronic shortage of planting material which occurs at the beginning of the rains in the many areas of Africa (and also elsewhere in the world) which suffer a prolonged dry season and is the main production constraint (Bashaasha et al., 1995; Kapinga et al., 1995; Yanggen & Nagujja, 2006; Gibson et al., 2009; Namanda et al., 2011). Natural dissemination by farmers copying the use of the method appears to be rapid. We are therefore very optimistic that this previously intractable problem is now largely solved, that we have made a large step towards climate-proofing the supply of planting material and that sweetpotato will now be able to take up its true food and food security role in areas of Africa with a prolonged dry season (providing further climate-proofing).

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