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Performance of Tissue-Cultured Sweet Potatoes Among Smallholder Farmers in Zimbabwe

Edward Mutandwa
Bindura University of Science Education, Africa

Tissue culture has the potential of improving the livelihoods of subsistence farmers that largely rely on vegetatively propagated crops. This study assesses the impact of growing tissue-cultured sweet potatoes on yields and economic profitability among smallholder farmers in the Hwedza District of Zimbabwe. A sample of 133 smallholder farmers was chosen using a multi-stage sampling process. Primary data was collected using structured and semi-structured interviews, focus group discussions, and direct-yield measurements.

The results of the study showed that yields were 0.5 and 1.8 tons per hectare for households using unimproved and tissue-cultured sweet potatoes, respectively. The net economic return for tissue-cultured sweet potatoes was Z$3,605,000 (US$36.05) per hectare while a net loss of Z$9,157,500 (US$91.58) per hectare was observed for unimproved sweet potatoes. Farmers were also constrained by an inadequate supply of improved planting material. These findings suggest the need to increase the supply of tissue-cultured planting materials and to consolidate farmer knowledge on vegetative propagation in local community tissue culture laboratories. This will enhance the role of tissue culturing sweet potatoes in the attainment of household food security.

Key words: sweet potatoes, tissue culture, yields, economic profitability, Zimbabwe.

Background

In Zimbabwe, sweet potatoes are becoming an important part of diets for rural and urban households (Ministry of Lands and Agriculture, Department of Agricultural Research and Extension [AREX], 2004). In urban areas, it is estimated that between 1-7 kg of sweet potatoes are consumed per capita while rural households consume between 3-5 kg of sweet potatoes per capita (Zimbabwe National Vulnerability Assessment Committee, 2004). About 11% of sweet potatoes produced in rural areas are consumed in urban areas of the country, thus contributing to household nutrition. Tsou and Hong (1992) note that regular intake of 100 grams (half a cup) of sweet potatoes with moderate amounts of β-carotene (e.g., 3mg/100mg) per day can supply the recommended levels of Vitamin A to children less than five years of age.

The increased demand for sweet potatoes in the country is mainly attributed to the high cost of processed starch foods, such as bread and other confectionary products. Despite the role that the crop plays in the household food economy, it is treated informally at the national level. This is shown by the lack of disaggregated data on national sweet potato output over the years and national programs that promote sweet potato production. Smith (2004) indicated that the national average yield of the crop is 6 tons per hectare with wide yield variations of up to 25 tons per hectare for sweet potatoes grown under irrigation. While this compares well with Africa's yield average of 6t/ha, it is below the global average yield of 14 t/ha and a yield potential of 18 t/ha (International Service for the Acquisition of Agri-biotech Applications [ISAAA], 2006). National sweet potato production levels in the country have generally not exceeded 10,000 tons per year (Scott, 2005). This tonnage is low when compared with other countries in Africa such as Uganda, Kenya, Rwanda, and Tanzania, which annually produce 1.7 million tons; 1 million tons; 900,000 tons; and 340,000 tons, respectively (ISAAA, 2006). Low yields partly result from mono-cropping, lack of planting material, pests, and diseases (AREX, 2004). Pest and diseases account for about 30% of yield losses in Africa (Vasil, 1998).

Biotechnology has often been identified as a tool or technology that can be used to break crop yield ceilings (Doyle, 2000; Kameri-Mbote, 2001; Persley, 2000), yet evidence on its impact in some developing countries still remains anecdotal. Experiences of developing countries, particularly in Latin America and Asia, with the impact of using tissue culture techniques in sweet potatoes have increased, but these have not been fully complemented with research observations in Africa. A study by Zuger (2003) in Peru showed that tissue-cultured sweet potatoes played an important role in feeding both rural and urban families because of their low cost and agreeable flavor and contribution against a nutritional deficit. They provided 113-123 calories and 1.3-1.8g of protein per 100 grams, as well as β-carotene (0.048-0.084g/100 grams). The crop was also widely used as a livestock feed supplement. Use of tissue-cultured sweet potato varieties by farmers lowered production costs by US$500-$700 per ha. These varieties generally met smallholder farmers' expectations (Zuger, 2003).

Masumba (2004) evaluated two tissue-cultured varieties in Eastern Tanzania—carrot-C and Ukerewe—using participatory methodologies with smallholder farmers. Formal evaluations showed that Ukerewe had a high establishment and partial resistance to diseases, especially the mosaic virus and weevils. Farmers preferred this variety because of its skin color, which increased its market value. Root yield, marketability, and resistance to drought, pests, and diseases were the main criteria used in the selection of sweet potatoes by farmers in Eastern Tanzania. In Malawi, several sweet potato varieties are grown, with the SPN/0 variety being the most widely grown among smallholder farmers. In a study to assess sweet potato yields, Moyo (2004) showed that yields ranged from 10.2 to 14 tons per ha. SPN/0 variety was shown to be an important source of cash and food for rural households. However, weevil damage, rotting, unavailability of new varieties, and poor cultural practices were identified as the main causes of low yields.

Research on the application of biotechnology in agriculture in Zimbabwe has continued to increase since the enactment of the Research Amendment Act of 1998, the Biosafety Regulation of 2000 (Sithole-Niang, 2000), and more recently through the promulgation of the National Biotechnology Bill, which will result in the establishment of a National Biotechnology Authority to regulate and coordinate biotechnology activities in the country (Muchena, 2006). As a result of this regulatory framework, techniques such as tissue culture, vegetative propagation, and in vitro storage of genetic materials are now used in the country.

In 2000, the Horticultural Research Institute (HRI), Biotechnology Trust of Zimbabwe, and academic research institutes including the University of Zimbabwe's department of Crop Science spearheaded efforts to clean sweet potato varieties using tissue culture techniques for commercial production. Tissue culture is a method based on vegetative propagation of planting materials. It involves in vitro multiplication of plant material under aseptic and controlled environmental conditions. Most commonly used materials include excised embryos, shoot tips, pieces of stems, roots, leafs, protoplasts, etc. (Ushewokunze, 2000).

Ex-post effects of using tissue-cultured sweet potatoes on yields still remain anecdotal in the country. The economic implication of using tissue-cultured planting materials, in a context characterized by a volatile macroeconomic environment, has received little attention in the country.

The broad objectives in this study are to

1. assess the effect of using tissue-cultured sweet potatoes on crop yields and
2. determine the economic profitability of tissue-cultured sweet potatoes.

Use of Tissue Culture Techniques in Smallholder Sweet Potato Production in Developing Countries

According to James (2006), approximately 90.0 million hectares of land were planted to biotechnology-improved crop varieties by 8.5 million farmers in 21 countries in 2005. The majority of the farmers (90%) were resource-poor farmers from developing countries. Integration of biotechnology-improved crops into smallholder farming systems resulted in higher incomes and also buttressed household food security. However, this area only consisted of crops such as soybeans, cotton, tomatoes, canola, squash, and papaya, which are all major crops in agricultural production.

Sub-Saharan Africa produces more than 7 million tons of sweet potatoes annually, which constitutes 5% of global production (Ewell, 2002). Africa's top producers of sweet potatoes are Uganda, Rwanda, Malawi, and Kenya. The extent to which tissue-cultured sweet potatoes are used by smallholder farmers varies from country to country. Most of the sweet potato varieties grown in Africa are diverse landraces selected by farmers for adaptation and taste. Tissue-cultured sweet potatoes are used for commercial production in countries such as Kenya, South Africa, Zimbabwe, Egypt, Uganda, and Nigeria, where specific biosafety guidelines exist on biotechnology.

Accessibility to improved planting material still remains a problem in most African countries. In Kenya, for example, only 7% of the smallholder farmers had access to improved crops such as sweet potatoes in 2001 (Roy-Macauley, 2002). This was mainly attributed to the absence of an effective distribution system of improved crops, technical expertise, and funding (Roy-Macauley, 2002). As a result of these disparities, some countries, including Brazil, Columbia, and the Philippines, are now using participatory technology development as a means of increasing access to improved sweet potato planting materials.

According to Van Veldhuizen, Waters-Bayer, and de Zeeuw (1997), participatory technology development (PTD) is an approach for developing technological innovations toward improving agriculture through purposeful and creative interaction between rural people and outside facilitators. In the Philippines, for example, farmers in Central Luzon were involved in a three-part assessment under the Sweet Potato Integrated Crop Management (ICM) and Livelihood Systems Project, involving identification of a) the role of sweet potatoes in the livelihood system in Central Luzon, b) ICM needs and problems, and c) virus disease complex affecting production of planting materials and roots (Campilan et al., 2002). One of the main problems identified in the project was the unavailability of suitable improved sweet potato varieties. Farmer field schools were then employed as a basis for farmer experimentation, which resulted in the production of clean materials and roots. Use of the high-quality planting materials generated by farmers resulted in a 37% yield increase, while incomes increased by 218% in the three-month period (Campilan et al., 2002). Sustainability of PTD, according to the Sweet Potato ICM and Livelihood Systems Project experiences, depended on how effectively this approach is integrated in the program priorities and strategies of research and extension institutions.

Sweet Potato Production Zones in Zimbabwe

Prior to Zimbabwe's independence in 1980, sweet potatoes were a backyard crop mainly grown as a food supplement by women farmers in rural areas. Over the years, the crop has increasingly become an important food source in the country. However, production estimates are not available in national crop statistics. Sweet potatoes are mainly boiled or roasted but not much has been done to add value to the crop. However, attempts have been made to explore alternative uses that include products such as flour and fresh chips.

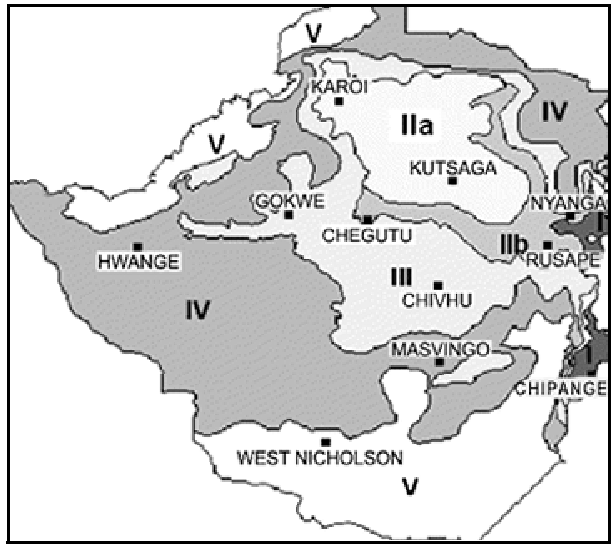

Figure 1. Sweet potato production zones in Zimbabwe.
Source: Raes, Sithole, Makarau, and Milford (2004).

Sweet potatoes are grown in most parts of the country, but the main production zones are found in Mashonaland Central, Mashonaland East, Mashonaland West, Manicaland, Masvingo, and Midlands, as shown in Figure 1 (AREX, 2004). In terms of natural regions, the crop is grown mainly in agro-ecological Zones I, II, and III. Natural Region I is characterized by rainfall of roughly 1050 mm per annum and relatively low temperatures of 16-24^{o}C. Natural Region I covers most parts of Manicaland province, and areas in this agro-ecological zone include Mutare and Chipinge. Natural Region II receives 700-1050 mm of rain per annum, mainly confined to summer (from November to April), while Region III has very erratic rainfall of less than 500 mm per annum (Rukuni & Eicher, 2006). Natural Region II covers part of Mashonaland Central, Mashonaland East, Mashonaland West, and Manicaland Provinces. Areas such as Bindura, Marondera, Chinhoyi, Chegutu, and Rusape are part of Natural Region II. Natural Region III generally spans across the Midlands province, covering areas such as Kwekwe, Gweru, and Kadoma. Sweet potatoes generally do well in loamy soils and clays that allow for easy growth of the tubers. Ideal temperatures range from 18-27^{o}C.

Zimbabwe's Experiences in Using Tissue-Cultured Sweet Potatoes

The Biotechnology Trust of Zimbabwe initiated a sweet potato project, in which about 27 varieties were cleaned and commercialized in three districts, namely Hwedza, Mudzi, and Murehwa in Mashonaland East province. Of the 27 varieties initially introduced, 9 varieties are currently being used by farmers and these are: Barnabas (red skinned), Brondal (red), ChiZambia (white skinned), Cordner (red), German 2 (red), Imby (red), Kamote (red), Pamhai (white), and Chigogo (red).

Most smallholder farmers obtain tissue-cultured sweet potato vines from HRI. Academic institutions and private organizations such as the University of Zimbabwe and Agri-biotech have also been actively involved in supplying tissue-cultured planting materials to smallholder sweet potato farmers. In 2004, Agri-biotech supplied 3,000 starter plants to 160 farmers, which increased supply of planting materials to farmers.

According to Smith (2004), use of tissue-cultured sweet potatoes by smallholder farmers in Zimbabwe has been shown to improve household food security. Smith (2004) further noted that some farmers who used tissue-cultured sweet potatoes such as Brondal obtained yields of up to 25 tons per hectare against a national average of 6 tons per hectare. Smallholder sweet potato farmers improved their livelihoods through purchase of assets using income earned from selling the crop. The main challenge identified was that farmers lacked adequate tissue-cultured planting materials and this contributed to declining yields over time.

An example of some farmers who have benefited from using tissue-cultured sweet potatoes in Zimbabwe is taken from Smith (2004):

> Boy Ncube, a farmer from Matebeland province and 19 other farmers were trained by Agri-biotech over three days in nursery management and production. Agri-biotech then supplied them with 3,000 rooted plants of Brondal sweet potato. Over two years, his 30 square meter plot increased to 2 hectares. He turned his initial investment of US$150-14,000 over the two-year period. This has enabled him to buy a milk cow and construct a brick and mortar house. His best returns have been 50 tons per hectare.

Experiences in Zimbabwe on the impact of tissue-cultured sweet potatoes on yields and incomes have also been confirmed by other studies in developing countries (Wambugu, 2001; Fuglie, Zhang, Salazar, & Walker, 1998; Moyo, 2004; Masumba, 2004).

Research Methodology

Study Sites/Sampling Frame

The research was conducted in the Hwedza District of Zimbabwe. It is located in Natural Region II and is one of the prime agricultural zones of the country. Prior to the structural re-organization of agriculture in Zimbabwe, the area was characterized by a significant number of large-scale farmers. However, smallholder farmers now dominate the agricultural landscape in the district. Rainfall averages 700-800 mm per annum in a normal rainy season and therefore allows for a wide range of crops and livestock activities to be done. The district was chosen mainly because of its pre-eminent position in terms of contribution to agricultural production in the country and also because of the time that has elapsed (5 years) since the introduction of improved sweet potato varieties.

Target Population and Sampling Method

Two main methods were used to examine the impact of tissue-cultured sweet potatoes on farm yields and incomes: a survey of farmers in Hwedza District and data from actual yield measurements.

The target population for this study consisted of six purposively selected wards[1] in Hwedza District where tissue-cultured planting materials were availed for production. These wards were identified with the assistance of AREX. Wards in the farm surveys included Makwarimba, Gonese, Zana 1, Chigodora, Goto, and Ushe.

Each ward had about two villages, making a total of 12 villages. Since the prevailing weather and soil conditions were relatively the same, a simple random sampling technique was used to select villages for inclusion in the farm survey. Each village had an equal chance of being included in the final sample. Five villages, namely Mawire, Magoko, Mashonganyika, Musekiwa, and Chigondo, were selected randomly using the lottery method. Existing financial resources influenced the number of villages selected. However, the number of villages constituted more than 30% of the target population. The total number of households for the five villages was estimated to be 400-500 households.

At the household level, a snowballing technique was employed to identify farmers who had grown tissue-cultured sweet potatoes in the 2004/05 cropping season. The researchers anticipated selecting an equal number

1. *A ward is a sub-district containing 2-12 villages, but this tends to vary from area to area in Zimbabwe.*

of farmers growing traditional varieties within the same areas. However, this was not possible since most of the farmers had abandoned growing unimproved vines, or they grew both types together in the same fields. A total of 133 sweet potato farmers were ultimately included in the sample.

Data Collection Methods

In this study, structured and semi-structured interviews as well as actual field measurements were used to collect data.

The Structured Interview Schedule. A structured questionnaire consisting of both closed and open-ended questions was administered to households. The advantage of the structured interview is that it takes place over a short period of time (Yin, 1994). The structured questionnaire consisted of five sections, with headings labeled as household demography, economic activities, use of sweet potatoes, agronomic requirements of tissue-cultured sweet potatoes, and tastes and preferences. Under the household demography section, items included the name of the farmer, gender, marital status, household size, highest level of education, and agricultural training status of the farmer. This was important in the characterization of the sample.

Under the economic activities section, respondents were asked to rank the different economic activities in their livelihood base using semantic scales or the monetary value of each activity per annum. Using this data, the researcher identified the relative position of sweet potatoes when compared with other economic activities on the farm. Specific issues under use of sweet potatoes included (a) whether the farmer grew tissue-cultured sweet potatoes in 2003/04, (b) names of varieties grown, (c) area, (d) sources of information about improved sweet potato varieties, (e) reasons for growing the varieties, (f) average yields from 2003/04 cropping season, (g) average yields, and (h) prices of output per unit from unimproved sweet potatoes.

Under the agronomic requirements section, respondents were asked about the (a) types, quantities, and prices of fertilizers used in both unimproved and tissue-cultured sweet potato production, (b) types of pests and diseases that attacked their crop, and (c) the control methods used. The data were used in the construction of sweet potato enterprise budgets. In cases where farmers used manure or did not sell outputs, shadow prices were used to impute economic values to non-market goods and services.

Under taste and preferences, farmers were asked to indicate whether they would continue growing tissue-cultured sweet potatoes and provide the reasons. In addition, the farmers indicated whether they preferred tissue-cultured or unimproved varieties for roasted and boiled crop. They were also asked to indicate the shelf life of tissue-cultured and unimproved varieties after harvest. The data was complemented with actual field measurements on yields. The structured questionnaire also included problems and constraints faced by farmers in sweet potato production.

Semi-structured Interviews. Semi-structured interviews were conducted with key stakeholders and these included officials from the Ministry of Agriculture, District Administrators, local councilors, and traditional leaders such as headmen. Issues discussed using this schedule were mainly to assess perceptions of these stakeholders on the acceptability of tissue-cultured varieties and problems faced by farmers in the use of varieties.

Focus Group Discussions. Focus group discussions (FGDs) take place between the researchers and groups of individuals taken from a particular community using particular demographic characteristics such as age, sex, area from which individuals reside, group membership, etc. They are essential in that they foster a spirit of trust between the community and the researchers, as focus groups make the respondents "open up" and share their information (Schilderman, 2002). FGDs were held with farmers at Mawire communal and irrigation and Mukondwa villages. Between 5 and 10 farmers participated and discussed issues that were drawn from the structured interview schedule.

Measurement of Sweet Potato Yields

In measuring sweet potato yields, two methods are usually used: namely the area frame and whole farm surveys (Marra, Pardey, & Alston, 2002). Area frames entail sub-dividing area planted to sweet potatoes into small segments. A random sample is used to select segments for further analysis. Yield measurements were made using the area frame technique by comparing equal areas of traditional and tissue-cultured sweet potatoes. The main parameter assessed was the average weight of sweet potatoes per frame.

Analytical Framework

The central question asked in the study was whether use of tissue-cultured sweet potatoes was profitable in terms of net benefits to the household economy. In this respect, the opportunity costs of land, labor, and capital, which are not purchased in the formal market and are not associated with any financial payment, were considered (Gittinger, 1982). Financial costs such as taxes, subsidies, loan receipts, and repayment of principal and interest were excluded (Gittinger, 1982). Tradable inputs (inputs with recognized markets locally and internationally) considered in this analysis included inorganic fertilizers, while the non-tradable items (inputs with thin markets locally and internationally) considered included labor for land preparation, weeding, harvesting, and transportation to the market. Shadow prices were used to value labor for weeding and harvesting. Shadow prices are opportunity cost prices that reflect what the economic agent could earn or pay if he/she had sold or purchased an input or output (Crawford, 1999). In this case, the opportunity cost prices for weeding, land preparation, and harvesting were the local charges in the district.

Construction of Farm Budgets

According to Crawford (1999), the purpose of financial analysis is to assess the attractiveness of an enterprise to farmers. The budget is calculated using market prices—prices paid or received by farmers. However, economic analysis is broader in that it includes the opportunity costs of resources such as land, labor, and capital. Economic profitability can be defined as follows:

Net economic profit = Benefits – Costs,

= Output Revenue – Tradable Costs – Capital Costs – Labor Costs

Benefits include the value of outputs expressed in economic prices where necessary (both marketed and consumed at the household level). Costs include both tradable and non-tradable inputs used in the production of sweet potatoes.

Data Analysis

Primary data for this research was entered, cleaned, and analyzed using the Statistical Package for Social Sciences (SPSS). The analysis used both descriptive and inferential statistics.

Table 1. Sources of improved sweet potato vines.

Source	Frequency	%
Local multiplication sites	29	21.8
Biotechnology Trust of Zimbabwe	43	32.3
Other local farmers	11	8.3
Local district agricultural shows	11	8.3
N/a	2	1.5
Total	**133**	**100**

Results

Household Demographic Characteristics

Respondents were drawn from six wards in Hwedza District. Most of the farmers resided in the Makwarimba ward, where approximately 31% of the sample was selected. This was largely attributed to the existence of a local multiplication site in the ward, which increased accessibility to tissue-cultured planting materials. Chigodora and Zana 1 also had a sizable number of farmers included in the survey as 22 and 15% of the total sample were selected, respectively. In the study, 30% of the respondents were male and 70% were female. Most of the sweet potato farmers were married (86%). The average age of respondents was 41 years, with a minimum of 17 years and an upper limit of 70 years of age. The average household size was five people per household. In terms of education, 50% of the respondents had secondary level education. On the other hand, some of the farmers attended either Standards 2 or 4, which is now equivalent to primary level education in the formal education system of Zimbabwe. Most of the farmers (83%) received training in production and management of sweet potatoes.

Sources of Improved Sweet Potato Vines

According to Table 1, about 32% of the farmers mainly acquired disease-free sweet potato vines from the Biotechnology Trust of Zimbabwe, which was operating in Hwedza District in the 2003/04 cropping season. The vines were cleaned at the HRI located Marondera in Mashonaland East Province. Other sources of disease-free vines were local multiplication sites, especially at Mawire Irrigation Scheme, and local farmer-to-farmer exchanges, which accounted for 8% of the responses. Farmers generally used tissue-cultured vines for three years. Recommendations are that the vines can be used for up to three years without significant yield decrease. Most farmers (75%) noted that lack of adequate supply of tissue-cultured planting materials negatively affected sweet potato production.

Use of Tissue-Cultured Sweet Potatoes by Farmers

Prior to the year 2000, virtually all farmers were using traditional (not tissue-cultured) sweet potato vines. Since then, most of the farmers use tissue-cultured sweet potatoes. The majority of smallholder farmers interviewed (93%) indicated that they used disease-free vines in sweet potato production, while only 7% still used the traditional sweet potato vines. This was linked to inadequate supply of improved planting materials from both the local multiplication sites and the HRI. These varieties were multiplied at local multiplication sites in the community. During the 2003/04 cropping season, 9 tissue-cultured varieties were available from the initial 27 at Mawire irrigation scheme. This was mainly attributed to unavailability of water to irrigate the vines.

Yields of Tissue-Cultured Sweet Potatoes

Average yields for the 2003/04 cropping seasons were 1.8 tons per hectare for tissue-cultured sweet potatoes, while unimproved sweet potato varieties yielded 0.5 tons per hectare. Significance tests at the 5% level ($P<0.05$) showed that there was a statistically significant difference in the yields of tissue-cultured and unimproved sweet potatoes.

Storage Life of Sweet Potatoes

Most of the farmers used soil pits as the means of storing the sweet potato crop. This method involves digging of pits at oblique angles. This is done to avoid accumulation of moisture that would in turn lead to rotting or germination of sweet potato tubers. Farmers applied ash at the base of the pit to sterilize the soil pits. The researcher compared unimproved varieties and the varieties that were reproduced in tissue culture laboratories by farmers to assess shelf life.

According to study findings, the shelf life of tissue-cultured sweet potatoes bred in local tissue culture laboratories was 2.1 months, while it was 4.87 months for traditional unimproved sweet potatoes. Hypothesis testing was done to determine whether there is a statistical difference between the mean times of storage for the two sets of varieties. There was a statistical difference between the storage period of the traditional and tissue-cultured sweet potatoes ($P=0.0012$) and thus traditional sweet potatoes had a longer shelf life after harvesting. Tissue-cultured sweet potato varieties bred in local tissue culture laboratories by farmers were characterized by early rotting.

Economics of Tissue-Cultured Sweet Potatoes

Farmers sold most of their harvest at Hwedza center in Mashonaland East Province. Sweet potatoes were sold in different quantities and measured in 20 liter tins. However, after conversions, a ton of sweet potato cost Z$11,760,000 (US$117.60). Generally, the market prices for both tissue-cultured and unimproved sweet potatoes were the same at Hwedza center. The gross economic profits for tissue-cultured and unimproved sweet potatoes were Z$20,200,000 (US$202) and Z$5,880,000 (US$58.80) per hectare, respectively. The major tradable inputs in sweet potato production were chemical fertilizers ammonium nitrate (farmers applied 62.5 kg per ha) and Compound D (145 kg per ha). The quantities applied per hectare did not vary for both tissue-cultured and unimproved sweet potatoes. Tradable variable costs were Z$9,545,000 (US$95.45) per hectare and they accounted for 56% of the total variable costs.

Most farmers grew sweet potatoes as supplementary to maize production. The crop was mostly grown on marginal land or at the edges of fields that are not usually utilized for crop production. The opportunity cost of such type of land is low and thus was not considered in this study. The main non-tradable inputs included labor for weeding, land preparation, fertilizer application, and harvesting. Planting materials were taken to be non-tradable since the market for vines is thin. According to Table 2, the cost of tissue-cultured planting material was US$18.75 per 50 kg pack of the crop. This value captured the cost of preparing tissue-culture planting materials. The cost of tissue-cultured planting material was the same as that of the unimproved crop. Since planting material was generally in short supply in Hwedza District, farmers placed value on accessing sweet potato vines rather than on the type of the planting material. The costs of harvesting were slightly different as the number of labor days required to harvest one hectare of sweet potatoes ranged from 7-21 days. Similarly, transport costs for tissue-cultured sweet potatoes were higher due to the fact that more was harvested per hectare. In March 2006, it cost approximately Z$600,000 (US$6) to transport a ton of sweet potatoes to Hwedza center.

The total variable cost (TVC) for tissue-cultured sweet potatoes was Z$16,595,000 (US$165.95) per hectare while it was Z$15,037,500 (US$150.38) per hectare for unimproved sweet potatoes. The main differ-

Table 2. Economic profitability of tissue-cultured and traditional unimproved sweet potatoes.

Item	Cost/returns (Z$)/ha tissue-cultured	Cost/returns/ha (Z$)/ha traditional or unimproved
Gross economic revenue	20,200,000	5,880,000
Variable costs:		
Tradable Inputs:		
Ammonium Nitrate	2,875,000	2,875,000
Compound D	6,670,000	6,670,000
Non-tradable inputs:		
Labor:		
Land preparation using ox drawn ploughs	1,250,000	1,250,000
Weeding	750,000	750,000
Fertilizer application	200,000	200,000
Harvesting	2,100,000	1,050,000
Transport to Hwedza market	875,000	367,000
Planting material	1,875,000	1,875,000
Total variable costs	16,595,000	15,037,500
Net economic profit	**3,605,000 (US$36.05)**	**-9,157,500 (US$-91.58)**

Note. Exchange rate: US$1=Z$100,000 (as of March 2006).

ence in TVC per hectare came from the higher transport and harvesting costs for tissue-cultured sweet potatoes. The net economic returns for tissue-cultured and unimproved sweet potatoes were Z$3,605,000 (US$36.05) and Z$-9,157,500 (US$-91.58) per hectare, respectively (Table 2).

Discussions

Storage Life of Sweet Potatoes

Storage of sweet potatoes is an important practice that enhances household food security in rural communities. In West Africa, smallholder farmers use dried slices of sweet potatoes since these can be stored for periods of up to four months (Hall, 1998). In Zimbabwe, farmers in Hwedza district store their harvest mostly in soil pits. Ash is used in these pits as a desiccating agent and to reduce the incidence of tubers rotting. According to farmers in Hwedza District, tubers from *traditional* varieties store for up to five months without rotting. However, tubers from *tissue-cultured* varieties generated by farmers in local tissue culture laboratories store for periods of up to 2 months. Hall and Devereau (2000) noted that, in general, sweet potatoes could be stored for between three to four months, and matches with current study findings.

While higher yields were obtained from tissue-cultured varieties, their storage life was shorter. This finding could be linked to the incidence of viral infection in local sweet potato laboratories or inadequate knowledge on preparation of tissue-cultured planting materials. Farmers at local tissue culture laboratories did not have adequate infrastructure and equipment to keep their vines under relatively aseptic conditions and also lacked soil-testing equipment. About half of the farmers (50%) who were involved in propagation of the crop at local tissue culture laboratories indicated that they required refresher courses on propagation. Farmer contacts with the Department of Agricultural Research were limited since agricultural extension officers did not have adequate transportation to reach out to farmers. Clark and Moyer (1988) also reported that viral diseases are the most poorly understood diseases of sweet potatoes.

Impact on Yields of Using Tissue-Cultured Sweet Potatoes

According to results, the yields of tissue-cultured sweet potatoes were higher (1.8 tons per hectare) than traditional sweet potato varieties (0.5 tons per hectare). The yield levels for tissue-cultured sweet potatoes were lower than the Zimbabwean national average of 6 tons per hectare. These results also vary from those of Moyo (2004), who found that sweet potato yields ranged from 10.2 to 14.0 tons per ha in Nkhata Bay of Malawi. The differences in findings could be attributed to the fact that most smallholder farmers grow sweet potatoes under dry land conditions. However, the ability of tissue-cultured varieties to increase productivity were confirmed in Peru by Fonseca, Zuger, Walker, and Molina (2003), who showed that tissue-cultured varieties had various advantages, such as higher yields. Furthermore, farmers preferred the good commercial value of tissue-cultured varieties introduced by the National Agricultural Research Institute in the Canete Valley of Peru. Smallholder farmers rarely apply chemical fertilizers in sweet potato production (AREX, 2004).

Economics of Sweet Potato Production

According to Table 2, the net economic returns for tissue-cultured and unimproved sweet potatoes were Z$3,605,000 (US$36.05) and Z$-9,157,500 (US$-91.58) per hectare, respectively. Higher economic profits for the tissue-cultured crop were mainly brought about by the increase in yields per hectare. Farmers growing traditional sweet potatoes made a net economic loss per hectare, thus the returns to productive resources were negative. Tradable inputs comprised more than 61% of the total variable cost in sweet potato production, while non-tradable inputs accounted for 39% of TVC. At least 60% of the gross economic revenue was used to cover the costs of tradable inputs used in sweet potato production. Profitability of sweet potatoes could be enhanced by replacing chemical fertilizers with organic manure, which is cheaper.

Parallels can be drawn from regional and international experiences on sweet potato profitability. In Uganda, the sweet potato was found to be a major source of income for smallholder farmers. The study further noted that traders and other middlemen made profits in the sweet potato marketing chain (Hall, 1998).

Tissue-cultured sweet potatoes were found to be profitable in Peru. According to Zuger (2003), sweet potato productivity in the country had been negatively affected by the incidence of diseases, which prompted research into new varieties. Use of tissue-cultured planting materials lowered production costs by US$500-700 per ha. Labor, especially during weeding and sowing, accounted for the greatest proportion of cost. Tissue-cultured varieties met smallholder farmers' expectations, but these sweet potatoes remained susceptible to nematode attack and the sweet potato viral disease (SPVD). In this study, production costs per hectare were higher for tissue-cultured sweet potatoes due to the higher number of days required to harvest and transport the crop to the market.

Conclusions and Recommendations

Use of tissue-cultured sweet potato varieties in smallholder agriculture enhanced crop yields when compared to unimproved sweet potato varieties. Higher yields per hectare for tissue-cultured sweet potatoes contributed to the attainment of higher economic returns for farmers growing the crop in Hwedza District. However, the storage life was shorter for tubers from tissue-cultured sweet potato vines developed by farmers under local tissue culture laboratories. This could be linked to the conditions under which the tissue-cultured vines were developed by farmers in Hwedza District, as most suggested the need for refresher training courses on sweet potato propagation. Farmers also indicated that there was inadequate supply of tissue-cultured planting materials. These findings suggest the need to increase the supply of tissue-cultured planting materials. However, there is need to reinforce knowledge among farmers who are involved in local tissue culture laboratories to reduce the incidence of viral infection during development of tissue-culture planting materials in the district.

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