Assessing the socio-economic impacts of non-transgenic biotechnologies in developing countries

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1. INTRODUCTION

Diffusion of both endogenous and exogenous innovations is a key factor for agricultural growth, hunger eradication and poverty reduction. The Economic and Social Council of the United Nations (ECOSOC) underscored in 2004[1], that most developing countries are unlikely to meet the internationally agreed Millennium Development Goals (MDGs) of reducing poverty and hunger without a clear political commitment to making science and technology top priorities in their development agenda and increasing the related budget up to at least one percent of the gross domestic product (GDP).

Among other innovations, agricultural biotechnology has been reported as offering considerable potential and opportunity for new solutions to some of the problems hindering sustainable rural development and achievement of food security in developing countries. The ECOSOC notes that: "promoting the development and application of new and emerging technologies, most notably biotechnology and information and communication technologies [….], will both reduce the cost and increase the likelihood of attaining the internationally agreed development goals, including those contained in the United Nations Millennium Declaration"[2].

To take advantage of the biotechnology potential, many FAO member countries need assistance in strengthening their overall capacities in research and development, and in formulation and enforcement of enabling policies and regulations.

Together with needs assessments and priority identification, assessing the impact of biotechnology is crucial for policy-makers to set priorities and use the most effective and efficient strategies and techniques to address food insecurity and rampant poverty. At the same time, impact assessment can

[1] United Nations Economic and Social Council (ECOSOC) Resolution 2004/68 "Science and Technology for Development" (E/2004/31)
[2] *ibidem*

help policy-makers, development partners and scientists a) to allocate scarce resources to applied agricultural research activities for optimal social returns; and also b) to evaluate the potential effects of biotechnology based projects on poverty reduction, gender, equity and sustainable livelihoods.

The commercial production of genetically modified organisms (GMO) crops in some countries has generated a highly polarized debate about their safety, and on the socio-economic and environmental consequences of their adoption (FAO, 2005), leading to numerous studies to demonstrate their actual and potential role in sustainable agricultural production. This focus has unfortunately excluded other biotechnologies, such as plant micropropagation, plant cell and tissue culture, molecular marker-assisted selection, and microbial biotechnologies for soil fertility enhancement, whose present role and potential for the improvement of agriculture production and for the breeding of new varieties are more widespread, especially in developing countries (Dhlamini *et al.*, 2005). The disproportionate focus on GMOs has led to a scarcity of useful decision-making information for policy-makers on the assessment of use and impact of these non-transgenic biotechnologies.

Consequently, this paper aims to contribute to the knowledge of socio-economic impacts of the adoption of biotechnologies other than genetic engineering (or non-transgenic biotechnologies). The first chapter is devoted to a discussion of a few common approaches used in innovations' assessment on different scales, with special attention on the economic and socio-economic impact of non-transgenic crop biotechnologies in developing countries; biotechnology effects relevant for small farmers, including income, health and vulnerability, are also presented and discussed. The second chapter presents a general overview of the non-transgenic biotechnologies, with some data derived from existing literature about their impacts on some relevant variables, such as yields, workload and income.

2. METHODOLOGIES FOR THE ASSESSMENT OF BIOTECHNOLOGY APPLICATIONS IN DEVELOPING COUNTRIES

2.1. Introduction

The Consultative Group of International Agricultural Research (CGIAR) defines impact as "ultimate social, environmental or economic benefits" that are consistent with the objectives of an activity (e.g. a research activity) (CGIAR, 2006). It is of special interest that impact is the *ultimate* benefit, as this benefit is the result of a sequence of *outputs*, which are basically the first deliverables of research, for example, new varieties, *outcomes*, which are understood as the dissemination of the outputs to target groups and the adoption by these groups. Impact assessment has to link outputs, outcomes and eventual impacts, and to describe and prove how outputs have led to the final impact. This description is commonly called the *impact pathway* (Steffen, 2007). Impact assessment of agricultural innovations can be performed by using an

Box 1 - Classification of agricultural innovations

Agricultural innovations can be classified according with several parameters; the most used ones are as follows:

a) Genetic, mechanic and chemical innovations, which can be patented (private goods), and agronomic, managerial and animal husbandry innovations, which cannot be patented (public goods).
b) Individual innovations, which can be adopted by one person, and collective innovations, which demand the adhesion of several persons.
c) Continuous innovations, which do not require any specific new knowledge or other changes, semi-continuous innovations, when only a fraction of present knowledge and assets is usable, and discontinuous innovations, which require new skills, other knowledge and even investments.
d) Labour saving innovations, which reduce the labour requirements, such as machinery or weed killers and land saving innovations, which increase yields, such as improved seeds, or fertilizers and irrigation.
e) Process innovation, when the innovation modifies the production techniques, but the final product remains the same, and product innovations, when a new good is obtained.
f) Endogenous innovations, generated by the local/national agricultural knowledge and information system (AKIS) and exogenous innovations, which have been devised and developed outside .

Box 2 - Innovation packages

Technical or organizational changes rarely occur in isolation: they are conceived or they occur as an integrated, simultaneous package of mutually dependent and consequential modifications, which should be adapted as a whole, if they are to give the best possible results. A new highly productive variety of an annual crop may require different distances between rows and on the row, a different sowing time, a more careful weed control, the use of a different pesticide, more or less fertilizers, as well as different irrigation schedule and quantity of water. The higher production might require different marketing strategies. The higher level of inputs might demand the use of short-term credit to anticipate the running costs, etc.

All these small and bigger changes compose the innovation package; its relevance and total feasibility is unfortunately very often ignored or underestimated by scientists and development planners. Quite often, farmers adopt the innovation packages only partially, and this leads to poor or even negative results.

This apparently illogical behaviour has several very logical motivations, such as the lack of participatory research activities, understaffed or poorly performing advisory services, lack of credit facilities, input availability, poor marketing systems, lack of labour, etc.

Better knowledge of the real physical, social, economic situation of the smallholders and of their environment, accompanied by a more holistic view by the scientists and advisers could reduce this negative phenomenon and facilitate the synergic adoption of the whole innovation package.

ex ante or an *ex post* approach. *Ex ante* studies try to estimate the potential impact of the adoption and diffusion of the concerned innovation, whereas *ex post* studies evaluate the effects that actually occurred after its adoption and diffusion. The methods used for an impact assessment depend on the types of innovation (see Box 2) as well as on the impact(s) to be evaluated, and on the scale and data availability.

Research institutions, governments and international organizations are presently searching for a better way to serve the farmers. This is currently being intensively debated at international level (Fuglie and Shimmelpfennig, 2000; Byerlee and Echeverrìa, 2002; World Bank, 2007). One of the most relevant aspects is the relevance of applied research for the rural poor and which

Box 3 - Generations of impacts

Innovations are introduced to change something. Technical and organizational changes occur because the decision-maker (the family head, the farmer, the farm manager, the group of producers, etc.) has decided that action is required in order to tackle a given problem and to search for a solution.

In agriculture, the first thought goes immediately to production: yield increasing varieties have been the generators of the green revolution, but the yield increase (technical impact) required purchasing the improved hybrid seeds, as well as fertilizers and pesticides. The farmer's income (economic impact) by consequence has increased less than the yield. Another impact was on the market price, which tended to decrease, due to the growth of the supply. This impacted negatively on the livelihood of millions of farmers, but other millions of consumers have benefited from such higher food availability and lower prices. Other impacts were on the labour demand, and on the gender distribution of the workload. Other effects have been/are on the total irrigation water demanded by some modern production systems, or on the biodiversity, at both farm and off-farm level.

All these examples show that technical progress requires careful attention, to qualify and then assess, better if ex ante, the likely consequences of some feasible innovation. They also make more difficult the macroeconomic assessment of innovations, because so many generations of impacts can be listed and their temporal and spatial evolution becomes longer and wider.

categories of innovations might benefit the highest number of producers (Biggs, 1986; Byerlee and Alex, 2003). Another subject of debate is the productivity of research, and how to orient the applied research funds towards the production of suitable innovations (Shue and Tollini, 1979; Ruttan, 1982). This leads to the socio-economic analysis of public and private investments in agricultural research, linking together the different phases and aspects of the innovation process, the so-called Agricultural Knowledge and Information Systems (AKIS): applied research, innovation, individual adoption and social diffusion (Leeuwis, 2004; Rivera *et al.,* 2005). Therefore, many mostly economic studies have focused on the micro and macro effects of biotechnology innovations, but in recent years also another wide range of aspects has been studied, sometimes by applying interdisciplinary approaches. In the following paragraphs, the most important approaches for assessing the socio-economic effects of biotechnology applications at farm, sector and national economy levels are discussed. A summary of these approaches is presented in Table 1.

Table 1 - Common approaches for assessing the impact of biotechnology applications

Level	Scope	Impact evaluated	Indicators used	Time frame	Approach/ model
Micro	Farm (family village)	Agronomic	Yield, cost of production factors	*ex ante*	Effects on production function
				ex post	
		Socio-economic	Workload, family income, health of workers, additional time	*ex ante*	Household approach
				ex post	
Sector	Market of a single product in a single country	Economic	BCR	*ex ante*	Dynamic Research Evaluation for Management (DREAM)
			Internal rate of return		Scenario analysis
			Net present value	*ex post*	Aggregate economic welfare analysis (single market partial equilibrium models)
			Distribution of benefits between operators of the production chain		Economic surplus models
Macro	Market of many products in a single country Market of a single product in many countries Multicommodity market in many countries	Economic	International price of products	*ex ante*	Partial equilibrium models (few commodities) Computable general equilibrium (CGE) models (across commodities and sectors) (DREAM) multimarket analysis
			Distribution of benefits between regions or countries (adopters/non-adopters)		
			Distribution of benefits between society categories	*ex post*	

The consequences of a new biotechnology application, as well as of any other technological change, in a developing country are manifold. They might include economic and social impacts at the microlevel (e.g. on-farm productivity, labour requirements or household income) and on the macro-level (e.g. welfare, enhanced food security, employment and trade, economic growth). These impacts can directly affect some categories of stakeholders, whereas they could reach indirectly other categories. Some consequences are difficult to qualify and to quantify, e.g. the empowerment of different social groups, as well as changes in their vulnerability or in the demand for new agricultural skills.

Apart from economic and social effects, the introduction of agricultural biotechnologies can also modify the pattern of land use and the environmental quality and they could also significantly affect human health. Such consequences are often interrelated: e.g. the reduced pesticide use, resulting from the adoption of insect-resistant varieties, has for example positive effects for both the environment and human health. Some biotechnology applications, such as high nutritional value varieties, directly improve human health.

2.2 Economic assessment at microlevel (farm, household)

A traditional way of assessing the impact of any agricultural innovation is to evaluate its effects at farm level. The impact of the new technology is assessed through a specified production function and is mainly based on factor productivity (yield, labour and other input productivity) associated with the use of the innovation. Using a production function, the impact of the new technology on yield, per unit cost of production, and total production per specific input (land, labour, fertilizers, seeds, etc.) can be evaluated. Indicators commonly used include increased yields or reduced work load, higher product quality and income. Recent examples for the assessment of the farm-level impact of biotechnology applications using the production function approach include Qaim (1999a) Bennett *et al*. (2003), Huang *et al*. (2002), Pemsl *et al*. (2003), Pray *et al*. (2001), Qaim and de Janvry (2005) and Qaim and Zilberman (2003), all on Bt cotton.

Agricultural household modelling in an African farming system recognizes that small-scale farmers produce mainly for the household food consumption and only partly for sale and manage farm resources accordingly. This has led to arguments for an analysis of farmers' perceptions on the consumption and production attributes of the new varieties (Edmeades *et al.,* 2004) and for an evaluation of household responses to changes in commodity and input prices, as well as access to off-farm employment opportunities (Bagamba, 2003), in order to assess the potential adoption of innovation packages including new varieties. The results from farm household modelling can be used as input data for assessing the national and regional *ex ante* and *ex post* economic impact of biotechnology innovations.

2.3 Economic assessment at sector and macrolevel

To assess the wider economic and welfare effects of a biotechnology application, analyses on the sector-level and beyond are needed. For this purpose, the most common approach is the economic surplus model that is also known as the economic welfare analysis. Economic surplus models have been used to assess the actual or potential effects of the introduction of a new technology on the overall supply and demand for a specific commodity. Changes in the supply of a commodity (partial equilibrium) by technical change normally affect market prices and thus have implications not only for producers but also for consumers. The model to be applied depends on the degree to which the commodity is traded and if volumes are significant enough to influence market prices. The economic surplus model associated with the use of a biotechnology application can be estimated for a specific period and can be summarized using common indicators like benefit-cost ratio (BCR), internal rate of return (IRR), and net present values (NPV). Costs to be considered are the research and development costs, the costs for the adoption and diffusion of technologies, and for regulation, and, where applicable, the fees for using a technology protected by intellectual property rights (IPR) or other technical costs such as the costs for segregation of GMOs. In addition, higher input and labour costs have to be taken into account, if the use of a new technology is associated with a need for an intensification of the production process.

Apart from assessing the aggregate welfare effects of a new technology, partial equilibrium models can be used to indicate the distribution of costs and benefits among producers and consumers and, for instance, different income groups (producer surplus, consumer surplus, social gains). Qaim (1999a) estimated the welfare effects of the introduction of tissue culture in the Kenyan banana sector and specified the benefits accruing to small-scale, medium-scale and large-scale producers on the one hand, and to consumers on the other hand. If technology innovators enjoy IPRs, the economic surplus model has to be extended to include the benefits accruing to IPR holders. Studies that consider the impacts of different biotechnologies on various stakeholders include Moschini and Lapan (1997), Moschini *et al.* (2000), Falck-Zepeda *et al.* (2000a and 2000b), Pray *et al.* (2001), Frisvold *et al.* (2003), Price *et al.* (2003) and Traxler and Godoy-Avila (2004), all on GMOs.

Ex ante impact assessment can use sensitivity analysis to assess the impacts of various scenarios of changes in key factors on the benefits and costs of the new technologies (input and output prices, yield, quality-related premiums or discounts). In order to guide agricultural research and policies, the welfare effects of different biotechnology products can be analysed using scenario analysis (Qaim, 2000). Also, scenarios can be used to assess the need for policy options accompanying the introduction of biotechnology products. For instance, Qaim's assessment of the potential impact of banana tissue culture in Kenya estimates the welfare effects of a market introduction of the technology with and without policy interventions (Qaim, 1999a). The study shows that subsidizing banana tissue culture (plantlets) or lowering unit cost of production would enhance technology adoption by small-scale farmers, and that the aggregate welfare gains would be eight times higher. It also shows that without measures to improve the accessibility to new technologies, income disparities could increase and small-scale farmers could suffer welfare losses in the long run. Similar scenarios for the introduction of biotechnology applications protected by IPRs can assess the welfare impacts of different technology fees charged by the technology owner.

A suitable model for assessing the economic surplus of agricultural technologies and constructing different scenarios is the Dynamic Research Evaluation for Management (DREAM) software[3] an *ex ante* economic model that generates estimates of aggregate and distributional economic consequences with and without the technology in single or multiple markets (Alston *et al.,* 1998). Examples of impact assessments using the DREAM model include an ongoing study on the impact of tissue culture-derived bananas in Eastern Africa (Lusty and Smale, 2003) and an evaluation of the impact of transgenic cassava in Colombia (Pachico *et al.,* 2002).

The impacts of any innovation on different markets and the spill-over effects on other commodities can be analysed using multimarket and multicommodity models. This is particularly useful if a commodity is traded freely between countries and if changes in the supply of one commodity have a significant impact on the supply and consumption of other commodities. Models can also be used to estimate the effects of agricultural policies, e.g. bans of biotechnologies such as the GMOs in specific markets or the introduction of legal labelling requirements.

Many of the models used to assess the impacts of the introduction of agricultural biotechnology products are partial equilibrium models covering a limited number of commodities and markets (Annou *et al.,* 2003; Flatau and Schmitz, 2004). When studying the wider effects of changes in agricultural product markets with significant cross-sectoral impacts, computable general equilibrium (CGE) models are used (Anderson and Jackson, 2004; Hareau *et al.,* 2005). In contrast to partial equilibrium models, CGE models are more comprehensive and developed to analyse aggregate and feedback effects across commodities and sectors, as well as additional economic shocks such

[3] For more information, visit http://www.ifpri.org/dream.htm.

as significant changes in employment level, wages, transportation costs, fiscal and monetary policies.

2.4 Towards a more comprehensive assessment

In recent years, studies aiming at evaluating the contribution of agricultural technologies to poverty reduction and food security in a comprehensive way have become more and more common. Due to the fact that purely economic approaches to assess the costs and benefits of a technological innovation do not account for a range of impacts that are of importance for the livelihoods of resource-poor farmers in developing countries, more comprehensive approaches have been introduced.

The awareness that so many smallholders remain out of the development process and do not adopt the proposed innovations has motivated several categories of social scientists (economists, sociologists, anthropologists, etc.) to investigate the motives and justifications behind the behaviour of the non-adopters (Rogers, 1983).

Furthermore, recognizing that innovations are not scale neutral, neither gender neutral, nor age neutral, more attention has been paid to understand better what makes the innovations attractive for the different categories of producers and to evaluate other impacts of the innovations, such as those on the labour distribution, as well on the use of the likely surplus (in kind or cash), by the different components of the same household.

One such method that has been designed to evaluate the impact of agricultural research on the livelihoods of poor farmers is the Sustainable Livelihoods Approach (SLA) framework (Chambers and Conway, 1991; Ashley and Carney, 1999). This approach looks at the social and economic effects of a new technology in an integrated way, taking into account how the introduction of an agricultural technology affects the vulnerability and the requirement of capitals demanded from the household (financial, physical, human, natural and social capital). The framework further allows for an analysis of the policies, institutions and processes that affect the adoption of a new technology by the poor and the resulting effects on farmers' welfare. Applying the SLA requires interdisciplinary work and the use of both quantitative and qualitative research methods. It involves using both conventional impact assessment methods for analysing hard facts and in-depth studies on the household and community levels, taking into account subjective factors and the people's values.

Although the SLA is well suited for capturing the complexity of a technology's impact on the poor, its use to date has been limited. To some extent, this is due to the complexity of the concept and the need for surveys capturing the various changes caused by the introduction of one or more innovations. Possibilities to

Box 4 - Sustainable Livelihoods Approach (SLA)

As applied to rural development issues, SLA focuses on the way in which farming households (the basic units of analysis) make their living by exploiting a variable and ever-changing mix of capital assets. These assets are classified as natural (e.g. land, planting materials, water availability, etc.), physical (housing, agricultural equipment and tools, infrastructure, etc.), human (working capability of household members, education, agricultural know how, access to extension and technical assistance), social (interhousehold cooperation and safety networks, cooperative, associations) and financial (income, credit, subsidies). Availability and use of capital assets mix is influenced by the vulnerability context to which farming households are exposed. This includes natural, economic and political shocks and trends, such as loss of soil fertility, drought, disease, inflation, wars, etc. The capacity of farmers to cope with the vulnerability context is influenced by the opportunities for change, which are brought in by institutions and policies (market, development policies, development services and cultural change). Interactions among household capital assets, its vulnerability context and the transforming processes and structure shape household livelihood strategies. These strategies allow the household to achieve livelihood outcomes (such as income, food security, health, capitalization and welfare) on a more or less sustainable basis (i.e. at an environmental, human, social and financial cost that the household can afford).

evaluate the impact of biotechnology applications on the poor, using the SLA, were identified (Falck-Zepeda *et al.,* 2002) by the participants in a consultation organized by the International Service for Agricultural Research (ISNAR).

When analysing the socio-economic impact of biotechnology, the environmental effects of a new technology have also to be taken into account. These include direct effects such as gene transfer to wild relatives or conventional crops, with the possible related induction of weediness or invasiveness, effects on non-target organisms and other unintended effects, as well as indirect effects resulting from changes in agricultural practices, e.g. changes in pesticide use and tillage patterns that can disturb the natural stands. Other important environmental effects that have to be analysed are impacts on soil erosion, moisture retention, soil organic matter, water quality and fossil fuel use.

There is a growing consensus[4] that environmental impact assessment of biotechnology applications should be science-based and conducted on a

[4] See the FAO statement published in March 2000 on the occasion of the "Codex Alimentarius Ad Hoc Intergovernmental Task Force on Foods Derived from Biotechnology", available at http://www.fao.org/biotech/stat.asp.

case-by-case basis, taking into account the specific conditions of the relevant agro-ecologic environment. Most environmental impacts translate directly or indirectly into economic impacts. In order to analyse them properly, long-term studies are required.

The use of agricultural biotechnology can also have positive or negative impacts on human health. As the benefits occur at the consumption and not on the production level, specific approaches are needed to measure the impact of agricultural varieties of improved nutritional value. One way of assessing the health benefits arising from the introduction of biotechnology applications is the health economics approach employed by Zimmermann and Qaim (2004). Here, the reduction of health costs due to the introduction of a new technology is quantified by calculating the years lost due to mortality and disability with and without the new technology. For this purpose, the methodology of disability-adjusted life years (DALYs) can be used. To attribute a monetary value to the number of DALYs won, Zimmermann and Qaim suggest a context-specific approach, deriving the value of one DALY from the per capita incomes and the willingness to pay for health services. While it is of great value for decision-makers to have an idea about the (potential) number of years gained due to a political measure such as the provision of healthier food, the total benefits go beyond the reduction of health costs and can hardly be quantified.

Another approach to assess the health benefits associated with a nutritionally improved variety is to estimate the increase in labour productivity of unskilled workers with low incomes that results from better nutrition (Weinberger, 2005). Weinberger's methodology applied to a case study of traditionally-bred mungbeans in Pakistan takes into account the nutritional impact of both the direct consumption of mungbeans and the higher wages being paid to better nourished workers, which again have an impact on the nutritional status of mungbean growing families. In a simulation of the market introduction of Golden Rice in Asia, Anderson *et al.* (2004) assume that in countries adopting Golden Rice the nutritional benefits translate into a 2 percent productivity increase of unskilled labour in all sectors. Total benefits of the introduction of a nutritionally enhanced crop go beyond quantifiable economic figures like labour productivity.

With a modelling approach, different policy options can be assessed for efficiency. This has been done by Albrecht (2002) for combating vitamin A deficiency in a hypothetical country. The study concludes that the introduction of Golden Rice could be more cost-effective than gardening and educational programmes and food fortification, and that it is preferable to supplementation programmes in the long run.

To measure the health impact associated with the use of some biotechnology applications such as insect-resistant crops, econometric (regression) approaches can be used. By using these methods, it is possible to establish the link between the use of a new technology and, for example, the reduced application of pesticides, as well as the link between the use of pesticides and the damages caused to farmers' health. This was done by Hossain *et al*. (2004) who modelled the health effects of the use of Bt cotton in China using a health production function with farmers' reports of poisonings as a dependent variable and pesticide use, farmers' socio-economic characteristics and environmental factors as independent variables.

3. ECONOMIC AND SOCIO-ECONOMIC IMPACT OF NON-TRANSGENIC BIOTECHNOLOGY APPLICATIONS IN DEVELOPING COUNTRIES

3.1. Micropropagation

Micropropagation is a popular technique used for propagation of plants. This technique is already commercially in place in more than 30 developing and transition countries[5].

The benefits of plant tissue culture propagation include potentially unlimited multiplication of selected plant lines or individuals, elimination of pathogens, production of true-to-type multiplication material of desirable plant lines, indefinite storage of genetic resources through long-term maintenance of propagule inventories.

The success of micropropagation may be explained by its relatively low cost and generally positive effects on productivity (especially of clonally propagated root and tuber crops). The most common application of micropropagation in developing countries is the production of virus free plantlets through meristem culture combined with explant heat treatment.

Despite the successful transfer and widespread use of micropropagation in many developing countries, there has not been much work done to assess and evaluate its socio-economic impacts. There are only few examples of plant micropropagation socio-economic impact studies, the most extensive ones being in China, Kenya and Viet Nam, on sweetpotato banana and potato, respectively.

[5] For more information visit the FAO-BioDeC database http://www.fao.org/biotech/inventory_admin/dep/default.asp. FAO-BioDeC is a database meant to gather, store, organize and disseminate, updated baseline information on the state-of-the-art of crop biotechnology products and techniques, which are in use, or in the pipeline in developing countries. The database includes more than 4 000 entries from 70 developing countries, including countries with economies in transition.

Box 5 - Micropropagation

Many crop plants, including banana and other fruit trees, and root and tuber crops like cassava, potato and sweetpotato, are not normally propagated by botanical seeds, as other major field crops are, but by plant parts. Edible bananas are parthenocarpic and normally seedless, while cassava, potato and sweetpotato may produce seeds, but they do not generate stable, uniform plants. Bananas are propagated through lateral shoots (the 'suckers') which are produced profusely at the base of each plant; potatoes are propagated through entire tubers or tuber sections with one or more buds (the 'eyes'); sweetpotato and cassava are propagated through stem sections, the cuttings for sweetpotato or the "minisets" for cassava. Thus, all of these crop plants are vegetatively reproduced, as clones and this ensures a stable, "true-to-type" propagation virtually in perpetuity. However, the suckers, the tuber pieces, the cuttings and the minisets, can carry pests and diseases that have infected the parent plant and thus infect the new plant. Continuous plant propagation cycles may accumulate infectious agents, making the quality of the propagation materials poorer and poorer. To avoid disease transmission, which impairs yields, the propagation materials of these plants are produced in specific areas under strict and expensive disease control measures. Farmers of developing countries are often denied access to high quality, disease-free propagation materials to establish fields of these crop plants. One way of overcoming this problem is to use micropropagation, the laboratory practice of rapidly multiplying stock plant material to produce a large number of progeny plants, using modern in vitro plant tissue culture methods. Shoot tips of banana or potato or sweetpotato are excised from healthy plants and cultivated on gelatinized nutrient media in sterile conditions (in test tubes, plastic flasks, or baby food jars), so that contamination with pests and pathogens is avoided. The obtained plantlets can be multiplied an unlimited number of times, by cutting them in single-node pieces and cultivating the cuttings in similar aseptic conditions. Millions of plantlets can be produced in this way in a very short time. The plantlets are then transplanted in the field or nurseries, where they grow and yield low-cost, disease-free propagation materials, ready to be distributed to farmers.

In the Shandong Province of China, the economic impact of micropropagated virus free sweetpotato has been assessed and results indicate that 80 percent of the farmers have taken up the technology because of its proven ability to increase yields by up to 30 percent; the IRR was estimated to be 202 percent, with a NPV of USD 550 million (assuming a 10 percent real discount rate). By 1998, the annual productivity increases were valued at USD 145 million, with an increase in agricultural income of the province's seven million sweetpotato growers by 3.6 and 1.6 percent, in relatively poor and better-off districts respectively (Fuglie *et al.,* 1999).

In Kenya, the commercial micropropagation of disease free bananas had been adopted by over 500 000 farmers (Wambugu, 2004) and has been predicted (Qaim, 1999a) and shown (Mbogoh *et al.,* 2003) to offer relatively higher financial returns than traditional production.

In Viet Nam, the introduction of improved high yielding and late blight resistant potato varieties and the subsequent adoption of micropropagation by farmers, has seen potato yields increasing significantly from 10 to 20 tonnes per hectare. The self-supporting plantlet production by the farmers has made the seed more affordable and the rate of return on investment in this new seed system highly favourable. Micropropagation not only increased the farmers' yields and incomes, but also led to the creation of rural micro-enterprises that have specialized in the commercial provision of disease-free seed (Uyen *et al.,* 1996).

In India the "Revolving Fund Scheme for Potato Breeders' Seed Production" integrated micropropagation and virus detection in the initial stages of potato breeders' seed production, leading to two to three fold improvement of health standards of the seed produced. The scheme generated a total revenue of over USD 4 million, over a period of ten years, with a cumulative balance of USD 0.735, deducting the total expenditures for the development of infrastructure and for the recurring costs (Naik and Karihaloo, 2007).

The success of these programmes cannot be attributed just to yield increases, but also to comprehensive policy decisions, including subsidies for the establishment of the multiplication programmes which have helped in hastening the adoption of the technology and keeping the per unit cost of planting materials low.

However, the above-mentioned studies only look at the aggregate economic effects and to a lesser extent, the distributional effects of the use of micropropagation, without any attempts to capture the technology's impact on poverty reduction. Furthermore, these studies do not cover the human side of the innovation process, i.e. the motivations which lead to change, as well as those who prevent farmers from changing.

To study the socio-economic impact of micropropagated planting materials, FAO has undertaken a field study in Africa. The first phase was carried out by national specialists in agricultural biotechnology and explored the extent of the diffusion of this technique in five African countries, namely Gabon, Mali, Nigeria, Uganda and Zimbabwe. The studies, which are summarized in the survey on micropropagation utilization in selected African countries to this paper, considered knowledge transfer and protection mechanisms, science-industry interactions and core competencies at the country level. The second phase of the study was focused on banana and sweetpotato micropropagation projects respectively in Uganda and Zimbabwe, where the use of micropropagated plantlets in rural households had been implemented over a considerable period of time and there had been no previous detailed micropropagation impact studies. The socio-economic impact studies, summarized in the case studies from Uganda and Zimbabwe were conducted by national experts in sociology and adopted a holistic approach, taking into consideration the interrelations among ecological, agricultural, economic, social, cultural and political factors. The sustainable livelihoods' analysis was focused on changes in household capital assets, household capacity to cope with vulnerability factors and to take advantage of opportunities and household livelihood strategy (including sustainability). The findings of the field studies allowed concluding that the pattern of adoption of the micropropagated material is influenced by the context; that the socio-economic impact is determined by mediation between immediate benefits and systemic changes in livelihood strategies; and that the adoption decisions were made by balancing costs and benefits against ('hidden') opportunity costs and risks. In conclusion, it is recommended that projects aimed at the diffusion of a new technology, such as the use of micropropagated materials, have to include service packages to technically assist the adopters and that the adoption patterns and impacts should be considered *ex ante* in the project design, in order to maximize the socio-economic impact.

3.2 Anther culture and embryo rescue

Anther culture involves the *in vitro* culture of immature anthers (the pollen-producing organs of the plant), in order to generate plants from the pollen grains before the fecundation process takes place. As the pollen grains are endowed with only one set of chromosomes instead of two sets as all the somatic parts of the plants are, the pollen-derived plants are haploids (plants endowed with half of the normal number of chromosomes). The haploid plants can afterwards be brought back to the normal diploid status by duplicating their chromosome number through application of chemicals (such as colchicine) or other *in vitro* techniques. The resulting plants will therefore have two identical chromosome sets (they will be perfectly homozygous) and therefore will give rise to true-to-type, perfectly homogeneous progenies. This technique is manly used for breeding purposes, as an alternative to the numerous cycles of self-pollination that are usually needed to obtain pure (homozygous) lines starting from a hybrid between different varieties. *In vitro* anther culture is now routinely used for improving some vegetable crops such as asparagus, sweet pepper, eggplant, watermelon and *Brassica* vegetables and to a lesser extent in cereal crops such as rice, barley and wheat.

Another culture has been used to develop improved rice cultivars and elite breeding lines in public breeding programmes in China and the Republic of Korea and by the International Rice Research Institute (IRRI) in the Philippines. This has led to the release of several improved varieties, but unfortunately little is known about their impact. Anther culture is also being used to develop improved wheat varieties by the International Center for Agricultural Research in the Dry Areas (ICARDA) in Syria and by national research institutes in Chile, Morocco, Serbia, The former Yugoslav Republic of Macedonia and Tunisia. An anther culture-derived durum wheat variety has reached the commercial phase in Tunisia, and an improved bread wheat variety derived from anther culture is commercially used in Morocco (Dhlamini *et al.,* 2005). Here again, little is known about their current adoption and impact.

Embryo rescue is a technique usually applied following crosses made between species which would not normally be sexually compatible. Wide crosses are often desirable in order to transfer genetic traits from secondary and tertiary genepools (i.e. crop wild relatives) into primary genepools (cultivated crop plants). Embryos that result from such 'wide crosses' usually abort before the mature seed is developed, as an effect of the presence of unbalanced endosperm (the part of the seed surrounding the embryo and containing the nutrients necessary for its development). Embryo abortion can be prevented by separating the embryo itself from the endorsperm and cultivating it *in vitro* on a nutrient medium, to replace the nutrients that are normally provided by the endosperm. An example of wide crosses made possible by this technique, is the synthesis of triticale, a new hybrid species resulting from the cross between rye and wheat and combining the high productivity and nutritional quality of the former with the good adaptation to harsh environmental conditions of the latter.

The most recent successful use of both embryo rescue and anther culture was in the generation of the New Rice for Africa (NERICA) by breeders at the Africa Rice Center (formerly West Africa Rice Development Association - WARDA[6]), who have used these techniques to cross *Oryza sativa* (Asian rice) with *Oryza glaberrima* (African cultivated rice). From the resulting germplasm, farmers have participated in the selection of new rice varieties with desirable qualities, such as higher yields, shorter growing seasons, resistance to local stresses and higher protein content than traditional African varieties. More than 100 upland varieties and 60 varieties for lowland/irrigated ecologies have been obtained and are under field test in 30 and 20 countries, respectively, in sub-Saharan Africa. WARDA reports[7] that NERICA varieties have been released

[6] Fore more information visit http://www.warda.org.
[7] http://www.warda.org/warda/nericas-at-a-glance.asp.

in almost 30 African countries, and are now planted in about 200 000 ha across Africa, mainly in Côte d'Ivoire, Guinea, Nigeria and Uganda. It has been estimated that the introduction of NERICA in Guinea alone led to import savings of USD 13 million in 2003 (Harsch, 2004).

WARDA and the interested National Agricultural Research Systems (NARS) are carrying out studies on adoption and impact of NERICA varieties in a number of countries, including Benin, Côte d'Ivoire, the Gambia, Ghana, Guinea, Mali, Nigeria, Sierra Leone, Togo and Uganda. The studies are based on an impact assessment methodology grounded within the 'counterfactual' outcomes or Average Treatment Estimation (ATE) framework and are at a different stage of development. The results show effects on productivity generally positive, even if heterogeneous between and within countries (Diagne *et al.,* 2006). Data for Benin show that the impact of adoption of NERICA is significant and positive for a number of economic parameters, including yield, production, incomes of producers, as well as for social indicators such as child schooling, school expenditure per child, consumption spending, calorie intake, gender parity index, household spending per equivalent adult (Adekambi *et al.,* 2007a and b). The spending deficit ratio of the poor was reduced, proving that NERICA adoption led to a reduction of the gap between their expenditure and the poverty line. A study of NERICA impact in Uganda showed increase of income and tendency to improvement income distribution, indicating good potential for poverty reduction (Kijima *et al.,* 2006).

An Evaluation Study Report prepared for the United Nations Development Programme (UNDP) and WARDA in 2005 discusses livelihood impacts of NERICA in Benin, Guinea and Mali and concludes that "NERICA rice impacts the whole spectrum of human life problems in the areas of health, nutrition, education, female empowerment, environmental protection, and improved collaboration and partnerships for enhanced development. The impacts in all the three countries are hence the same although they vary in magnitude" (Obilana and Okumu, 2005).

3.3 Marker-assisted selection

A more sophisticated biotechnology that could be of great use for agricultural development in developing countries is marker-assisted selection (MAS)[8], which is an alternative to conventional (phenotypic) selection in plant breeding. It involves the use of molecular markers, i.e. identifiable deoxyribonucleic acid (DNA) sequences linked to the gene(s) controlling a specific trait, to select plants with the trait(s) of interest (Ruane and Sonnino, 2007). Although relatively complex and costly, MAS offers the possibility to speed up breeding

[8] For a discussion of the relevance of MAS for developing countries cf. http://www.fao.org/biotech/c10doc.htm

programmes aiming at the development of high-yielding, drought-tolerant and disease-resistant varieties that could be of high value especially for resource-poor farmers in developing countries. Despite its great potential, however, there are still few applications of commercially produced crop varieties in developing countries that have been developed using MAS (Sonnino *et al.,* 2007). This is mainly due to the lack of the necessary molecular marker maps and genetic linkage maps for many economically important species and to the inherent costs and level of sophistication of the technology.

Despite MAS' high potential, the technology's current impact in developing countries has not been thoroughly studied. This is partly due to the relative short history of the application of MAS in plant breeding. While the socio-economic impact of this innovative method has not been assessed to date, thorough economic studies on MAS focus on its cost-effectiveness in comparison with conventional selection. These studies suggest that the cost-effectiveness of both methods depends on the particular circumstances of the specific application (Dreher *et al.,* 2003, Morris *et al.,* 2003). Case-by-case analysis is therefore required in order that informed decisions be taken about whether or not to incorporate MAS into a breeding scheme (William *et al.,* 2007).

3.4 Microbial biotechnologies for soil fertility enhancement

Another basic, widely adopted biotechnology is the use of micro-organisms (bacteria, fungi and algae) to improve soil fertility. The biological nitrogen fixation (BNF) refers to the process of micro-organisms hosted by the root system of many leguminous plants fixing atmospheric nitrogen, and making it available for assimilation by plants. Other micro-organisms, such as mycorrhiza, are active in establishing symbiosis with cultivated plants and forest trees and facilitate phosphorus uptake. In many cases these micro-organisms are already present in the soil, but inoculation with these microrganisms has proven to be an efficient way to substitute or complement chemical fertilization. The use of these biofertilizers can increase yields or enhance the profitability of farms by reducing the cost of agricultural inputs.

A study on the use of rhizobial inoculants in Thailand shows that this technology can effectively replace chemical fertilizers in the production of soybeans, groundnuts and mungbean (Boonkerd, 2002). The author estimates that the use of Rhizobia in Thai soybean, groundnut and mungbean production between 1980 and 1993 produced accumulated benefits respectively of USD 100.2, USD 17.0 and USD 4.2 million for the producers of these three crops. Nevertheless, another study on the use of inoculants in Thailand shows that nitrogen-fixing inoculants have had widely different effects in different locations, even within small areas, and that their performance varied over time (Hall and Clark, 1995). This can partly be explained by the fact that the performance of inoculants depends on micronutrient conditions in the fields and by the persistence of bacterial populations in the soil. Therefore, local farmers' knowledge and experience is essential to decide whether and how to apply biofertilizers.

In Kenya, the rhizobial inoculant Biofix has been marketed since 1981. In Kenya's Nyeri district it is being used by most smallholders, organized in farmers' groups having access to the product (Odame, 2002). However, the national adoption rate is much lower, although the product's effectiveness has been demonstrated in field trials in Kenya[9]. Explanations include a poor distribution system, lack of information about the product, insufficiency of extension services, poor access to credit, prevailing package size and other constraints (Odame, 1999). Nevertheless, the low adoption rate can also be explained by the mixed performance of the product. Depending on site-specific conditions, one of these factors is the need for simultaneous phosphorus provision. This problem, however, is being addressed by the producers of Biofix by developing an improved product that contains also rock phosphate for countering phosphorus deficiency.

Another efficient, low-cost and sustainable way of enhancing soil fertility is the use of fungal inoculants to produce organic fertilizer from organic waste. In the Philippines, a technology for speeding up the process of organic fertilizer production from different kinds of plant substrates such as rice straw has been developed. The Rapid Composting Technology (RCT) involves inoculating the substrate and minor amounts of animal manure with cultures of Trichoderma, a cellulose decomposer fungus. Using this inoculant, referred to as compost fungus activator (CFA), the composting time has been reduced to 21-45 days depending on the type of plant residues used.

Since 1990 the technology has been promoted by the Government of the Philippines which constructed several production centres for the supply of the CFA and promoted the production and use of organic fertilizer by farmers' cooperatives, private enterprises and non-governmental organizations (NGOs) and their members. Although the production and use of compost as fertilizer is more labour-intensive then the use of chemical fertilizers and although the low availability of animal manure constituted a constraint to compost production in some locations, adoption spread in most parts of the Philippines.

An impact study concluded that rice and sugarcane farmers adopting the RCT use significantly less chemical fertilizers, have higher yields and higher net incomes (Rola and Chupungco, 1996). For example, rice farmers using

[9] Odame (1999) states that the national adoption rate among farmers growing common bean was less than one percent in 1999. Evidence on Biofix's ability to increase maize yields in Kenya is presented by Okalebo and Woomer (2003).

both organic fertilizer produced with RCT and chemical fertilizer produced 15 percent more than farmers using only chemical fertilizer. Net income gains per hectare were about USD 171. The main advantage of the substitution of chemical fertilizer with organic fertilizer is its positive effect on soil nutrient content as well as soil tilth and texture. This makes it superior to the application of chemical fertilizers as it is prevailing in the Philippines (Cuevas, 1997). Furthermore, the introduction of rapid composting generated employment in the 160 facilities producing compost and/or the fungal inoculant. Some of these facilities have up to 33 employees, most of them on a contract basis. Even though the production and use of organic fertilizer using the RCT is still subsidized by the Government, a farmer survey established that most farmers would continue producing or buying the fertilizer if the subsidies were removed (Rola and Chupungco, 1996). However, factors affecting positively the adoption probability are large size, other sources of income and frequent contact with extension services. The removal of subsidies is therefore likely to result in lower adoption rates.

As in the case of micropropagation, the commercial use of micro-organisms for soil fertility enrichment does not correspond to the standard of knowledge about the technology's economic and socio-economic impact. While there are no detailed economic studies on the use of rhizobial inoculants, some knowledge has been developed about the factors affecting farmers' adoption and the constraints impeding access to the technology. As far as the use of micro-organisms in the production of organic fertilizers is concerned, the technology's impact has only been assessed in the Philippines.

4. CONCLUSIONS

The actual and potential socio-economic impacts of micropropagation and other non-transgenic biotechnologies are still waiting to be fully investigated, even if a vast array of methods have been developed to assess the consequences of the adoption and diffusion of innovations. There are multiple reasons for the scarce attention paid to date to this type of study: firstly, the possible application of non-transgenic technologies and their possible contribution to the development of rural areas are not controversial and are therefore overshadowed by the highly polarized debate about the consequences of genetically modified crop adoption. Furthermore, only in a few instances is the application of biotechnologies spread among a sufficient number of adopters and from a sufficiently long period to allow accurate field studies. In many developing countries even the most popular and mature biotechnologies, such as the production of virus-free plant propagation materials, are still far from being adopted in significantly vast areas and from a sufficient number of years to permit accurate assessments of their economic and social impacts. The pathways of technology adoption are often more complex than the processes of technology development, and long time frames are required before the research and extension efforts are translated into appreciable effects on-farm productivity and rural livelihoods (Dargie, 2007).

The available evidence suggests that the briefly presented technologies offered opportunities for yield increase, poverty reduction and sustainable development. Non-transgenic biotechnologies can help to increase agricultural production, raise income, improve food security and nutritional intake and reduce the utilization of costly and sometimes hazardous agricultural inputs, and consequently impact the livelihood of rural people.

However, when a biotechnology is readily available, a number of conditions have to be fulfilled to allow these benefits to take place. These conditions range from actual access to the technology (e.g. access to information, affordability, physical accessibility and opportunity cost), to availability of technical assistance, to contemporaneous adoption of other innovations, to opportunities for marketing the additional production.

Furthermore, it has been shown that in some cases, where technologies are not scale-neutral and there are different barriers to access, targeted policies are needed to increase access as well as to maximize and spread equally the gains that can be derived from their use. This can be done by subsidies or other incentives, enhanced access to technical advisory services and the improvement of rural infrastructures.

The adoption of new technologies does not follow a linear, top-down transfer process going from research institution to farmers, passing through extension systems or other technical advisory services. It follows a much more complex route, which requires sophisticated integration between researchers, extension agents, farmers, policy-makers and relevant institutions, in order to develop, fine-tune and adapt to the local context the innovation in a reiterative process. Policy- and decision-making about agricultural research and technology development need factual information before deciding on priorities and investments. Information on expected socio-economic impacts of the introduction of the new technology is obviously critical in the decision- or policy-making process.

Survey on micropropagation utilization in selected African countries

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1. INTRODUCTION

Research initiatives on plant micropropagation are reported to be ongoing in 25 African countries and to cover a broad spectrum of plant species, including root and tuber crops, vegetables, industrial crops and fruit trees, with emphasis on the species of interest for the agriculture in tropical and subtropical environments (Table 1).

Micropropagated plants were reported to be under commercial utilization in twelve African countries (Table 2), but the extent of its diffusion and the impacts in these countries were not well documented. In 2003, FAO launched a research project aimed at "identifying the extent of adoption of commercial utilization of micropropagation technologies in some African countries, and subsequently assessing their socio-economic impact".

The first phase of the project focused on the analysis of the state-of-the-art of micropropagation in the five selected countries, namely Gabon (Ndong Biyo'o, 2004), Mali (Bretaudeau, 2004; Koné, 2005), Nigeria (Kuta, 2005), Uganda (Sengooba, 2004) and Zimbabwe (Mugwagwa, 2004). These countries were selected to represent the diverse agricultural systems and agro-ecological zones of Sub-Saharan Africa. This initial phase involved establishing the extent of micropropagation adoption and utilization, including, among other indicators, knowledge transfer and protection mechanisms, science/industry interactions, core competences, quantitative and qualitative trends.

For such country studies, a national specialist in agricultural biotechnology was recruited in each country with the following mandate:

a) Identify the stakeholders engaged in the commercial plant micropropagation technology development, transfer and utilization.
b) Use secondary and primary data sources to compile quantitative and qualitative information about:

- basic economic information of each organization, before and after its adoption of the technology;

Table 1 - Research initiatives on plant micropropagation currently ongoing in Africa (Source: FAO-BioDeC)

Plant type	Crop plants currently under investigation
Root and tuber crops	Cassava, cocoyam, frafra potato (Solenostemon rotendifolius), potato, sweetpotato, yam
Vegetables and condiments	Artichoke, Baselle (African Spinach), garlic, ginger, kanna (*Sceletium tortuosum*)
Industrial crops	Coffee, cocoa, oil palm, pyrethrum, sugarcane, tea, tobacco
Fruit trees	Almond, banana, cactus, citrus, coconut, date-palm, ensete, granadilla, grape, lemon tree, mango, olive tree, pistachio, pineapple, plantain, strawberry

- knowledge acquisition processes;
- further research and technology development;
- integration of the technologies involved;
- types of services and products;
- sales, volumes and value, market share;
- levels of adoption of the technology by different categories of farmers over time and socio-economic impacts due to the adoption of the technology; e.g. other required modifications, yield changes, etc.;
- employment, jobs created, skills development;
- policy issues for further expansion and diffusion;
- potential environmental impacts.

Information collected was used to compile the country reports, whose main findings are summarized in the next paragraphs.

2. GABON

In Gabon, *in vitro* plant culture was introduced in 1983 by the plant physiology laboratory of the *Centre d'introduction et d'adaptation du matériel végétal (CIAM)*. This was after the 1980 devastating outbreak of black sigatoga disease (caused by *Mycosphaerella fijiensis*) that destroyed banana plantations around Libreville. Following this outbreak, due to the strong need to eradicate the disease and to supply clean planting materials to farmers, the *in vitro* laboratory was introduced by the Government of Gabon with assistance from the European Union. Initially the CIAM laboratory multiplied banana, plantain and cassava materials imported from the International Network for the Improvement of Banana and Plantain (INIBAP) and the International Institute of Tropical Agriculture (IITA) for field trials. There had not been

Table 2 - Commercially micropropagated crops in Africa (Source: FAO-BioDeC)

Country	Crop
Cameroon	Banana, Tea
Gabon	Banana, Cassava, Plantain
Kenya	Banana
Madagascar	Amaranthus
Mali	Potato
Mauritius	Potato, Sugarcane
Morocco	Date-palm
Nigeria	Cassava, Ginger, Plantain, Yam
South Africa	Potato
Tunisia	Almond, Citrus, Date-palm, Grapevine, Olive tree, Potato
Uganda	Banana, Potato, Sweetpotato
Zimbabwe	Cassava, Sweetpotato, Potato

much effort to disseminate the *in vitro* materials to farmers until 1996 when a campaign to promote micropropagated materials began. However, due to lack of adequate financial support for laboratory and extension activities the programme was prematurely aborted. From 1997 to 2001 CIAM only managed to distribute 900 bananas, 160 cassava plantlets and 500 China rose bushes. Despite these inadequate numbers, farmers showed preference for micropropagated banana plantlets to their traditional suckers and thus demanded more, but unfortunately CIAM was no longer in a position to meet the increased demand. On the other hand, cassava farmers preferred their local cuttings to the *in vitro* plantlets that were considered to be too delicate to handle in the field. The Ministry of Agriculture is currently implementing a CIAM rehabilitation programme and it is envisaged that the centre will soon resume its work on micropropagation.

To meet the demand for micropropagated materials the *Centre national de la recherche scientifique et technologie* (CENAREST) established a new plant biotechnology laboratory in 2002 with a mandate of cleaning and producing vegetable planting materials. Considering its infrastructure and human resource base, CENAREST is now the biggest *in vitro* propagation facility in Gabon. By 2004 this laboratory was already producing micropropagated pineapples, bananas and plantains that were expected to be distributed to farmers by 2005.

3. MALI

The use of micropropagation in Mali is not widespread, despite the high level of vegetatively propagated crops such as potato, banana, yam, sweetpotato and sugar cane in the country. At present, micropropagation is only used at commercial level in potato production. *In vitro* propagated date-palm plantlets, are imported from France, Israel and Spain. As the bulk of the potato planting material is also imported, foreign seeds are expensive and not always consistent in quality. Furthermore, imports often fail to meet the quantitative needs of all producers. There was thus an urgent need for the establishment of local potato micropropagation facility. In 2000 the *Laboratoire d'agro-physio-génétique et de biotechnologies végétales* of the *Institut polytechnique rural de formation et de recherche appliquée* (IPR/IFRA) in Katibougou acquired modern tissue culture equipment and skilled personnel to work on plant *in vitro* propagation with special emphasis on potato. The laboratory has a capacity to produce more than 250 000 minitubers annually. The laboratory has also undertaken the training of farmers in producing seed potato from the minitubers. Beyond meeting local demand, the laboratory has also managed to export certified potato seeds to Burkina Faso, Cameroon, Guinea, the Niger and Senegal. Other countries in the region, namely Benin and Togo, are also interested in acquiring this micropropagated material. The laboratory is still grappling with quality control issues such as what material (*in vitro* plantlets, microtubers or minitubers) to use in the first generation, the cut-off generation in which seed can be certified, as well as what pathogens and pests to assay for in the certification process.

The IPR/IFRA laboratory is also doing some preliminary work for the micropropagation of date-palm, banana, sugar cane and some forestry tree species.

4. NIGERIA

In Nigeria vegetatively-propagated crops (cassava, yams, sweetpotato, pineapple, plantain, banana, etc.) have a significant relevance for food security and poverty reduction. The Federal Government is making efforts to rapidly apply biotechnologies for the propagation of some of these important crops, especially cassava, the staple food for the majority of Nigerians. Cassava products also have a tremendous export potential. A national programme, code-named "Presidential Initiatives for Cassava Production in Nigeria", aims at replacing local cultivars of cassava with improved ones; this programme has lead to an unprecedented high demand for quality cassava planting materials. Micropropagation was promptly considered as the method of choice for the elimination of pathogens and rapid propagation of cassava planting materials.

Twelve (12) organizations have micropropagation research and development programmes (Table 3). Among these institutions, only two are privately owned and funded. All others are IITAs, or government-controlled and funded institutions. Only four organizations (IITA, National Root Crops Research Institute [NRCRI], Molecular Bio/Sciences, the National Centre for Genetic Resources and Biotechnology [NACGRAB] and Biotechnology Advanced Laboratory [Nigeria] [BAL]) have taken so far *in vitro* plants out of the laboratory to farmers' fields. The remaining institutions are still at the protocol development stage and have yet to start field trials. In those areas where micropropagated plants have been distributed to farmers, adoption rates and demand are quite high, due to their demonstrated advantages over conventionally produced materials.

All the institutions highlighted a number of constraints to their micropropagation activities, the most relevant being the inadequate funding and lack of access to credit, as well as the irregular supply of inputs with certified quality. Consequently, the current micropropagation centres cannot meet the demand. However, with the government biotechnology policies developed and implemented by the National Biotechnology Development Agency (NABDA), it is envisaged that in the near future more stakeholders will contribute to further research and biotechnology development. For instance, the Government of Nigeria, through NABDA, is establishing plant tissue culture laboratories in six universities, one in each of the six geopolitical zones of Nigeria. These laboratories will serve as micropropagation centres for the most relevant crops of the surrounding area and for further micropropagation research and training.

5. UGANDA

Plant tissue culture was initiated in 1991 by the Banana Based Cropping Systems Research project at the Department of Crop Science, Faculty of Agriculture, Makerere University, with funding from the Rockefeller Foundation. The primary objective of this project was to mass-produce disease-free planting material to contribute to the revival of the production of the East African highland banana. It also intended to provide hands-on tissue culture training to university students as well as provide tissue culture facilities to researchers from the Ministry of Agriculture. The implementation of the Farming Systems Support Project (FSSP) in 1992 for the rehabilitation of coffee production created a demand for elite planting materials to rejuvenate the old plantations and to establish new ones. Thus coffee was the second crop to be micropropagated by the University's tissue culture laboratory through nodal cuttings and somatic embryogenesis. The technology has since expanded to other institutions and it is presently applied to several crops for various purposes, including plant germplasm conservation, improvement

Table 3 - Organizations involved in micropropagation in Nigeria

Organization	Major Activities	Funding
1.Biotechnology Center, Ahmadu Bello University	Development of protocols for the micropropagation of selected crops	Allocations from the Federal Government
2. Molecular Bio/Science Limited	Micropropagation of plantation crops and medicinal herbs	Privately funded
3. Tissue Culture Laboratory, Jigawa Research Institute	Production of improved planting materials of pineapple, banana, plantain, sugarcane, cactus and date-palm Agricultural extension	Allocations from the State Government
4. National Center for Genetic Resources and Biotechnology	Research, training and consultancy on plant genetic resources and their *in vitro* propagation/conservation	Allocations from the Federal Government
5. Tissue Culture Laboratory, Nigerian Institute for Oil Palm Research (NIFOR)	Production of improved planting materials and provision of extension and advisory services	Allocations from the Federal Government and donor agencies
6. Tissue Culture Laboratory, IITA	Pathogen elimination, micropropagation, conservation and distribution of cassava, yam, plantain and banana Training of national scientists	International donor agencies
7. Biotechnology Laboratory, NRCRI	Micropropagation of root and tuber crops Training and extension services	Allocations from the Federal Government and donor agencies
8. BAL, SHESTCO	Micropropagation and distribution of plantain, pineapple, banana, cassava, acacia *spp.*, etc. Development of protocols for genetic transformation of indigenous crop plants	Allocations from the Federal Government, funding from donor agencies
9. Biotech Unit, Forestry Research Institute of Nigeria (FRIN)	Development and release of improved vegetatively propagated cuttings of forest species of economic importance	Allocations from the Federal Government
10. Tissue Culture Laboratory, Nigerian Institute of Horticultural Research (NIHORT)	Micropropagation and distribution of improved planting materials	Allocations from the Federal Government, and funding from donor agencies
11. Biocrops Biotechnology Limited	Contract micropropagation of planting materials of plantation crops	Private funding
12. Tissue Culture Laboratory, Institute of Agricultural Research and Training (IAR&T)	Tissue culture of selected crops (fluted pumpkin, cassava, yam, etc.)	Allocations from the Federal Government

and production of pathogen-free planting materials. There are basically four functional tissue culture laboratories in Uganda (Table 4). The tissue culture products from the different laboratories are mainly used for research and technology dissemination purposes, except for Agro-Genetic Limited laboratory, that exclusively propagates for selling to farmers.

Agro-Genetic Limited produces 250 000 plantlets worth 250 million Uganda Shillings annually. The company has set up nurseries in seven districts and a farmer-based distribution network, to train farmers on their product, to provide a cheaper product and to ensure farmer participation in the product development. The plantlets are taken immediately after the laboratory and they are weaned and hardened by the farmers themselves. This system involves training farmers on hardening, weaning and good agricultural practices for the product. An estimated 370 000 tissue culture plants have been distributed into the farming system through Agro-Genetic Limited. Preliminary assessments indicate that the farmers prefer these tissue culture bananas to traditionally propagated unpared suckers. Comparative studies have never been performed, because micropropagation has been used for the introduction of new genetic lines, which have also required the adoption of some other technical improvements.

6. ZIMBABWE

Plant tissue culture was first introduced in the early 1970s at the Tobacco Research Board (TRB), where in particular the anther culture was used to speed up tobacco breeding. Over the years, the technology has spread to more than 80 public and private institutions (Table 5). The majority of the private operators focus on the commercial production of various crops, such as sweetpotato, potato, cassava, coffee, sugarcane and various horticultural and forestry species. Public institutions and NGOs are mainly involved in micropropagation research and development, as well as in providing extension services to the farming communities.

The pioneer private company to commercially exploit micropropagation in Zimbabwe was Tissue-Cult (Pvt) Ltd in the early 1980s. This company has managed to develop expertise in the commercial production and handling of high value crops including horticultural crops and flowers through tissue culture. The products are sold mainly to local private growers and nurseries. Another commercial tissue culture facility is Agribiotech (Pvt) Ltd. The company produces disease-free planting materials, mostly of sweetpotato and potato on contract and it is also supplying an international organization, the Swedish Cooperative Centre, with micropropagated sweetpotato planting material for distribution to multiplication nurseries, established in all the eight provinces

Table 4 - Tissue culture laboratories for agricultural research and development in Uganda

Type of laboratory	Institution	Crops handled – current and in past	Year started
Tissue culture	Makerere University Agricultural Research Institute	Banana climbing yams, coffee, cassava, muvule tree, coco yams, alfalfa, potato and sweetpotato, tree species	1991
Tissue culture, molecular biology and transformation	NARO – Kawanda Agricultural Research Institute	Banana, coffee, passion fruit, potato	1998
Tissue culture	NARO – Namulonge Agricultural Research Institute	Potato, sweetpotato, cassava	1992
Tissue culture	Private Sector – Agro-Genetic Limited	Banana, coffee, vanilla, aloe vera	2001
Tissue culture	IITA laboratory at NAARI	Banana	2002

of the country. The company also produces cassava cuttings, and these are mainly supplied to NGOs which are trying to promote the production and consumption of the crop in Zimbabwe.

The Horticultural Research Institute (HRI) of the Government's Agricultural Research and Extension (AREX) has a fairly well equipped tissue culture laboratory, in which they work mainly on sweetpotato and potato, in addition to strawberries and other important horticultural crops. The institute benefited in the mid to late 1990s from the activities of the Southern African Root Research Network (SARRNET), mainly working on sweetpotato and cassava (Kiambi *et al*., 2003). The Institute has also been part of a multistakeholder project funded by the Biotechnology Trust of Zimbabwe (BTZ) aimed at providing disease-free, true-to-type sweetpotato planting material to farmers in two pilot districts, Hwedza and Buhera, since 1997. Other institutions which participated in the programme included the Biotechnology Research Institute (BRI) of the Scientific and Industrial Research and Development Centre (SIRDC), the TRB, the HRI, Chiredzi Research Station, the Zimbabwe Farmers' Union (ZFU), the AREX, extension officers in the pilot districts, and the smallholder farmers in the two districts. Greenhouse, laboratory and field-trial capacities were established at the participating institutions under this programme. The

Table 5 - Tissue culture techniques employed by different institutions in Zimbabwe

Tissue Culture or propagation technique	Institutions involved	Products produced/ envisaged
Meristem culture	TRB, BRI, Tissue-Cult (Pvt) Ltd, UZ-Biochemistry, Bluedale Enterprises, HRI, National Botanic Garden	Disease-free planting material Plant regeneration
Anther culture	TRB	Breeding stock
Callus and suspension cultures	UZ-Crop Science, Agribiotech, TRB, Coffee Research Station	Induction of genetic variability/new cultivars
Induction of apical dominance	UZ-Crop Science, TRB, most fruit and ornamental tree enterprises	True-to-type planting material
Adventitious budding	Mazowe citrus, most flower nurseries, most agricultural colleges, Africa University	Rapid multiplication of species which are slow to propagate
Embryo rescue techniques	TRB, HRI, Agribiotech	Conservation of germplasm
Budding and grafting	HRI, most flower, fruit-tree and seedling nurseries, Forestry Company, The Wattle Company, Border Timbers, ARDA Estates, ICRAF	Clonal propagation of true-to-type cultivars

HRI and BTZ now also produce and sell disease-free sweetpotato planting material to smallholder farmers and the newly resettled farmers (BTZ, 2003), some farmers also sell vines from farmer managed nurseries that have been established by the programme in the two districts.

There is a high level of development, adoption and commercial utilization of micropropagation techniques in Zimbabwe and the reasons for this wide use vary from institution to institution. Sweetpotato is by far the largest crop on which tissue culture techniques are being applied, especially when the size of market for the products is taken into consideration. Potato, strawberry, cassava and banana are also important crops.

Case studies from Uganda and Zimbabwe

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1. RESEARCH RATIONALE AND APPROACH

Micropropagation is a widely utilized biotechnology in many developing countries and studies carried out in a number of countries have shown that adoption of this technology can lead to significant yield increases and promising rates of return at the programme level (Fuglie *et al.,* 1999; Qaim, 2000). However, economic evidence of positive micropropagation impact on farmers' income and welfare are less straightforward. For instance, Quaim (2000) suggests that farm size and technology costs might significantly affect the economic viability of micropropagation for household farmers.

Like any other technological innovation, the adoption of micropropagated plants on small- and medium-size farming household economies are also likely to be influenced by other market-related factors, such as credit availability, access to markets and transaction costs. Moreover, a host of non-market factors need to be considered (Ellis, 1993; Ellis, 2000; Dixon *et al.,* 2001). These include:

- availability of conventional planting materials;
- improved plantlets' resistance to local pathogens, weather, rainfall regime, etc.;
- farmer perceptions of risks associated with technological change;
- time lag to shift from initial on-farm small-scale micropropagation testing to full adoption;
- amount (and distribution among household members) of the additional work required to transport and transplant the seedlings and care of micro-propagation specimens;
- actual use (and distribution among household members) of micropropagation additional income (if any);
- acceptability of micropropagation crops for self-consumption (taste, appearance, etc.);
- value attached to indigenous cultivars;
- role and overall importance of micropropagation crops in farming household economy (e.g. commercialization versus self consumption);
- national and local policies towards micropropagation suitable crops;
- availability and effectiveness of micropropagation extension services;
- economic environment, including cooperatives, associations and contract farming opportunities, which can facilitate the commercialization of surpluses.

The socio-economic impact of micropropagated planting materials is thus best assessed through a holistic approach capable to capture interrelations among ecological, agricultural, economic, social, cultural and political factors affecting technology adoption and its outcomes. Sustainable livelihoods concepts (Chambers and Conway, 1991; DFID, 2001) are particularly useful in this connection. Livelihood analysis of the impact of micropropagated planting materials has a threefold focus on:

a) changes in the household capital assets endowment (e.g. improved planting materials, technical skills, extra income);
b) changes in the household capacity to cope with vulnerability factors (e.g. short supply in planting materials, plant disease, draught) and to take advantage of opportunities for change (enhanced crop commercialization, more remunerative prices, better access to markets, use of available extension services, etc.); and
c) changes in the household livelihood strategy as a whole.

The number of variables involved in such analysis and the complexity of their interrelationship make it difficult to document these changes through conventional evaluation designs, such as time-series (before/after) or quasi-experimental (adopters versus non-adopters) designs.

However, recent livelihoods research has shown that it is possible to gain a fair understanding of the modifications in rural household livelihoods associated with the introduction of new technologies and activities, by focusing on proxies, which can be collected through a relatively rapid and cheap combination of qualitative and quantitative methods (Ellis, 2000; Meinzen-Dick, 2003, Meinzen-Dick *et al.,* 2004).

Essential information needed to make sense of the consequences of micropropagated planting materials include:

a) background information on micropropagated-plantets production and commercialization in the study area before and in different points of micropropagation introduction, including a rough estimate of changes in yield and market value of the crop at stake subsequent to micropropagation technology introduction;
b) micropropagated plantlets adoption rates and trends over a four to five year period and actors affecting adoption or non-adoption according to farmers' perception. The adoption rate will be interpreted as a proxy indicator of farmers' trust and appreciation for micropropagation and, hence, of micropropagation relevance to farmers' needs;
c) narratives of farmers' perceptions of changes in their livelihoods related to micropropagated plantlets adoption. This information (to be elicited

though in-depth interviews) allows to record farmers' view about micropropagation outcomes.

Following the studies described in Chapter 2, three countries; Mali, Uganda and Zimbabwe where initially selected for the field study, because they had programmatically implemented the use of micropropagated plantlets in rural households over a considerable period of time and there had been no previous detailed micropropagation impact studies. However, due to logistical constraints the study was not completed in Mali.

2. RESEARCH SITES

The study was carried out (Figure 1) in Chigodora Ward (Hwedza District, Zimbabwe) and in Bamunanika Parish (Luwero district, Uganda). These two sites were selected for offering opportunities to investigate micropropagation impacts in two different socio-economic settings: a fast growing rural economy (Bamunanika Parish, Uganda) and a sluggish economic and institutional environment (Chigodora Ward, Zimbabwe). The two sites show staple food cropping, local markets for crop sales and several years of extension programmes managed by the state.

3. RESEARCH OBJECTIVES AND DATA COLLECTION METHODS

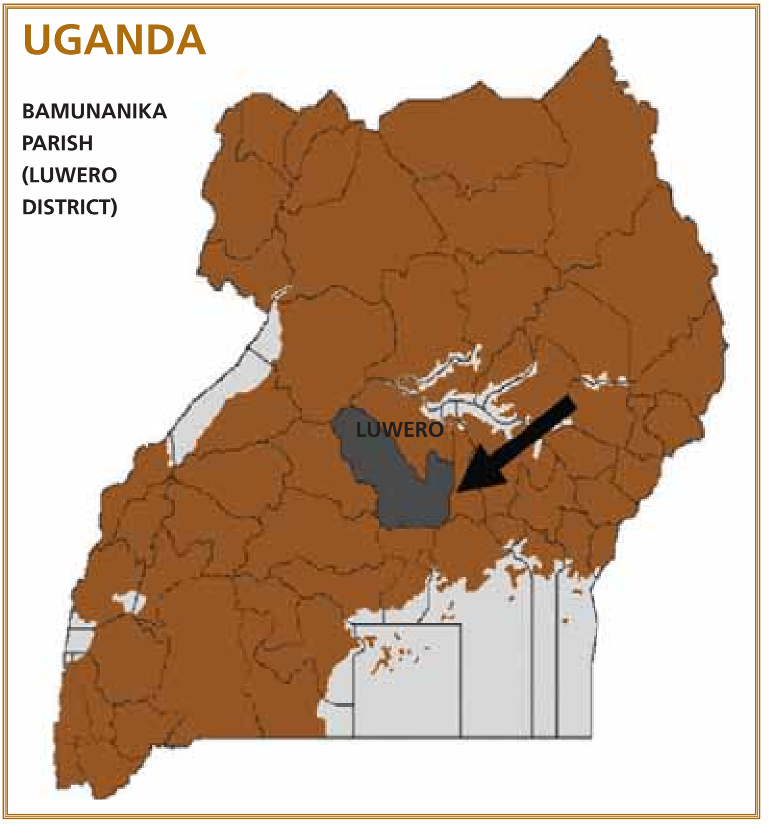
In light of the above, each field case study aims at:

a) describing the geographic, environmental, socio-economic, socio-cultural and institutional context and the basic infrastructure of the case study areas;
b) identifying the rationale and objectives of the micropropagation programme in the case-study area and describing its implementation strategy and its outcomes and its evolution through time;
c) assessing micropropagated planting materials adoption rate over time;
d) characterizing adopters and non-adopters in the light of selected household capital assets (e.g. farm size, labour force available, farmer education, cash availability, etc.) and vulnerability factors;
e) describing farmers' perceptions of livelihood changes related to micropropagated plantlets adoption.

Information related to objectives a) to c) was collected at the beginning of the study from a review of local statistics, project records and other secondary

Figure 1 - Research Areas

SWEETPOTATO MICROPROPAGATION PROJECT SITE



BANANA MICROPROPAGATION PROJECT SITE

sources. Informal interviews with key informants (programme managers, local government officers, wholesale traders, etc.) were also conducted. In both research sites, quantitative data on micropropagated plantlets adoption and adoption promoting factors was collected during a household survey with a sample of 210 households, grouped in 30 village clusters, randomly selected within each research site. The interviews were performed during the months of August through December 2006, by selected local experts, who were then trained for this purpose. The questionnaires, containing both closed and open questions have been translated into local languages and pre-tested, with some minor modifications introduced after the testing. The collected information was transferred into an EXCEL database and have been elaborated using STAT-Calc EPI-INFO. Ethnographic information on perceived impacts was then collected through in-depth open-ended interviews to farmers.

4. SWEETPOTATO PROJECT, ZIMBABWE

Zimbabwe is the latest country in Africa to achieve independence from the United Kingdom. Post-colonial legacy is still evident in rural areas where two main different agricultural systems co-exist: agribusiness/commercial farming (which since a few years ago, was mostly practiced by white Zimbabweans); and the indigenous, livelihoods-oriented, homestead farming. Agribusiness accounts for 14 percent of GDP and 45 percent of exports; it is thus a major drive of Zimbabwe's economy. On the other hand, homestead farming has primarily a microeconomic significance; it feeds most of the national population. These two systems are linked by wage labour: insufficient land and unfair terms of trade push millions of rural Zimbabweans every year to work seasonally or on a part-time basis for the agribusiness sector.

Since independence, the Government of Zimbabwe has tried to mitigate such dualism. Efforts were made to strengthen homestead farmers' capacity to contribute to national food security and improve their living standard. Land reform and reclamation, infrastructure development, creation of parastatal boards and cooperatives, new technologies improvement and extension have transformed the agrarian landscape. However, in the last twenty years, droughts, Acquired Immune Deficiency Syndrome (AIDS), land and ethnic conflicts, economic crisis and inadequate governance affected the Zimbabwean countryside. Due to the international controversy on the Government's land reform policy and the subsequent foreign currency and fuel shortages, the situation has been worsening in the last years. In September 2005, when this case study was conducted, the yearly inflation rate was about 300 percent, fuel was strictly rationed and in rural areas, supermarkets and stores were short of basic commodities (sugar, cooking oil, etc.).

Biotechnology has played an important role in the modernization of Zimbabwean agriculture. This case study focuses on the "Sweetpotato Project" carried out from 1996 to 2003, by the BTZ and AREX in Hwedza and Buhera Districts, in Mashonaland East and Manicaland Province, respectively. The objective of this project was to increase sweetpotato production, utilization and marketing in both districts, through the production, distribution and use of pathogen-free, high quality seed stocks of true-to-type varieties adapted and acceptable to the local communities (BTZ, 2003).

Other stakeholders involved in the implementation of the project included the TRB, the Horticulture Research Institute (HRI), the BRI of the SIRDC, the University of Zimbabwe (UZ) and farmers. This was in recognition of the fact that successful adoption of the technology by the farmers was to be supported by high quality planting materials, on-farm testing and participatory learning. Supply of planting materials to end-user farmers was based on multiplication of micropropagation-generated materials in local nurseries, usually located in areas with irrigation facilities and run by interested farmer groups. This mechanism was devised to facilitate supply of clean materials and at the same time, to create a new business for nursery groups. The nursery groups were expected to sell disease free sweetpotato vines to their neighbours. Their members were trained in production and maintenance of healthy sweetpotato planting materials, nursery and business management. Action-research exercises were conducted and a farmer-to-farmer extension process was initiated. On-farm performance of new sweetpotato varieties was monitored through participatory methods.

A final evaluation held with selected nursery groups in 2003 (Chinyemba, personal communication) identified logistic problems in the delivery of micropropagation-generated materials to the nurseries ("not enough, too late") and technical shortcomings in nursery management. Notwithstanding, since selling sweetpotato vines and tubers on the local market was found to be profitable, the participants ranked "sweetpotato vine and tuber production" first, out of a list of four comparable diversification crops including also sugarcane, tomato and "vegetables".

Widespread diffusion of the micropropagated cultivars was an additional benefit expected by the BTZ/AREX project. Indeed, sweetpotatoes were grown in Buhera and Hwedza districts well before the inception of the project: the 1996 baseline survey had found that 96 percent of the farmers in the two districts already grew sweetpotatoes; other findings were that there was a lack of good crop management, the crop was often pest infested, particularly with the potato weevil (*pongwe*), the growth was poor and yields were low due to virus infection. Furthermore, planting materials were in short supply and often not available on time to allow to plant at the beginning of the season. There were also limited varieties available. In addition, local people perceived sweetpotato as a secondary, kitchen-garden crop, grown for the sake of diet diversification, but with limited nutritional and economic significance for household livelihoods.

Based on these findings, the BTZ/AREX project was largely inspired by the hypothesis that there was an important agronomic and economic potential for sweetpotato in Buhera and Hwedza that micropropagation technology can tap. This case study assesses the validity of this hypothesis in the light of *ex post* field data, collected in Chigodora Ward (Hwedza District).

4.1. Research project site

Chigodora Ward is situated about 45 km from Hwedza Centre. It is made up of 54 villages, each one with 10 through 30 households. The total population of the ward is 7 800 people.

The ward is characterized by mountainous terrain with two major streams running through it; the vegetation is predominantly savannah woodland. The average annual rainfall is between 600 and 800 mm and the duration of the rainy season is between six and seven months. The soils are sandy to sandy loams.

Land tenure in Chigodora is based on the agrarian reform of the 1980s. Original allocation of land was 8 acres per household, but due to inheritance, the land holdings are now generally smaller than that. According to household survey findings, average land holding is actually about 5 acres. Landlessness is a major problem in the ward, as about 670 families are landless.

The ward has 1 950 farming households. Farming is largely for consumption, but all farmers commercialize some surpluses. According to survey findings, maize, groundnuts and sweetpotato are the three main crops grown for consumption and selling[10]. Almost all families raise chicken and goats and 70 percent own few cattle heads. The size of family cattle herds range between one and twenty-three animals, with an average value of five and a modal value of two. A minority of farmers grow cash crops such as soybean (20 percent), sunflower (8 percent) and cotton (3 percent). Some farming households are involved in sorghum contract farming with cooperative organizations, that provide seed and other inputs and purchase all the produce.

Education[11], agriculture and infrastructure development projects have been implemented in the last ten years in Chigodora. Many farmers are members

[10] Maize is a controlled commodity and has to be sold to the Grain Marketing Board (GMB), a parastatal.

[11] There are six primary schools in Chigodora Ward and approximately two-thirds of the households are settled within an hour's walk to the nearest primary school.

of the Zimbabwe Farmer's Union (ZFU). Over 90 percent for men and over 80 percent for women, literacy levels in the ward are high, as well as formal education: 47 percent of survey respondents completed primary school and 19 percent finished secondary school.

A major change in lifestyle has been taking place in Chigodora during the last 15 years, largely based on universal education, extension and development initiatives. A tangible indicator of such change is the proportion of households that can afford modern technologies, such as family latrines (61 percent), brick under tile houses (67 percent), solar panels (12 percent), radios (44 percent), and bicycles (22 percent)[12].

Nevertheless, due to limited farm size, the recurrent droughts and the ever-increasing costs of inputs and fuel, farming is not rewarding in Chigodora. According to survey data, half of farming households receive remittances from migrant relatives and 60 percent of households are involved in some kind of non-farm income generating activity. Moreover, due primarily to emigration and AIDS, Chigodora farming is increasingly "feminized": 25 percent of the households in Chigodora are woman headed, and the male/female ratio in the ward is 1:1.5.

4.2. Adoption of micropropagated sweetpotato varieties

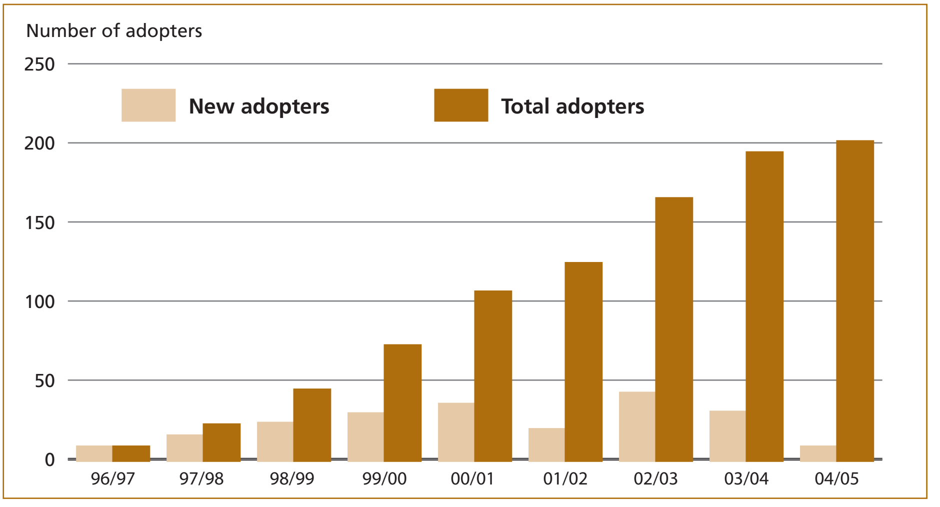
All surveyed households grow sweetpotato and 97 percent of them have adopted micropropagation generated sweetpotato varieties. As shown in Figure 2, the diffusion of these new planting materials is related chronologically to the BTZ/AREX project, which from 1997 to 2003 has operated a pilot nursery in the ward (Chigondo irrigation scheme).

Survey findings indicate that 44 percent of adopting farmers have received or bought initial planting materials from BTZ/AREX nursery. A woman from Munapi Village, who is still a member of the Chigondo nursery group, summarizes the story of these "official" adopters, as follows:

> *After the construction of the dam, which is about 2 km away from here, the authorities invited those who wanted to establish irrigation projects to apply. My extended Gwatidzo family indicated interest and an irrigation infrastructure was established in our field. When the sweetpotato project came, we were already irrigating some crops including the traditional varieties of sweetpotato. Our irrigation was selected as one of the satellite nurseries for the multiplication of the*

[12] It must be noted that only a very small affluent minority can afford piped water in the house (3 percent), car/trucks/tractors (4 percent), or TV (5 percent).

Figure 2 - Micropropagated sweetpotato varieties adopters: 1996 – 2004



new sweetpotato varieties to sell to farmers in the surrounding areas. Initially we were selling vines to farmers, but we later realized we could make more money by selling tubers as well. So we now sell both vines and tubers. After being selected as a satellite nursery, we were taken to Marondera to attend various courses, which included business and nursery management. We were also trained on how to prepare certain products from sweetpotatoes such as chips and bread. We are now passing the training to other farmers. Those who are interested come to us and ask about how to plant the new sweetpotato varieties. We pass on the knowledge that we gained through the training.

Informal exchanges among neighbours and relatives were indeed the primary source of information and supply of new sweetpotato varieties for the majority (56 percent) of surveyed adopters. Stories of these "informal" adopters are as follows:

I got the new sweetpotato planting materials from my daughter who lives in Buhera. She was not feeling well and when I visited she told me about these new sweetpotato varieties. I asked for some vines, which I planted for the first time in the 1998/1999 season. I was very happy with the new varieties and since then I have been replanting the ones I have (Woman, Kunongo Village).

I have planted sweetpotato for a long time. We had our own traditional varieties of sweetpotato, the likes of Tambararwa, but when I heard my neighbour talking about the new varieties that had been brought to Chigondo irrigation scheme, I decided to try them, he gave me some *vines and I tried them for the first time in 1997. He is the one who supplies me with planting materials every time I need them. He has a well with which he waters his garden. That is why he multiplies the planting materials, which he sells to those of us who do not have water for gardens (Woman, Manyere Village).*

I have been growing sweetpotato for a long time, but then I heard about these new varieties and just decided I would try them. I can't recall who first talked to me about this. You know when something begins to be talked about by almost everybody in the village, you cannot tell exactly who mentioned it to you first and where. It just becomes a popular topic among farmers (Masendeke Village head).

Only 11 percent of survey respondents declared having received technical assistance in new sweetpotato varieties cultivation from AREX or BTZ extension staff, and only 3-4 percent stated having received assistance from these institutions in input procurement and post-harvest marketing. Thus, adoption of micropropagation-generated sweetpotato varieties in Chigodora has been largely the result of a spontaneous process, mediated by kinship and neighbourliness, based on local knowledge, and economically contained within the local trade and reciprocity networks.

After the initial test, the large majority of adopters continued to plant micropropagation-generated sweetpotato varieties. Seventy percent of them did so for three years or more. Only 10 percent of farmers got yearly fresh and certified planting materials from the BTZ/AREX assisted nursery. The vast majority (90 percent) replanted cuttings of the previous year or bought low cost cuttings preserved in local gardens. A new adopter from Jena Village explains the logic of this behaviour:

I bought my planting materials for 2004-2005 from the pilot nursery, but for the next season I will replant the ones I have in my garden nursery. The planting material is getting expensive and I can't afford to continue buying from the nursery. I was told by the AREX extension worker that you can replant the same material that you get from the pilot nursery for up to three years before you destroy them and get new ones. However, there are people in the village who have been replanting for over three years and they say they do not see any difference.

In the long run, home multiplication might actually result in spreading diseased planting materials. However, home multiplication and exchanges are facilitating adaptation and diffusion of those cultivars better fitting the local preferences and conditions. The survey found a large consensus (73 percent of survey respondents) about the highest qualities of the Chirikadzi variety (Table

1) against traditional varieties (e.g. Tambararwa) and other micropropagation-generated sweetpotato varieties (e.g. Chigogo, Chizambia, Carrot)[13].

4.3. Costs and benefits of micropropagated sweetpotato varieties

Data provided by Chinyemba (personal communication) show that the cultivation of the new micropropagated varieties of sweetpotato was profitable, although the income improvement had been quite small, due to the increased cost of production (Table 2).

The majority of farmers concur that Chirikadzi gives higher yields, grows faster and produces more vines (to be used for multiplication) than the local varieties, but only half of them describe it as more drought-tolerant and remunerative. Sixty-five percent do not see any advantage in terms of pest resistance, input demand, and labour saving. Farmers' discourse about the benefits of the new sweetpotato varieties is well captured by the following statements:

> *Well, new sweetpotato varieties have a number of benefits. They are more resistant to pests, drought- tolerant, grow faster, produce big tubers, taste better and they give us more money. Generally, they demand fewer inputs than the ones we used to plant. In terms of labour demand, I do not see any difference. Also, we still apply the same amount of fertilizer as we used to do with the traditional varieties (Woman farmer, Kunonga Village).*

Table 1 - Opinions about Chirikadzi variety

Advantages	Respondents (percentage)
Higher yields	93
Better taste	86
Faster growth	71
Higher vine production	60
Higher market price	52
Tolerance to drought	48
Better appearance	35
Moderate input	29
Resistance to pests	24
Less labour	15

[13] Other favourite MP sweetpotato varieties include Chingova (18 percent) Chigogo (6 percent), and Chizambia (3 percent preferences).

Table 2 - Benefits and cost (USD) in Hwedza district

Item	Year	
	2001	2002
Revenue from tubers		381
Revenue from vines	152	73
Total revenue	152	454
Cash cost	63	212
Net profit	89	242
BCR	1.71	1.87

Source: Chinyemba (personal communication)

Compared with the old ones, the new varieties have higher yields, have a better selling price and taste better. They require hard work and inputs. I mean that as a farmer if you want to harvest more you should be prepared to put in more in terms of work and inputs. We have increased the area in which we plant sweetpotatoes since we started planting the new sweetpotato varieties. That is why we need to work harder and apply more inputs. The new varieties require (per se) less labour and input (Woman farmer, Kurwa Village).

The cultivation of new sweetpotato varieties is associated with an increase in the scale of production or vulnerability factors (inflation, ageing, disease), rather than to planting material properties:

For one to get these benefits one has to be prepared to work hard. Sometimes we plant twice a year, because of that it means more work and the sweetpotatoes then compete with other crops for labour and inputs (Woman, Jena Village).

You have to apply the right quantities of fertilizer for you to get a good crop. We also have a water pump here, which we use to irrigate sweetpotatoes. The price of fuel keeps going up every time. There is also the problem of frequent shortages of fuel. The cost and frequent unavailability of petrol and paraffin sometimes present problems to us. Many times, we are forced to buy the fuel from the black market, which is very expensive. There are also costs for servicing and repair of the pump (educated young man, Zifambi Village).

We are now old and we need assistance during planting and harvesting. So we hire labour, people to do maricho (piecework). We pay them either in cash or kind with sweetpotatoes. We still need inputs such as fertilizer and pesticides. We also hire draft power. We only have one cow so when it is time for planting we have to hire draft power. Those *are some of the costs that we have. But that applies to other crops as well. So these costs are not particular to sweetpotatoes only (old male farmer, Chitengo).*

The above-mentioned statements illustrate how demanding sweetpotato cultivation can be for some Chigodora farmers, in particular when practiced on a relatively big scale under irrigation and with income generation objectives. This explains why widespread adoption on new sweetpotato varieties has not been followed by a major increase of the land area allocated to this crop. According to survey findings, in the 2004/2005 season, the average (and modal size) of sweetpotato plots was about 0.5 acres, corresponding to 2 percent of the average (and modal) family land. Only eight farm households out of the 210 samples (4 percent) utilized one-third or more of the family land to grow sweetpotatoes.

The role of sweetpotato in household economy thus continues to be ancillary and subsidiary, as compared with that of "staple food" crops, such as maize or groundnuts and "true" cash crops such as soybeans. This is because sweetpotato is still largely perceived as a cheap substitute for other foods or as a complementary, though not essential, source of petty cash. Significantly enough, several informants refer to the use of "extra" cash got from sweetpotato selling to buy chemical inputs for staple food crops. In this case, sweetpotato income is apparently invested to subsidize maize and groundnuts. This practice can pose a dilemma: which is well captured by the following statement:

From the sale of sweetpotatoes we are able to improve our yields of other crops by buying inputs. Because of the money we get from selling sweetpotatoes we are tempted to increase the area in which we plant them. That obviously reduces the area in which we plant other staple crops. But, this can be looked at from both sides. If we set aside more land for planting sweetpotatoes, we can harvest more and then make more money, which we can use to buy the things we want, including inputs for the other crops. This means that we can have higher yields from smaller pieces of land (middle-aged woman farmer, from Chitida Village).

4.4. Livelihoods impacts of micropropagated sweetpotato varieties

Widespread and relatively rapid spontaneous adoption of micropropogation-generated sweetpotato varieties in Chigodora, suggest that local farmers perceived the comparative advantages and benefits of the new planting materials as overcoming their comparative disadvantages and costs. In-depth interview findings confirm this interpretation by highlighting different positive changes in household livelihoods that informants relate with adoption of new sweetpotato varieties:

> *We have been getting substantial income from the sale of sweetpotatoes and that is the income we have used to dig the well, buy construction material and pay labour for the construction of the house. We have also used some of the money we get from selling sweetpotatoes to buy inputs for other crops. This means that the planting of these new sweetpotato varieties has enhanced our farming as well as our standard of living as a household (woman, Kurwa Village).*

> *Thanks to sweetpotato selling, I bought a kitchen unit and goats. My husband died in 1999 and we used some of the money we got from the sale of sweetpotatoes to get him help from the hospital and from traditional doctors. Then, I would not have been able to send my children to school or feed them if it were not for these sweetpotatoes. My lifestyle has improved because of these sweetpotatoes (widow woman, Munapi Village).*

Livelihood improvements associated to the adoption of new sweetpotato varieties include diet diversification, food security, increased capacity of investing in other agricultural activities (inputs, etc.), purchasing equipment and animals, paying school fees, affording social ritual expenses (participation in funerals), and coping with vulnerability factors (drought, disease, inflation). Although these considerations are recurrent in the Chigodora farmers discourse on the new crop, their economic significance is likely to vary, according to the relative investment made by each sweetpotato adopting household.

Survey data indicate that 39 percent of households include sweetpotato among the three most important commercial crops, and 44 percent households mention it among the three most important food security crops. However, in both cases, an average household investment in sweetpotato cropping is modest: on average, in 2004-2005, adopters allocated 9 percent of the family land to this crop. The majority actually grew small sweetpotato gardens of 0.5 acres or less. Among the remaining 43 percent, half planted bigger gardens of 0.5-1 acre, allowing for significant surpluses, and half invested in scale production on 1 to 2 acre plots.

Statistically, households with more than the average of 5 acres of land, have the propensity to allocate the biggest plots to sweetpotato production and have surplus for selling. Families with large holdings (>5 acres) have 3.3 times the chances to grow a sweetpotato plot bigger than 0.5 acres than owners of smaller land holdings have ($p = 0.0008$). Owners of a sweetpotato plot bigger than the modal 0.5 acre plot have 2.7 times the chances of mentioning sweetpotato among the most important crop for selling than owners of smaller plots have (p = 0.004). However, no statistically significant association was found among relative importance of sweetpotato for income generation, on the one hand, and ownership of social status markers (brick under tile house, well, solar generator, bicycle, cattle) on the other hand. This suggests that this crop is not seen as a very attractive opportunity for investment by the more endowed households. Also, sweetpotato is rather a secondary, risk-spreading income generating activity.

> *According to several informants, lack of a profitable market outlet for sweetpotato surplus is the main factor preventing sweetpotato to become a major cropping enterprise. Most sweetpotato surplus are sold on-farm or in Hwedza market (educated young man from Nechiwari Village).*

Under this perspective, the limited interest for sweetpotato cropping by Chigodora farmers is apparently a sound economic choice: the longer storability, higher off-season and higher nutritional value of maize and groundnuts over sweetpotato are important. However, from a more "entrepreneurial" perspective, there might be scope to exploit more intensively the recognized potential of this crop by selling the harvest on urban markets (where demand for sweetpotatoes is high). There have been attempts to send local produce to Mbare Musika (market) in Harare, but transport and transaction costs proved unsustainable. Fuel crisis and inflation are obviously worsening this situation.

4.5. Conclusions

As mentioned, the BTZ-AREX Project was based on the hypothesis that micropropagation-generated varieties could help Buhera and Hwedza farmers in tapping agronomic and economic potential of sweetpotato. Findings from Chigodora Ward substantially validate this hypothesis. In this post-project scenario, 97 percent of the farmers has adopted micropropagated sweetpotatoes. The majority of farmers recognizes that these new varieties produce higher yields, and are more palatable and more profitable than local varieties. Before the project, sweetpotato was basically a garden crop, but now it has become one of the most important crops grown for household consumption and for selling by 44 and 39 percent of farmers, respectively.

New sweetpotato varieties proved attractive for worst-off and better-off farmers. The former found that small (0.5 acres or less) sweetpotato gardens can contribute to household food security and produce petty cash surplus. The latter planted sweetpotato on a quasi commercial or commercial scale (0.75–2 acres), with the primary aim of diversifying income sources and taking advantage of the drought-tolerance of these cultivars to buffer bad season impact on maize and groundnut yields.

Notwithstanding, both groups believe that there is no scope to expand sweetpotato production any further. For cultural and nutritional reasons, the tuber cannot replace maize and groundnuts in household food security and is too perishable for being sold off-season, when price is more profitable.

Marketing constraints appear as the main shortcoming of the BTZ-AREX project. Transaction costs are deemed too expensive for taking advantage of the urban high demand for this crop. Relevant assistance focused on commercialization of planting materials and hence, limited to nursery groups. Little attention was given to what would happen when sweetpotato production increased, as a result of the adoption of micropropagation-generated varieties.

A recently published economic study on performance of micropropagated sweet potatoes in Hwedza District (Mutandwa, 2008) confirms that the use of micropropagated planting materials enhanced crop yield and economic returns when compared with traditionally propagated planting materials.

Emphasis on technological aspects and on-farm research (as per the BTZ mandate) prevented the project from making full sense of the changes that adoption of new varieties was determining in farmers' livelihood strategies. Subsequently, the effect of increased yields on local market dynamics was not recognized and a sound alternative marketing strategy was not developed. These factors have restrained the potential socio-economic impact of the new technology.

5. BANANA PROJECT IN UGANDA

After two decades of civil and ethnic turmoil, in the 1990s Uganda achieved a relative socio-political stability and started a promising development process. Ethnic conflicts are still rampant in the northern areas of the country. However, central Uganda is almost completely pacified and civil society is committed to economic and social development. This trend is particularly evident in the Lugogo River Valley, where this case study was conducted. Small towns on the main road connecting Kampala to Luwero district are burgeoning market places where local agricultural products are exchanged for manufactured goods. Pick-ups and motorbike-taxis (pik-pik) are on hand to transport passengers and commodities to the countryside villages. Computers, internet and digital literacy services and mobile phones are also available under a variety of arrangements. Human Immunodeficiency Virus (HIV) and malaria awareness materials are displayed on buildings and along the main road. Other signboards make visible the presence of the development industry.

On average, during the last five years, Ugandan GDP has increased 6 percent per year. The inflation rate was 5 percent in 2005. In 2004, agriculture accounted for 32 percent of national GDP, with services and industry accounting for 47 and 21 percent, respectively. The tertiary sector is increasingly replacing agriculture as the primary source of wealth of the country. Diffusion of digital technology has played a major role in this process: between 2000 and 2005, the proportion of internet users has increased from two to five per 1 000, while fixed and mobile phone subscribers have increased threefold, from 11 to 33 per 1 000.

The Uganda National Banana Research Programme (UNBRP) was implemented in 2001-2003 by the National Agricultural Research Organization (NARO), in collaboration with the national extension service and several local NGOs. The project was funded by a Gatsby Foundation grant. It aimed at developing new high performing and pest-resistant banana cultivars, and supporting their diffusion among farmers, in order to improve yields, income and livelihoods. Laboratory studies and experimental research were carried out at NARO's Agricultural Research Institute in Kawanda (KARI). On-farm research and extension work took place in nine subcounties, belonging to five different districts of central Uganda. These were sites where, due to pests and inadequate management, banana production was in a state of severe decline.

Expected project outputs were as follows:

- categories of farmers, their characteristics and banana technology needs identified;
- new/superior micropropagation-generated banana cultivars and relevant crop intensification technologies available to farmers;
- at least six million improved micropropagated plantlets distributed to farmers[14];
- two thousand farmers and eleven extension agents trained on improved banana technologies;
- a farmer-to-farmer extension scheme for disseminating new cultivars established.

Participant farmers were identified with the support of local councils. Selection criteria included: (i) possession of land on which no banana had been grown for two years; (ii) ability to manage at least 50 improved mats; and (iii) leadership and willingness to train other farmers. A communication campaign was launched at the beginning of the project involving local NGOs

[14] Initially micropropagated planting materials were produced at the UNBRP experimental station at Kawanda Agricultural Research Institute (KARI), Kampala. However, in response to the rapid increase of planting material demand, the project purchased additional plantlets from Agro-genetic Technology (AGT) Ltd, a private tissue culture laboratory in Kampala.

and with the assistance of local media. Short courses were delivered at parish level, following which a core group of 80 farmers in each one of the eight project locations was recruited for on-farm testing. Each one of these farmers was supplied with 50-100 micropropagated plantlets of different cultivars. Extension agents provided technical support and regular monitoring to on-farm research participants. Inputs and services were provided free-of-charge, under the agreement that farmers would give micropropagation-generated cultivar suckers and training to interested neighbours. Farmer-to-farmer extension was further supported by the establishment of village-level banana groups and by social events, like fairs and competitions. As part of its follow-up, the project supplied these farmers with additional micropropagated planting materials or improved suckers.

Although the initial six million plantlets target was not achieved, the project allowed for a fast diffusion of the new cultivars among farmers. It is estimated that in Bamunanika subcounty the number of new cultivar mats has increased from the 8 000 supplied for on-farm testing in 1999 to about 70 000 in 2002. Project monitoring data suggest that success of new cultivars was primarily related to their high yielding property: the 2002 estimate for new varieties is 360 percent higher than the 1999 yield estimate for old varieties (8.7 versus 2.4 tonnes per hectare). Other project data on the economic performance of new cultivars are presented in Table 3. These data refer to the second year of operation of a new plantation. Cost estimates did not include initial investment (in clearing the land, planting bananas, etc.), nor the annual depreciation. Moreover, as in 2002, the market was still incipient, the price for these improved bananas was particularly low (about 60 percent of the indigenous banana market price). Considering these limitations, data indicate that benefit and cost of improved banana would have practically equalled, if a side market for suckers (largely subsidized by the project) had not have been developed. Including sucker income, the BCR of improved cultivars achieves 1.7.

The estimates of new cultivars' economic performance were not high and probably would not have motivated farmers to adopt the new technology once the side market for suckers was saturated. However, this contrasts sharply with the prevalent farm-gate banana trade that was observed during the field study in August 2005.

5.1. Research site profile

Bamunanika subcounty is located halfway between Kampala and Luwero (the District Capital). It comprises six parishes, inhabited by 25 000 people. The National Census classifies 88 percent of this population as "rural" and 80 percent as agricultural. However, virtually all Bamunanika subcounty households are involved in farming.

Table 3 - Yield, cost and economic benefits micropropagated banana in 2002

Micropropagated-banana yields tonnes per hectare	87
Production costs, including labour and input (USD per ha)	273
Average banana price per quintal (USD per ha)	3.2
Income from banana (USD per acre)	278
Income from suckers (USD per acre)	195
BCR (not including sucker income)	1.01
Total BCR (including sucker income)	1.73

Based on figures reported by Ssennyonga (2005)

The subcounty lies at an average altitude average of 1 100 m. Its climate features two rainy seasons (in March-June and September-November), with no clear cut-off points between the dry and rainy seasons. The prevalent farming systems can be described as banana- and tuber-based. Crops grown include cooking and beer bananas, cassava, sweetpotatoes, maize, groundnuts, beans, sorghum, soybeans, potatoes, fruits and vegetables. Except for coffee and indigenous beer banana (kayinja), there is no clear-cut separation between food and cash crops. Cattle, goats and sheep are kept on-farm for milk, meat and farmyard manure (the most widespread fertilizer), and as an investment for savings. Wage labour, trade and services are the most important non-farm activities in the subcounty. According to the survey, non-farm activities are practiced by 30 percent of farming households.

The monarch of Buganda (the central region of Uganda) legally owns most of the agricultural land in Bamunanika subcounty. According to customary law, the king's land is given in tenancy (kibanja) to households at a nominal rent (in general, less than one US Dollar per acre per year). The right to become a king's tenant is inherited along the father line. Thus 98 percent of tenants are men. According to survey findings, the average household farmland is about 5 acres, often split into two or more different plots. Kibanja plots can also be rented from other tenants. However, only 21 percent of farmers in the sample rented arable land in 2005.

According to Bagamba *et al*. (2001), the average annual income of farmers was at USD 304, ranging from USD 560 for better-off farmers to USD 250 for worst-off farmers. Although farming generated the highest proportion (54 percent) of household income, off-farm income (at 44 percent), was also very important, suggesting the existence of a dual rural economy, largely based on local off-farm wage-labour and temporary urban migration (Kampala is only 50 km away from Bamunanika subcounty).

According to survey findings, the average Bamunanika farming household is composed of 6.4 persons, with a dependency ratio (>15/<15) of 0.9. Twenty-five percent of interviewed households are women headed. Twenty-one percent receive remittances from a kin-person working in town or abroad[15]. Twenty-four percent of respondents are illiterate and 47 percent have not completed primary school education. Only 5 percent completed secondary education.

Banana plays multiple roles in the Bamunanika rural economy. As elsewhere among the Baganda, matoote, smashed cooking-banana porridge, is the every-day staple food. Surpluses of cooking bananas and dessert bananas are sold at the farm gate to traders that supply Kampala and other towns or on local market. Moreover, kayinja bananas are grown for brewing homonymous beer. Carried out at different scales, according to investment capacity, kayinja brewing is one of the most popular and widespread cottage industries in this area.

Since pre-colonial times, banana has been a well-established crop in Bamunanika. However, by the mid-nineties, it faced a severe decline, due to pests, soil exhaustion, inappropriate husbandry and meagre yields. The NARO project was conceived in 1998-1999 as a response to this situation[16]. Prior to securing international funds, NARO involved selected skilled and motivated farmers in field-testing of high yield, micropropogated-generated, cultivars.

5.2. Adoption of micropropagated banana varieties

On-farm research continued until 2001. In the subsequent phase (2002-2003), banana groups were created and a farmer-to-farmer extension process launched. "Initiators" were asked to assist in training their fellow farmers in improved husbandry. These were subsequently supplied with planting materials (suckers and tissue culture materials) from NARO. The story illustrates the way in which this second generation of adopters was engaged:

> *A friend came and informed me that cultivation of these new banana cultivars is of great benefit. This friend submitted my name (to NARO) and came to inform me that it was time for us to go for training). They trained us how to plant banana. The gentleman who was teaching us was a member of the first group that got these cultivars before we knew about the programme. We visited his plot and admired his banana. I asked him to give me some suckers and he submitted my name (to*

[15] It must be noted that local wage labour and remittances from migrated relatives were reported as a source of income by 30 and 20 percent of surveyed households, respectively.

[16] The local component of the Uganda National Banana Research Project (UNBRP) is known in Bamunanika Subcounty as "NARO project" (after the National Agricultural Research Organization logo which appears on vehicles, uniforms and materials).

NARO). After the training, I cleared the field with my son. NARO people came and measured it, after which they brought the planting material. We joined hands with NARO people to plant the 100 malanga (tissue culture) plantlets they gave us. Then they gave us instructions on how to look after them (woman farmer from Kiteme Village).

Adopters' identification process was rather selective. Only farmers with "viable" potential to successfully undertake the new enterprise (in terms of land availability, labour force, know-how and motivation) were selected as participants in village-level banana groups. Parallel to this organized form of farmer-to-farmer extension, some spontaneous adoption took place, based on kinship and neighbourhood networks and fed by the increased availability of locally grown new cultivar suckers.

Household survey findings suggest that in September-October 2005 out of 210 Bamunanika banana farmers[17], 76 (36 percent) were growing new (micropropagation-generated) cultivars. Virtually all these adopters also continued to grow old cultivars as the non-adopters did. The average size of adopter and non-adopter banana plot was respectively 0.7 and 0.5 acres, most of which was intercropped. On average, non-adopters have 206 old cultivar mats in this half-acre plot, whereas each adopter grew 300 banana mats on the plot, out of which 160 (53 percent) and 140 mats were new and indigenous cultivars respectively. Of the 76 adopters 65 percent were given inception planting material by the NARO project, while 34 percent obtained it from neighbours, relatives or friends (generally for free). Only 1 percent purchased improved planting materials from official or local sources. A clear correlation (Table 4) exists between the NARO project implementation and adoption rate timelines. Post-project (2004 and 2005) increment accounts only for the 11 percent of the total adopters. Such a small increment of post-project adoption reflects both saturation of the "viable" farmer groups and the impact of the 2004 banana bacterial wilt outbreak in Bamunanika that prevented farmers from further investing in both old and new banana plantations.

New cultivars were adopted by about a third of the surveyed farmers, on a rather partial basis and, in most cases, in connection with project delivered assistance and incentives (which were targeted on "viable" farmers). Findings on non-adoption shed light on this trend. Non-adopter households are a majority in the sample (64 percent). Main reasons for non-adoption (Table 5) include investment/cost factors, such as workload, land and input availability

[17] In this survey, a "banana farmer" is a farmer who had sold banana at least some bunches in the last year. Farmers growing a few mats for household consumption (i.e. growing banana on a "gardening" scale) were not considered eligible as respondents.

Table 4 - Micropropagated banana cultivars adoption (first planting) during NARO project

Year	New adopters (no.)	Total adopters (no.)
2000 (Project preparation)	18	18
2001 (Project year 1)	19	37
2002 (Project year 2)	17	54
2003 (Project year 3)	14	68
2004 (End of project year 1)	7	75
2005 (End of project year 2)	1	76

Table 5 - Reasons for non-adopting micropropagation-generated banana cultivars (no = 134 non-adopters)

Reason for non-adoption	no.	percentage*
Too demanding (in terms of workload, land, inputs, etc.)	60	45
Too expensive	58	43
Not interested	35	26
Mistrust towards the planting material	32	24
No chance to get planting materials	19	14
Not informed	4	3

* Multiple answer question

and financial cost (45 percent of respondents) and disinterest and mistrust (25 percent); shortage of planting material (14 percent) and lack of information (3 percent) play a secondary role.

In most cases, people did not adopt the new cultivars because of lack of the required assets (land, labour, cash). This fact reflects the project choice to target primarily "viable farmers" and is supported by strong statistical associations between micropropagated cultivar adoption and socio-economic variables, such as land hold size, literacy, bi-parental family and cash availability. In particular, large farmers owning five acres of land or more[18] have a threefold higher likelihood to adopt new banana cultivars than those owning less than five acres (odd ratio 2.98; p. 0002). Households where both parents are literate have more than four times the chance of being adopters than those in which one of the two parents (or both) are illiterate (odd ratio 4.31; p. 01). When compared with women headed households, bi-parental (men headed) households have the

[18] In Uganda, 0.5 acres is the threshold according to which farmers are classified as small- and medium-size farmers.

double of chances to engage in new cultivar production (odd ratio 2.1; p 0.05). Finally yet importantly, adoption is two times higher (odd ratio 2; p. 0.05) among households receiving remittances from a relative in town or abroad, than among those not relying on such additional cash input.

Interviewed farmers suggest that mistrust and lack of interest for the new technology and husbandry practices at project inception had influenced adoption choices, although they were not conclusive factors.

These tiny plantlets initially gave a poor impression. Some of our neighbours laughed and explicitly told us that they did not want this stuff near their homes. They feared they would harm their indigenous banana crop. Some just did not like them at all. They thought they were harmful. No one believed that they could sprout into healthy plants. However, within three months they sprouted with great vigour, thrived with amazing strength and fruited big bunches. Then the people turned around to not only admire them but also place their sucker requests. These were the very people who had condemned them in the first place (man farmer from Buwanuka Village).

5.3. Cost-benefit of micropropagated banana varieties

Farmers' perception of benefits and costs associated to the improved micropropagated banana varieties (Table 6) help to further understand the dynamics of adoption and non-adoption (as well as the only partial changeover to new cultivars among adopters).

The majority of adopters feel that the main comparative advantages of new cultivars consist of higher yield, faster growth and more palatable fruit.

The most important benefit of new cultivars is yield. Indigenous bunches weighs no more than 20 or 25 kg, but I obtained 75 kg from one bunch of Mpologoma. I sought the assistance of another person to lift and load it onto the bicycle (male farmer, Mityebiri Village, Mpologoma Parish).

Once you plant malanga, it grows very fast. Its bunch is very large. I brewed beer from it. One bunch from the Phia 25 cultivar, which I grow, yields one full jerry can of nectar, and more. One bunch can weigh 100 kg or more. The heaviest bunch harvested in my farm weighed 126 kg (Banana beer brewer, Kanjuki Village, Kibanyi Parish).

The traditional cultivars cannot compete with the new cultivars. In particular, malanga bunches are very big. I have also discovered that the new cultivars grow much faster than the traditional ones and take

Table 6 - Advantages of the best micropropagated as compared with indigenous cultivars (no. 76 adopters)

Perceived advantage	No.	Percentage
Higher yields	60	78
Faster plant growth	45	60
More palatable fruit	41	54
Rapid multiplication	16	21
Resistance to pest	14	18
Demanding less inputs	3	4
Demanding less work	2	1

Note: multiple answer question

a shorter time to fruiting (male farmer, Buwanuka Village, Kiteme Parish).

Most respondents recognize that the new cultivars are more demanding, in terms of inputs and labour requirements, than the old ones, because of the changes in land and crop husbandry recommended as indispensable accompanying measures for the successful development of new cultivars.

There is a big difference in the way we deal with the indigenous cultivars and the new ones. We would plant the old cultivars and neglect them thereafter. But, we were told that it is better to plant a few mats of the new cultivars, maintain them well and get high yields. Thus, we planted only the new cultivars which we are able to nurse appropriately, rather than plant many but get little yield. This is a departure from our own indigenous way of growing bananas (a male farmer from Kanjuki Village, Kibanyi Parish).

The improved cultivars have one difficulty, namely, they require great care. If you do not put in a lot of effort, you will fail. Our Ugandan cultivars recover quickly even after leaving them for long spells with over grown weeds. They recover quickly and rarely die out. But the improved cultivars require intensive care, like a child (male farmer, Mpanga Village).

The new cultivars require much more labour than the old ones. We did not provide nutrients to the old banana type: after planting, we weeded them and only carried out a few sanitation activities. Now we apply a lot of labour to the new cultivars. We also buy farmyard manure and apply fertilizers (male farmer, Kyalira Village).

During the dry season, new cultivars have to be protected from drought. In the midst of every four mats, you dig a hole to store manure so that

> *the four mats feed on it for two years. You can also dig trenches to capture water run off, but you must be careful not to dig too deep lest you cut the banana roots (male farmer, Kanjuki Village).*

5.4. Livelihoods impact of micropropagated banana varieties

In the Baganda culture, banana matoote porridge and kayinja beer are daily foods. They provide a significant share of caloric intake and are symbolically associated to physical vigour, good health and household food safety and welfare. However, in our sample, banana ranks third (50 percent)[19], after sweetpotato (88 percent) and cassava (61 percent), among the three most important food crops grown on-farm. This reflects the decline of banana harvests in the 1990s, due to pests, reduced land availability per household, soil exhaustion and inappropriate crop husbandry. Since then, many households began purchasing banana for home consumption from those neighbours able to produce marketable surpluses or from a few relatively large producers existing in the area.

In light of the above it is not surprising that when asked about the change brought in by the new cultivars, virtually all interviewed informants emphasized the restoration of household banana self-sufficiency.

> *We now feed on banana from our garden unlike in the past when you had to go and buy it from the market. Now you harvest and prepare a meal for them and if we reach harvest time, you even sell some and buy sugar and salt. The (new) banana cultivars have come to our rescue (male farmer, Besweri Kawooya).*

> *The first change (I noticed since I have adopted new cultivars) is in food supply. I feed on those bananas. Even as we are talking now, I am preparing a meal of bananas. This is an important change in my life and home (woman farmer, Kiteme Village, Kiteme Parish).*

> *I got food for household consumption. Although these are not our banana cultivars, you do not wish you had cassava. The children cook them as they wish. Sometimes I myself request my wife to prepare it for our meal. We eat it with great appetite. It has no fault because it is good for our bodies. I used to be frightened by the thought that we had run out of food. I would fear that all was lost. I would buy one bag of maize flour but it would not take us through the month. All that is now history, because food is readily available. The effort I put into growing these new cultivars in addition to sweetpotatoes and cassava, gave me*

[19] No significant difference was found in this connection between adopter and non-adopters.

a big relief from worrying about having to buy food (male farmer Kito Village, Sekamuli Parish).

Following the "food self-sufficiency" special value, most adopters end-up recognizing that impact of banana cultivars on household livelihoods was largely due to the enhanced cash flow cash generated by selling surplus bunches and (to a lesser extent) new suckers[20].

The first lot of bunches was for home consumption, but as the number grew bigger, we started to sell some. The money was a benefit, supporting us and taking away poverty (male farmer from Mpanga Village).

The money earned through the sale of bananas produced by micropropagated plantlets is largely used to purchase other food (e.g. sugar, salt, tea, meat, etc.), pay for health care, invest in children's education, or improve house furniture and facilities. Several respondents associate the social capital and personal development benefit to new cultivars that originated from their participation in the NARO-assisted farmers groups.

We formed farmers' groups. In this village we have such a group known as Tusitukire wamu ("Let's progress together") Banana Group. If a member has a function such as a funeral, we collect bananas and give them to him or her. If it is a wedding, we do likewise. This is something we were unable to do in the past. You also get different kinds of friends in the village who admire your good fortune. Group membership has been of benefit to us. If you are farming on a bad piece of land, you can ask members to assist you. There are female members who are incapacitated by illness. These ask group members for help. Cooperation is not restricted to agriculture; it extends to every activity (female farmer, Kitobola Village, Kiteme Parish).

Evidence was also collected that micropropagated cultivars have triggered empowerment of some adopter woman farmers.

I am not as I used to be. NARO introduced me to training courses. I was as raw as one can imagine. I knew nothing. But after they educated me, I gradually became enlightened and made improvements in the home.

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[20] According to survey findings the proportion of adopters including banana among the three most important crops for selling (88 percent) is double than the corresponding non-adopter proportion (44 percent). A significant statistical association (odd ratio 2.1; p. 04) exists between these two variables. On the contrary there is no statistically significant difference among the two groups in connection with growing banana as a food crop.

I acquired things I did not have before. I had no livestock but, using money from the sale of banana, I bought and reared pigs. I bought food and other household items as well as spent money to support my children at school. Another important change is that I have expanded my banana husbandry skills. I have also trained my neighbours and given them suckers so that they too were able to grow the new cultivars (female farmer, Kiribirizi Village, Kiribirizi Parish).

As I have told you, I started selling bananas and suckers. The money came very handy, enabling me to pay for the education of my children. We also had more food. I ceased asking my husband for money to support the children. In the lean season when I had no bananas for selling, I sold suckers. My capacity to generate income increased. The windows in this house only had frames but no glass. I bought the materials and asked the builder to fix these new windows. My husband was very surprised and asked: "Hey, my dear, what is this?" I replied, "My dear, it is (the benefit of) my own banana business." (female farmer, Kitobolo Village, Kiteme Parish).

The above-mentioned evidence suggests that according to farmers' perception, the micropropagated new cultivars, improved husbandry and farmer groups had a significant impact on livelihoods, in terms of food security, income, health, education, access to commodities and amenities, social capital, personal development and gender relationships. According to respondents, the most striking difference between the end of the project and the current situation is the ever-increasing demand for the new cultivars on both the local and regional markets.

At first, people who came to buy did not like the new cultivars because they had never seen them. You would plea with the buyer pointing out that it was a very big bunch for which he should pay 3 000 Shillings (USD 1.7)[21] He would respond that had it been one of the traditional cooking type, he would have paid 3 000 Shillings for it. He would then pay just 1 000 Shillings for it. You would feel cheated to sell your bunch at such a throw away price. However, gradually, people and traders discovered the real value of these cultivars and eventually came to pay the 3 000 Shillings. Nowadays whenever you have bananas, you are able to sell them at the right price. There is no lack of market. You can sell the bananas whenever they are ready (male farmer from Kiribizi Village).

[21] Uganda Shilling/US Dollar exchange rate is calculated according to the official September 2005 Uganda Revenue Authority rate of 1.810 Uganda Shillings per 1 US Dollar www.ugarevenue.com, visited on 12 January 2006).

> *At first, people were sceptical about these bananas, thinking they were different from our local cultivars. Then, they discovered that they were very palatable and soft. Traders began to come to our plots with requests to buy Mpologoma, Atwalira and other cultivars. The number of traders looking for these bananas is increasing. They are here everyday because it has become an important food elsewhere, not just here. When I went to Entebbe, I found people loading new cultivar bananas on pick-ups at the border between Uganda and Gulu districts. These people had bought the bananas from our place (farmer from Kangulumira Village).*

Thanks to the market expansion, the new cultivar selling price has increased. Though important variations may exist among varieties, seasons and terms of trades, selling prices mentioned by several informants suggest that current benefit per acre for new cultivar bunches would be at USD 358 (instead of USD 278), and BCR would be at 1.31 (instead of 1.01). If, under current post-project conditions, additional income from suckers is estimated at 20 percent of bunch benefit, total benefit per acre per year increases to USD 430, with a total estimated BCR of 1.57.

Several households were actually able to capitalize and reinvest their increased earnings in livelihood assets such as improved houses, school fees, or cattle. Moreover, 64 farmers (84 percent of total adopters) have extended the area with micropropagated bananas. This suggests that in the majority of cases some capitalization and re-investment process followed the initial adoption. The significance of such a process is well captured by the more than two-fold increase of the average number of plants owned by adopters of micropropagated plantlets, from 68 at inception time to 160 when this survey was conducted.

Notwithstanding, as mentioned, most adopters have not completely replaced the old varieties and the plots for micropropagated varieties are generally small (Table 7).

Several reasons for such apparent contradictions can be found: the first year investment costs, the increased workload, the costs related to pest control measures, and first of all, the general prudential attitude of small farmers regarding risk management.

Table 7 - Size distribution of micropropagated banana plots

Size (acres)	Percentage
< 0.30	22
0.30	37
0.31 – 0,60	30
> 0,60	11

Indeed, although nutritionally and culturally important, banana is not the only important food and cash crop in the household economy (Table 8). As survey

Table 8 - Most important crops grown for food and for market (percentage of the 76 adopters)

Crop	Growers for home consumption	Growers for the market
Banana	55	80
Sweetpotatoes	91	29
Cassava	91	71
Maize	63	44
Beans	86	34
Coffee	n.a.	64
Rice	n.a.	26

data indicate, banana plots account for only 10-20 percent of the average available land, with all the other food and cash crops accounting for the remaining 80-90 percent of land.

In this perspective, the adoption of new micropropagated cultivars appears to be part of a strategy that seeks to ensure sustainability and resilience to household livelihoods, by distributing the risk over a more diversified portfolio of on-farm and off-farm activities.

5.5. Conclusions

In the late 1990s, the NARO's UNBRP sought to address the decline of cooking banana production in Banunanika subcounty by introducing, among household farmers, micropropagation-generated, high yielding cultivars, and other necessary husbandry techniques. Notwithstanding the use of a participatory farmer-to-farmer extension approach, the project only reached about one-third of potential adopters, most of which belong to the better-off stratum of the local farming population. Adoption was facilitated by high yields and spontaneous development of a market segment for the more palatable fruits of the new cultivars. In addition, despite the increase in supply of the new cultivar fruits, their farm-gate prices have increased. However, relatively high capital and recurrent costs of these new cultivars have prevented a less endowed household from participating in the new enterprise altogether or have limited their investment in small plots of about 0.5 acres. The risk associated with banana production in the area was further increased by the outbreak of the banana wilt disease in 2004, which hampered the expansion of the small plantations. Subsequently, notwithstanding the favourable BCR and an expanding market, the production of new micropropagated banana cultivars is integrated into the broader on-farm and off-farm livelihoods diversification strategy.

Cash generated by the new cultivars is used for purchasing additional food and household amenities and/or invested in education and health care.

A minority of farmers have been able to re-invest new cultivar money in cattle or in extending their plantation above 0.5 acres. Evidence also exists that participation in the project-promoted farmer groups has had positive effects on social capital and personal development, also triggering a women empowerment process.

However, the majority of farmers in the subcounty were excluded from this innovation, by lack of the required asset (namely labour, cash and education). This trend was worsened by the end of project operations, NARO's cost recovery policy (after which micropropagated plantlets started to be sold at a price that farmers perceive as very expensive) and the aforementioned banana wilt outbreak.

6. OVERALL CONCLUSIONS

This study was developed under the working hypothesis that the actual impact of micropropagated planting materials on farming households is the outcome of a mediation between their immediate agronomic and microeconomic benefits, and the more comprehensive requirements and adjustments in household livelihoods that adoption entails.

Immediate benefits (such as increased yields) are of course necessary conditions for determining a positive impact of micropropagation-generated cultivars on farming households, but systemic modifications in livelihoods strategy are also necessary to materialize these benefits, in terms of improved food supply or increased income. These contemporary changes imply "hidden" opportunity costs and risk management concerns that often are not apparent to scientists or to project designers.

Local environmental, economic, socio-political and cultural factors are also likely to influence adoption behaviour and subsequent impact of micropropagation technologies on livelihood strategies.

A comparative analysis of what has been seen in the two case studies can consequently facilitate the elaboration of some more general comments and guidelines for future actions.

As suggested in Table 9, in Chigodora-Zimbabwe, the marginal role of sweetpotatoes in the farming system and culture, and the lack of market opportunities, prevented micropropagated sweetpotato to become a major crop. On the contrary, in Bamunanika-Uganda the adopters were supported in their decision of engaging in micropropagated banana production by the strong dietary and symbolic value attributed to banana by Baganda culture,

Table 9 - Local context compared

Aspects	Chigodora (Zimbabwe)	Bamunanika (Uganda)
Agro-ecology	Low productivity, semi-arid savannah with limited opportunities for irrigation development	High productivity, tropical forest environment with high rainfall and two rainy seasons
Prevailing farming system	Animal powered maize, groundnut and pulse farming. Soya as the major cash crop	Machete and hoe plantain, tuber and roots farming. Coffee as the major cash crop
Role of crop in diet and culture	Sweetpotato is a secondary gardening, diet diversification, crop. As compared with "staple food" crops such as maize or groundnuts, its role in household food security is ancillary and subsidiary. Sweetpotato is perceived as a "cheap" substitute for other foods	*Matoote* porridge and *kayinja beer* are every-day foods. They provide a significant share of caloric intake and are symbolically associated to physical vigour, good health and household food safety and welfare
Local market	Poorly developed and largely controlled by parastatals. Largely unlinked with the national market	Burgeoning micro and small, on-farm and off-farm enterprises, linked by private intermediaries with national market
Macro-economic environment	Market regulation policies, with a high inflation, increasingly depressed	Free market development policies with limited inflation and sustained growth
Social environment	Envisaging a major crisis, with increasing poverty and HIV incidence institutions confronted with stability problems	Recovering from a major political and social crisis, with decreasing poverty and HIV incidence and stable institutions

and by the favourable economic and sociopolitical situation. In particular, the existence of a farm-gate trade network linking Bamunanika countryside with the urban markets has ensured a safe outlet to banana surpluses and generated attractive profits. However, following losses from banana wilt disease outbreaks, opportunity costs and risks were re-assessed by farmers and the availability of subsidized planting materials and commercialization started to be mentioned as a necessary condition for continuing the new enterprise.

This suggests that local context trends and shocks contribute significantly to determine the adoption (and consequent impact) of impact of micropropagated varieties and should be carefully considered in project design.

Another finding is that in both cases the projects have been implemented, since their very beginning, with a very traditional trickle–down approach, favouring the better-off farmers (Table 10). In both Uganda and Zimbabwe, the innovators were selected by using variables such as land and water availability,

Table 10 - Project intervention compared

	Chigodora (Zimbabwe)	Bamunanika (Uganda)
Programme objective	Increasing sweetpotato production, utilization and marketing through distribution and use of micropropagated varieties adapted and acceptable to the local communities	Supporting the diffusion of micropropagated banana cultivars among farmers, in order to improve yields, income and livelihoods
Target group	Farmers with land in irrigated areas, willing to establish a cooperative vine production nursery	Better-off farmers, with implementation capacity and willingness to participate in on-farm research
Extension strategy	Participatory extension, evolving into an informal farmer-to-farmer extension system	Participatory extension evolving into a formal farmer-to-farmer extension system
Planting material provision	Vines from micropropagated plants grown off-site (several cultivars) Eleven percent (11%) of interviewed adopters got planting materials from the project	Micropropagated plantlets grown off-site and suckers of local micropropagation generated plants (several cultivars) Sixty-five percent (65%) of interviewed adopters got planting materials from the project
Services provided	Assistance in nursery development and nursery training, supply of planting materials, vines and tubers processing training, group management course	Crop husbandry training, on-farm technical assistance, supply of planting materials, group management courses, marketing events (fairs, exhibitions, etc.)
Subsidies delivered	In-kind (planting materials, fertilizers, nursery equipment)	In-kind (planting materials), plus purchase of locally reproduced suckers

farm size, education and willingness to cooperate, and most of them have even received free propagation materials and free access to advice. In some cases, the innovators have even benefited with marketing initiatives.

Comparing the logic of adoption and non-adoption followed in Chigodora (Zimbabwe) and Bamunanika (Uganda) and the way in which it was affected by project agencies and context factors, helps validating the initial hypothesis.

Adoption logics followed by Chigodora and Bamunanika farmers are compared in Table 11. In both locations, adoption of micropropagation-generated planting materials has been associated to significant changes in livelihoods outcomes and endowments. These changes are substantially similar in Chigodora and Bamunanika (food security, income, education health, social capital).

Table 11 - Adoption logic compared

Impact Indicator	Chigodora (Zimbabwe)	Bamunanika (Uganda)
Changes in livelihood outcomes and endowments and associated with the adoption of micropropagation generated planting materials	Diet diversification and food security Increased capacity to buy commodities equipment and animals Increased capacity to afford school fees and ritual expenses	Food security and improved nutritional status Increased capacity to buy commodities and amenities Increased capacity to afford health service and education fees Enhanced social capital personal development and gender relationships
Adoption rate	Adoption rate at 96% of sweetpotato growers in the ward; no statistically significant difference between better-off and worst-off farmers	Adoption rate at 36% of banana growers in the subcounty; better-off households are 58% of adopters.
Relative importance of micropropagation-generated cultivars in household economy (post-project)	Thirty-nine percent (39%) of adopter households include sweetpotato among the three most important commercial crops Forty-four percent (44%) of households mention it among the three most important food security crops	Eighty-eight percent (88%) of adopter households include banana among the three most important crops grown for selling Fifty-five percent (55%) mention it among the three most important crops grown for food
Land allocated by adopters for growing micropropogated-generated plants (2004-2005)	Average family landhold is 5 acres and size of sweetpotato gardens is 0.5 acres Twelve percent (12%) of the family land allocated to this crop	Average family landhold is 5 acres and average size of new cultivar plantation is 0.4 acres Eight percent (8%) of family land allocated to this crop
Labour and input	Moderate recurrent (annual) cost	High capital (first year) investment and recurrent (annual) cost

Due to a very high adoption rate (96 percent), in Chigodora these changes have benefited the majority of households, with no significant difference among better-off and worst-off households. On the contrary, the 36 percent of Bamunanika adopters are concentrated among better endowed and more affluent households. Moreover, land allocation to the new crop is proportionally higher in Chigodora, adoption-related labour and input costs are much higher in Bamunanika. In addition, the economic significance of adoption (as illustrated by the proportion of adopters that include the new crop among the three most important crops for food and income) is higher in Bamunanika than in Chigodora.

These findings suggest that the logic of adoption choice has been different in the two locations (Table 11). In Chigodora, the adoption of micropropagated sweetpotato is primarily aimed at enhancing livelihood resilience against vulnerability factors (such as drought, disease and inflation) and, in particular, at buffering drought-related maize-failure risk. Notwithstanding, Chigodora farmers stress that the tuber cannot replace maize and groundnuts in the household diet and that surplus selling is not remunerative. Hence, adopters see little scope in expanding further sweetpotato cultivation. On the contrary, in Bamunanika, micropropagated bananas are adopted primarily to generate income. Yet, due to high investment requirements and high pest-related risk, this enterprise is perceived as viable only on a small-scale (unless further subsidies and services are made available).

Summarizing, Chigodora sweetpotato is a low risk investment, prioritizing safety over profit; whereas Bamunanika bananas are a demanding and high risk investment, which may allow for major profit, but cannot be undertaken on a bigger scale without securing risk limitation measures. Thus, even though the adoption patterns are different in Chigodora and Bamunanika, the economic logic through which the new crops are accommodated into farming household livelihood strategy is substantially similar: adoption decision is made by balancing direct costs and benefits against opportunity costs and risks.

Based on the above-mentioned conclusion, adoption of micropropagated varieties seems to be depending on the capacity of the promoting agency to motivate farmers to accept opportunity costs and risks. In both cases, promotion activities indirectly addressed these issues by focusing on "viable" farmers, i.e. those with higher capacity to bear opportunity costs and take risks (irrigation scheme settlers in Zimbabwe and "better-off" and skilled growers in Uganda). In both cases, planting materials, training and technical support were provided as an incentive to motivate eligible innovators. Indirect subsidies were also delivered in Uganda, by purchasing "second generation" suckers from innovators. However, no measures were taken to assist these first adopters in affording initial investment costs (e.g. soft credit), nor in tackling crop-failure risk (e.g. crop insurance).

A participatory extension process was launched in Bamunanika to further expand adoption (and enhance social and human capital). But this allowed only a modest increase of the adoption rate. On the contrary, in Chigodora, where project extension activities continue to focus on nursery groups, the large majority of current adopters were reached through an informal farmer-to-farmer extension process, mediated by local neighbourhood and kinship networks.

Hence, in Chigodora, micropropagated sweetpotato varieties spontaneously made their way into local livelihoods, with little or no project support. This was because new sweetpotato varieties proved able to generate immediate benefits (yield, drought resistance, taste, etc.) without requiring any significant increase in labour and inputs, nor entailing any additional risk. On the other hand, in Bamunanika, adoption of micropropagated banana demanded a three-fold increase of labour and inputs compared with conventional banana husbandry. Moreover, the banana-wilt outbreak showed that the labour intensive new varieties are as vulnerable to pests and diseases as the low-labour indigenous ones. These factors prevented spontaneous adoption by less endowed households and significantly limited the replacement of old cultivar plantations among adopters.

These findings suggests that effects of project-led training and technical support services on adoption trends are negligible, if compared with the pivotal role of the opportunity costs and risks associated with the innovation. It also highlights that material incentives (such as subsidized planting materials and fertilizers) and development services (such as marketing, transport and crop insurance) are a needed complement to technical extension and training.

Last but not least, the need for greater attention towards the smaller and less endowed families must be stressed once again. Too many individuals and households risk to be left behind and to be further marginalized by development projects which suppose technologies to be scale neutral. All aspects of the innovation(s) should be carefully analysed, because even a seemingly small change is normally linked with other technical modifications (innovation packages). Social impact assessment during project formulation, should pay more attention to the different strata of the population, which only apparently look very homogeneous and appropriate measures should be tailor-made to reduce the number of laggards to the minimum.

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This publication aims to contribute to the knowledge of the socio-economic impacts of the adoption of non-transgenic biotechnologies (viz. biotechnologies other than genetic engineering). The first paper discusses some approaches used in impact assessment of innovations and presents a general overview of the literature about the impacts of non-transgenic biotechnologies. The second paper presents some studies on the extent of micropropagation application in Gabon, Mali, Nigeria, Uganda and Zimbabwe. The third paper reports the findings of two field studies carried out with an anthropological approach in Uganda and Zimbabwe, aimed at better understanding the process of adoption of micropropagated planting materials and its impacts on livelihoods.

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