Assessing the Impact of Banana Biotechnology in Kenya

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Foreword

This publication contains an in-depth socioeconomic study conducted by the Center for Development Research (ZEF). It is an analysis of preliminary benefits and impacts that could be brought about by the dissemination of tissue culture banana plantlets to resource-poor farmers in Kenya. We believe it is an important example of the contribution biotechnology can make to developing country agricultural and food sectors.

The present study by Matin Qaim demonstrates that biotechnology holds great potentialities for the poor population segments, including food producers and consumers. The potentialities, however, need to be translated into action, which is not only a question of technological attributes but also of equitable access to the innovation. We hope that the study may be the basis to further refine the distribution mechanisms in Kenya which could allow thousands more farmers to benefit from the banana technology. Technological developments always have to be understood in a dynamic fashion. Establishing efficient biotechnology distribution channels will also create alleys for innovations yet to come for bananas as well as for other crops.

Given the scarcity of natural resources, such efforts of modernizing farming systems—including the small farm sector—are necessary to face the challenges of growing food demand in developing countries. Improving the knowledge base for poverty reduction strategies is the main purpose of ZEF, and we recognize the participation of the poor in advanced technological developments as one of the key factors in this respect.

The successful implementation of the study in Kenya was made possible only through the support of various organizations. We gratefully acknowledge the financial contributions by the German Research Society (Deutsche Forschungsgemeinschaft—DFG), the German Agency for Technical Cooperation (Deutsche Gesellschaft für Technische Zusammenarbeit—GTZ) and the German Ministry for Economic Cooperation and Development (Bundesministerium für Wirtschaftliche Zusammenarbeit und Entwicklung—BMZ). Our thanks also go to the many institutions and individuals who have been involved in the project brokered and developed by ISAAA. Finally, we are grateful to ISAAA and KARI for having allowed us unhindered access to all the necessary information and contacts which enabled us to prepare this independent study.

We hope that the findings on socioeconomic implications of the biotechnology transfer project in Kenya will also be of interest and value to a wider group of stakeholders.

Joachim von Braun
Director, ZEF

Executive Summary

Due to the dearth of sound information on the socio-economic repercussions of agricultural biotechnology in developing countries, the international debate about the topic is often emotional, and it is mostly split according to ideological beliefs. This study attempts to contribute to a rationalization of the discussion by providing some empirical evidence. The potential impact of tissue culture technology in Kenyan banana production is analyzed.

Unlike in large parts of Latin America and other export-oriented banana-growing regions of the world, in Kenya the crop is predominantly grown by peasant farmers for home consumption and for the national market. Apart from being the most popular eating fruit in the country, the banana cooking varieties also serve as an important staple food. The crop covers around 1.7 percent of Kenya's total arable land. For the individual producer, banana is usually part of a diversified cropping pattern, including semi-subsistence commodities, domestic cash crops, as well as typical export commodities. Within these farming systems, banana is mostly seen as a security crop, which renders a continuous in-kind and in-cash income flow under very low input regimes. Consequently, in terms of input and factor allocation, banana production is a rather neglected enterprise. It is often managed by women.

To analyze distribution effects of the new technology, the growers are subdivided into three groups according to their banana acreage, i.e. small-, medium- and large-scale producers. Generally, the prevalence of smaller farms is higher in the western parts of Kenya, whereas large-scale farmers are mostly found in the Central and Eastern Provinces. The home-consumed proportion usually declines with the increasing size of the banana holding, and the input intensity of production rises. Likewise, the obtained yield levels are somewhat higher on the larger farms. Nonetheless, even the large-scale producers—with a mean banana area of about 5 acres (2 hectares)—are comparatively small in an international context, and their production systems are still rather traditional. The average banana yields in Kenya are meager. With 5.7 tons per acre (14 tons per hectare), they achieve less than one-third of the crop's potential under the favorable conditions of the humid tropics. Apart from the low input levels, the oppressive infestation of banana with various pests and diseases is the main determinant for this yield gap. The economically most import banana pests in Kenya are weevils and nematodes. Severe disease damage is primarily attributable to Panama disease and black sigatoka, both caused by fungi. All these pathogens are spread through infected banana suckers being used by farmers for plant propagation, due to the lack of clean planting material, and also because of the farmers' limited knowledge. The resulting yield losses make banana a relatively expensive commodity for consumers, and reduce the cash earnings of producers as well as the potential of the crop to contribute to the food security of rural households.

To tackle this general problem, the Kenya Agricultural Research Institute (KARI) launched an international collaborative biotechnology project in 1996/97. The project is facilitated by the International Service for the Acquisition of Agri-biotech Applications (ISAAA) and is financially supported by the Rockefeller Foundation (RF) and the International Development Research Centre (IDRC). Through the use of tissue culture (TC) laboratory techniques, banana growers are supplied with pathogen-free planting material. Technical assistance for the implementation of the project is provided by the Institute for Tropical and Subtropical Crops (ITSC), a public research institute in South Africa, where the use of in vitro banana plantlets is already common practice. Since 1997, KARI has conducted on-station field trials with the TC material in different provinces of the country, and on-farm trials are also under way. Generally, farmers are quite interested in the innovation, and the first yield experiences are most promising. Besides further applied research (e.g. developing TC protocols for additional varieties) and technology demonstration, the main challenge in the future will be to expand the commercial production capacity for in vitro plantlets and to establish efficient biotechnology distribution channels.

At this stage, no solid information is available about the long-term yield effects of TC technology under farmers' conditions in Kenya. The impact assessment is, therefore, carried out within an *ex ante* analytical framework. It builds up on farm level data—as currently observed, i.e. without the widespread use of in vitro plants—and on banana experts' projections and estimates about future developments. The potential effects of TC plants are analyzed for the three identified farm types. For this purpose, current enterprise budgets are compared to hypothetical ones, where technology application is assumed. The potential growth in average yields is substantial and, interestingly, it is highest for the small-scale producers. For the large farms, an average yield increase of 93 percent is anticipated, whereas it would be 150 percent for the smallholders. The medium-scale farmers would gain 132 percent.

However, the use of the technology also entails a considerable increase in the cost of production. The in vitro material is quite delicate, especially in the first months after field transplantation, and it demands good growing conditions to produce satisfactory yields. This implies that the prevailing banana cultivation practices would need to be intensified to some extent, and it emphasizes that it is absolutely essential to combine technology dissemination with relevant extension services. Another major additional cost component for farmers is the TC planting material itself. To date, the price of a plantlet produced in a commercially run laboratory is around 100 Kenyan Shillings (KSh), which is about seven times the average cost that growers incur for the acquisition of conventional suckers. It is expected that—due to growing experience and/or competition—the laboratory cost of producing TC plantlets will be reduced significantly in the medium-run. Nevertheless, it will remain higher than the current cost for suckers. In the calculations, a TC price of 75 KSh is assumed. Considering the whole plantation cycle, which on average is 14 years in Kenya, the total cost increase through using the technology for the small-, medium- and large-scale farmers would be 130, 118 and 92 percent, respectively. Although income projections reveal that this is more than offset by the expected gains in banana revenues, the high cost outlays indicate additional risk, especially in the given situation of severe imperfections in rural markets for credit and information. Thus, it is reckoned that particularly the small and resource-poor producers, for whom the relative cost increase is most pronounced, will be hesitant to take up the innovation at commercial prices.

The expected aggregate welfare effects of the biotechnological progress are analyzed by means of an economic surplus model, which builds on the results from the farm-level analysis. The model is run until the year 2020. Projected average annual benefits from TC bananas are 94 million KSh and, juxtaposing the benefits to the total project investments, an internal rate of return (IRR) of 42 percent is produced. It is worth noting that banana consumers would capture more than 40 percent of the overall gains because of technology-induced price decreases. Distribution effects across the three identified farm types are also analyzed. Main beneficiaries would be the medium- and large-scale farmers. Owing to the predicted restrained adoption of the innovation by the smallholders, their benefit portion would be only marginal, with a concomitant rise in income concentration among banana producers.

As mentioned, the cost of the in vitro material itself plays an important role. Although TC technology cannot be reproduced by farmers themselves, it is likely that there will be some carry-over effect of yield advantages from the in vitro mother plant to subsequent sucker generations. The implications of such a "technology self-propagation" option are investigated by lowering the assumed price of TC material from 75 KSh to 35 KSh per plantlet in the model calculations. Corresponding to the lower cash outlay, technology adoption is presumed to be much faster. Strikingly, the aggregate welfare gains under these assumptions reach a level which is more than eight times (764 million KSh per year) the benefits in the initial higher price scenario, and the IRR would rise to 91 percent. Moreover, the equity effects are improved remarkably, because the TC price reduction would have the biggest relative impact on small-scale farmers. Other instruments to speed up technology adoption of small producers should particularly focus toward removing factor market imperfections. This should involve, *inter alia*, improving the flow of information and establishing suitable micro-credit schemes.

In summarizing, TC technology is likely to bring about considerable aggregate welfare growth in the Kenyan banana sector. Potential yield and income gains for the poorest farmers are even higher than those for the relatively richer and larger farms. Yet, due to the high additional cost outlays associated with the technology, the small farms particularly are facing the most severe adoption constraints. Providing this group with appropriate access to the technology will require a major institutional effort. It must not be forgotten, though, that in addition to the direct TC impacts—for which quantifying was tried—the establishment of viable biotechnology distribution channels within the project will also facilitate future innovation developments. For instance, the international availability of transgenic banana varieties with resistance to major biotic stress factors is expected in the next 10 years. The project opens up avenues for the quick introduction of such biotechnologies that are most promising, especially for resource-poor producers.

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List of Abbreviations and Acronyms

AFC	Agriculture Finance Corporation
BGA	Banana Growers Association
FAO	Food and Agriculture Organization of the United Nations
GNP	Gross National Product
GTL	Genetic Technology Limited
ICIPE	International Centre of Insect Physiology and Ecology
IDRC	International Development Research Centre
IITA	International Institute of Tropical Agriculture
ILRI	International Livestock Research Institute
INIBAP	International Network for the Improvement of Banana and Plantain
IPM	Integrated Pest Management
IRR	Internal Rate of Return
ISAAA	International Service for the Acquisition of Agri-biotech Applications
ITSC	Institute for Tropical and Subtropical Crops
JKUAT	Jomo Kenyatta University of Agriculture and Technology
KARI	Kenya Agricultural Research Institute
KSh	Kenyan Shilling
MALDM	Ministry of Agriculture, Livestock Development and Marketing
NGO	Non-Governmental Organization
NPK	Nitrogen, Phosphate, Potassium (mixed fertilizer)
R&D	Research and Development
RF	Rockefeller Foundation
TC	Tissue Culture
USA	United States of America
US$	United States Dollar
ZEF	Zentrum für Entwicklungsforschung (Center for Development Research)

1. Introduction

In the international agricultural biotechnology debate, fear has often been articulated that technological developments might neglect or even discriminate against the poor in developing countries. Little empirical evidence is yet available to support or disprove this argument. Solid impact assessment has been identified by international stakeholders as a priority tool with which to improve the knowledge base on biotechnology, and to guide its evolution in desired directions (Cohen et al., 1998). This study makes an attempt to contribute to a rationalization of the debate among researchers, policy-makers and the general public, by analyzing the expected economic impact of banana biotechnology in Kenya.

Banana is often considered as a typical export crop of developing countries, grown to the major extent by multinational companies or their contractors for consumption in the USA or in Europe. While this is partly true in some of the Latin American countries, the situation is different in Asia and Sub-Saharan Africa, where the crop is mainly consumed domestically. Of the global banana production, less than 20 percent is traded internationally. If the total production of *Musa* (i.e. bananas and plantains) is considered, the exports' share is only 14 percent (Hallam, 1995). In East Africa, bananas are predominantly grown by small-scale peasant farmers for home consumption and for local markets. In the region, banana is very often a crop managed by women. Besides being the most popular eating fruit, the cooking varieties also represent an important staple food. Although statistics on the production of semi-subsistence crops are often unreliable, it is obvious that obtained banana yields of about 10 tons per hectare in East Africa fall significantly behind the potential yields of more than 40 tons in tropical areas. Apart from low input levels, under which bananas are grown in semi-subsistence farming systems, this substantial yield gap is also due to the widespread use of planting materials infected by pests and diseases. The resulting yield losses make banana an expensive commodity for consumers, and reduce the cash earnings of producers as well as the potential of the crop to contribute to the food security of rural households.

This problem has been identified by public research organizations in Kenya. In 1996/97, the Kenya Agricultural Research Institute (KARI) launched an international collaborative program with the aim of providing small-scale farmers with pathogen-free banana planting material through the use of tissue culture (TC) biotechnology. The program is institutionally supported by the International Service for the Acquisition of Agri-biotech Applications (ISAAA) and is sponsored by the Rockefeller Foundation (RF) and the International Development Research Centre (IDRC). In vitro micropropagation of banana is common practice in other parts of the world, but has not been commercially used before in tropical Africa. The advantage of the technique is that large numbers of healthy banana plantlets can be produced in the laboratory in a comparatively short period of time. This reduces pest and disease problems for banana growers and offers an ideal opportunity to quickly introduce new and superior germplasm on a large scale. Laboratory protocols for tissue culture in conjunction with popular international banana varieties had been previously available. Now, with technical assistance from the Institute for Tropical and Subtropical Crops (ITSC) in South Africa, several new protocols for local banana cultivars are being developed by KARI. Since 1997, KARI has conducted on-station field trials with the TC material in four Kenyan provinces. On-farm trials are also under way in collaboration with local farmers. First experiences have been very promising with respect to farmers' interest in the project and yield-increasing potentials of the technology. Strategies to expand the commercial production capacity for in vitro plantlets, and to establish efficient biotechnology distribution channels, are currently being developed in order to allow the TC plantlets to be available to small-scale banana growers on a country-wide basis.

The specific objectives of the economic analysis presented in this paper are: (i) to demonstrate the benefit potentials of the technology in quantitative terms, and (ii) to identify key issues that have to be accounted for in the project design in order to fully reap these potentials. Furthermore, some general insights shall be gained regarding the implications of using tissue culture biotechnology in developing country agriculture.

1.1 Conceptual Framework and Data Basis

The study first of all investigates the present Kenyan banana sector situation, i.e. without the widespread use of the tissue culture propagation techniques, and projects how this situation is likely to change through the collaborative biotechnology program. As these changes and their impacts are not easily observable at this stage, the analysis builds upon an *ex ante* conceptual framework described in greater detail by Qaim and von Braun (1998). Potential technology effects on cost and income of banana production at the individual farm level are analyzed by comparing currently observed crop enterprise budgets with hypothetical ones, where the use of TC material is assumed. For the quantification of the expected aggregate benefits and distribution outcomes, an economic surplus model is applied. The required data for the analysis were collected by the author in the second half of 1998. In addition to secondary sources, two different semi-structured interview surveys were carried out. The first survey consisted of meetings with 46 banana farmers in the five major growing provinces of Kenya (Nyanza, Western, Central, Eastern, and Coast, see Figure below). This regional approach was chosen to get an overview of possible geographical differences in the country's banana production systems. Within the provinces, the farmers to be visited were selected randomly, and country-wide data were derived by weighting the figures with the provinces' respective national production shares. The farm interviews centered around input-output relations in banana cultivation, problems of growing the crop, including access to factor and commodity markets, and farmers' general openness to innovations. Whenever possible, the compiled farm information was supplemented by discussions with field extension workers in the same locations. The second interview survey was conducted with 25 banana experts and focused on various aspects of banana research, features of the tissue culture technology and expected adoption rates of banana farmers. Of the 25 expert interviews, 15 were with researchers directly involved in the biotechnology project. For *ex ante* projections, however, it is important to include independent experts as well, in order to minimize a possible information bias that might otherwise occur due to vested interests. The remaining 10 interviews were performed with independent banana experts from different national and international research organizations (i.e. KARI scientists not involved in the project, ICIPE scientists, different researchers from national universities).

1.2 Study Overview

Chapter 2 will present an outline of the Kenyan banana sector with a special focus on the prevailing farming systems. Owing to the fact that banana is produced semi-commercially, and has traditionally hardly received any policy attention in Kenya, only little specific published information is available on such issues. The presented data mainly draw on the primary data collection procedure described above. We differentiate between small-, medium- and large-scale farmers, a classification based on which distribution effects of the technology are analyzed in later Chapters. Aspects of the biotechnology project and the tissue culture technology itself are discussed in Chapter 3, also considering the future project outlook. Chapter 4 scrutinizes potential repercussions of the biotechnology application at the individual farm level, before the expected welfare effects for the three banana producer groups and for consumers are quantified in Chapter 5. The aggregate benefits are also weighed up against the costs of R&D and technology dissemination to derive the overall return on investment produced by the considered biotechnology project. In Chapter 6, the results are discussed and some conclusions are drawn.

2. The Kenyan Banana Sector

East Africa accounts for about 8 percent of the global banana production. Most of the produce is consumed within the region, and exported quantities are rather low. Initially, banana germplasm probably entered East Africa from two directions: the humid tropics of Western and Central Africa, and the Indian Coast. Yet the number of distinctive clones recorded in East Africa suggests the importance of the region as a secondary center of diversity (Davies, 1995). In Kenya, banana is cultivated on about 74,000 hectares, which makes up 1.7 percent of the country's total land used for crop production (MALDM, 1997).[1] This area has shown a trend toward increasing during the last decade. Banana ranks eighth in the Kenyan government's crop priority list for enlarging food production in order to keep pace with population development (Nguthi, 1996).

Banana is grown in various agro-ecological zones of the country, from the coast up to an altitude of about 2000 meters in the Western Highlands. Cultivation takes place predominantly under rainfed conditions in areas that receive an annual precipitation of at least 1000 millimeters. In all of Kenya's eight provinces ba-

[1] The FAO gives a banana area of 40,000 hectares for Kenya in 1997 (FAO, 1998). This is similar to what MALDM gave for 1994 and 1995. National statistics, however, were corrected upwards in more recent years especially due to prior underestimates of the banana area in Nyanza Province, so that these corrected figures appear to be more realistic.

nanas are grown, although the four major growing provinces (Nyanza, Central, Eastern, and Western) make up 90 percent of total national production (see Figure 1 and Table 1). Nyanza is the most important banana-producing province with a share of 56 percent.

Figure 1: Map of the Kenyan Provinces

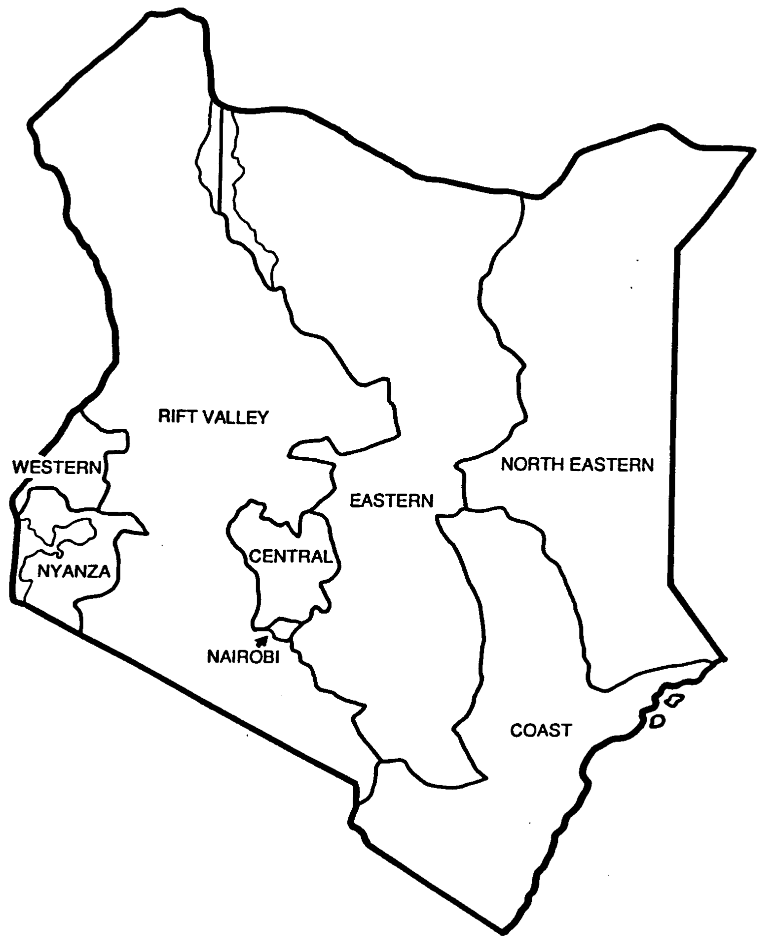


Table 1: Banana production statistics for the Provinces of Kenya (1996-97 averages)

Province	**Area** (ha)	**Production** (t)	**Yield** (t/ha)	**Production share** (percent)
Central	16,913	169,316	10.0	16.5
Coast	5,743	55,341	9.6	5.4
Eastern	9,669	97,144	10.0	9.5
Nairobi	48	409	8.5	0.0
North Eastern	271	1,522	5.6	0.1
Nyanza	30,234	574,740	19.0	56.1
Rift Valley	2,688	39,781	14.8	3.9
Western	7,800	86,107	11.0	8.5
Total	**73,366**	**1,024,360**	**14.0**	**100.0**

Source: MALDM (1996, 1997).

Bananas are produced for different purposes in Kenya. The dessert type varieties constitute the most popular fruit among urban and rural consumers, and the cooking type varieties are an important staple food, particularly for rural households. The processing of banana for banana beer, which is quite common in other countries of Eastern Africa, is rare in Kenya. The crop is mostly cultivated on comparatively small farms with an average banana holding of 0.3 hectares (0.8 acres). Although it is still a semi-subsistence crop, commercialization has expanded in recent years. Reasons for this are the higher market demand due to the rising degree of urbanization as well as diminishing farm incomes from the more traditional cash and export crops, notably coffee.

2.1 Banana Varieties

In Kenya a wide range of banana varieties is grown. The first obvious separation between varieties can be made between the ripening (dessert) bananas on the one hand, and the cooking types on the other. Some of the varieties are also used for both purposes. Ambiguity can occur with the term "plantain". For many, plantains represent all cultivars that are used for cooking. Others confine the expression to a subgroup of the AAB triploid hybrids, which constitutes only a small fraction of all commonly used starchy cooking type varieties (cf. Robinson, 1996).[1] There appears to be no generally accepted rule of distinction between bananas and plantains. According to FAO statistics, the Kenyan area cultivated with plantains is more than double the area under bananas (FAO, 1998). Kenyan researchers and national statistics, however, say that the use of plantains in the country is negligible. Here, only the term banana is used, with the description differentiating between ripening and cooking type varieties. According to the interview survey, about half of the Kenyan banana production is of the ripening type, whereas the other half is made up of cultivars mostly used for cooking.

Among the ripening varieties there are some which have been used for a long time in Kenya, the most prominent of which are Gros Michel (AAA), locally often named Kampala, and Apple Banana (AB). Other ripening types have been introduced to the country more recently, especially those of the Cavendish subgroup (AAA), such as Dwarf Cavendish, Chinese Cavendish, Lacatan, Valery, Grand Nain, Williams, Paz and others, generally with a fairly good acceptance among banana producers and consumers. Many of the cooking varieties used in Kenya belong to the subgroup of East African Highland Bananas (AAA). Not all of them have been genetically identified, so that some appear with different local names, although in cytological analyses they turn out to be very similar. Local names of popular cooking varieties include Matoke, Kiganda, Mutahato, Bokoboko among others. A commonly used local double purpose cultivar is Muraru (AAA). KARI estimates that around 35 different banana varieties are commonly used in Kenya.

2.2 Pests and Diseases

Bananas are stressed by a number of biotic factors, particularly in the humid tropics where the climate is favorable for the propagation of pests and diseases. The most constraining pests in all banana-growing regions of Kenya are weevils (*Cosmopolites sordidus*) and nematodes (particularly *Radopholus similis* and *Pratylenchus goodeyi*). Weevils and nematodes are dispersed by soil infestation and by the use of contaminated sucker material. Host plant resistance for these pests is not known in any of the domesticated or wild banana species, although some varieties show a moderate degree of tolerance to nematodes (Sarah, 1993). Both weevils and nematodes lend themselves for integrated pest management (IPM) measures, including crop rotation and the appropriate choice and preparation (paring) of planting material. Field sanitation (weeding, chopping of old pseudostems) is especially important against weevils, in order to eliminate potential hiding and breeding places. Reddy et al. (1998) report some promising experiences with the dissemination of IPM information in Nyanza Province. In general, however, the degree of related knowledge is low among farmers and extension workers alike. Weevils and nematodes can also be controlled by pesticides, but the use of such chemicals on a regular basis is rare in Kenya. Thus, farmers are often faced with gross damage caused by these pests, which can be quite severe. Yield reductions due to weevils, for instance, can easily reach 50 percent. And losses are increased when there is an interaction between weevils and nematodes (Speijer et al., 1993).

The most important banana disease in Kenya is Fusarium wilt, effected by the soil-borne pathogen *Fusarium oxysporum* f. sp. *cubense*. This fungal disease is often referred to as Panama disease, since it was in Central America where it caused oppressive problems at the end of the last century. In Kenya, the disease was observed

[1] The modern banana classification was devised by Simmonds and Shepherd (1955). It characterizes the number of chromosome sets (ploidy) in the genome of a variety, and the relative influence of the two basic wild species, *Musa acuminata* (A) and *Musa balbisiana* (B). The conversion of starch to sugar in the ripening process is usually slower in the varieties which contain *M. balbisiana* characteristics.

for the first time in 1952, but a severe outbreak has only been reported in more recent years (Kung'u, 1995). Today, Panama disease is endemic in all of the country's banana-growing regions. However, the severity varies because of the varying susceptibility of different varieties, and different regional varietal preferences. In Coast Province, for instance, Fusarium is not considered a constraint to the same degree as it is in the other provinces, particularly in Central and Eastern, where the strongly affected variety Gros Michel (Kampala) is most popular. In other parts of the world, Panama disease outbreaks in the 1950s and 1960s led to the complete replacement of Gros Michel by resistant varieties, mainly from the Cavendish subgroup. Other susceptible varieties grown in Kenya are Apple Banana, Bokoboko and Muraru. Fusarium infects the plant's root system and is spread through unclean sucker material, surface water runoff and infected soil carried around on farm implements. The fungus can completely destroy a new plantation within a couple of months, and even when the host plant itself is removed from the plot, it can endure for decades in the soil. Strategies to directly combat the disease are not available. Prophylactic control measures include the planting of clean material on uninfected soils and the use of resistant varieties. Many of the local cooking types are fairly tolerant to Fusarium and, as was mentioned, the Cavendish varieties are resistant to the disease as well. Hence, although Gros Michel is especially appreciated for its excellent taste and post-harvest characteristics, it is likely that Cavendish types will more and more supersede the traditionally used dessert varieties. So far, only race 1 of *Fusarium oxysporum* f. sp. *cubense* has been reported in Kenya. In some subtropical areas, though, another race (race 4) occurs, which is also attacking Cavendish cultivars (Robinson, 1996). Breeding success in combining race 4 resistance with acceptable quality characteristics in a single banana variety has so far been only moderate (Ortiz et al., 1995).

Another fungal disease of banana with economic relevance in Kenya is black sigatoka (*Mycosphaerella fijiensis*) which was reported in the country for the first time in 1989 (Kung'u et al., 1992).[2] It can cause yield losses of up to 50 percent. The fungus is spread by the wind or by water and attacks the leaves of the plant. Pathogen dispersal through infected planting material is also possible. Black sigatoka has so far only been found in Coast, Central and Eastern Provinces. The disease can be controlled by systemic fungicides, but their use is environmentally harmful and economically often beyond the reach of smallholder farmers. Most of the banana varieties commonly used in Kenya are affected by black sigatoka, including the Cavendish types. Developing resistant varieties is one of the major objectives of international breeding programs. Viral diseases, albeit problematic in many other parts of the world, have so far not been reported in Kenya.

In fact, all of the major banana pests and diseases of economic importance in Kenya are spread through infected suckers used for propagation. Thus, vigorous plant development is hampered from the initial stages of growth. The widespread use of sucker material from questionable sources is one of the main reasons for the observed gap between potential and actually obtained banana yields in the country.

2.3 Banana Farming Systems

2.3.1 General Aspects

Agricultural production systems in Kenya are quite diversified. In the farm interview survey, 90 percent of all farmers mentioned at least ten different enterprises they are active in. These enterprises normally include the production of different grains (mainly maize and sorghum), starchy root crops (mainly cassava and sweet-potato), fruits, vegetables, and livestock keeping. The crops are usually grown in small patches or are intercropped with other plants. Forty-six percent of the farmers—even many smallholders—also produce typical export commodities, notably tea and coffee. This diversification of farm incomes is looked upon as a household strategy to insure oneself against the risks of production and market instabilities.

Among the horticultural crops, banana is generally the most important one with respect to area and income generation. Nearly every rural household has at least a couple of banana plants around the homestead. In the sample survey, only farms with a minimum of 10 mats were considered. Table 2 shows some general characteristics of banana production and of banana farming systems in Kenya as derived from this sample. A typical banana holding is 0.8 acres, which makes up some 13 percent of the total farm area on average.[3] Yet within the cropping schemes, banana usually receives a compara-

[2] Yellow sigatoka (*Mycosphaerella musicola*) does also occur but is much less damaging than black sigatoka. Another less important though existent fungal pathogen is *Verticillium theobromae* which causes cigar end rot, a banana fruit disease.

[3] Notwithstanding official area statistics are usually given in hectares, we use acres to describe the farming systems, which is the more common reference among farmers themselves (1 acre = 0.405 hectares).

tively low priority in terms of labor and input allocation. Although the yields could be multiplied by more intensified husbandry techniques, banana is rather seen as a security crop, that—in contrast to crops with seasonal production peaks—provides a more or less continuous income flow throughout the year, even under low-input regimes. The security function of banana cultivation for the rural households is also stressed by the semi-subsistence nature of the crop in Kenya. Twenty-four percent of all bananas are consumed in the same households where they are produced. Since subsistence and semi-subsistence crops often belong to the female domain, women play the dominant role in banana production. Seventy-three percent of the sampled banana holdings are predominantly managed by women, who are responsible for most of the field operations. This, however, does not determine the ownership status of the crop, which may vary from case to case sometimes due to tribal traditions. Men are often the official owners and control the income as soon as cash sales are involved, even though women are usually responsible for the work associated with banana marketing.

In 51 percent of the cases, bananas receive no regular inputs at all, i.e. they are neither treated with farm chemicals nor with organic manure. Furthermore, planting material is rarely bought from official sources. The establishment of new banana holdings or plantation replacement is usually based on suckers of questionable quality, either obtained from old mats or—when own supplies are scarce—from neighboring farms. As seen in section 2.2, the widespread use of pathogen-infected sucker material is the main way of transmitting banana pests and diseases in the country. Average plantation replacement is after 14 years, although this figure hides the fact that many holdings are over 40 years old. Notwithstanding that the yield performance in such old plantations is fairly poor, farmers often shy away from the investment associated with new establishments. But, especially in more recent times, farmers are often forced to replace their orchards after shorter periods because of complete devastation caused by pests or diseases. Information about regional differences in banana farming systems is also given in Table 2.

It can be seen that average total farm sizes and banana holdings are significantly smaller in the western regions than they are in the central and eastern parts of the country. This is mainly a reflection of the high population pressure on land in the Lake Victoria Basin. Subsistence orientation is also more pronounced in the West, associated with a larger share of cooking type varieties and lower input intensities. The latter is somewhat surprising, given that yields in Nyanza are above the national average (cf. Table 1). Although our sample size is rather small and might thus be biased, local farming systems specialists and own field observations confirm that the banana producers in the western regions are generally poorer than those located in the other parts of the country. The higher yield levels obtained in Nyanza

Table 2: Regional aspects of banana production in Kenya

	Western regions [a]	Central and eastern regions [b]	Total Kenya
Total farm size (acres)	4.2	11.0	6.4
Banana holding (acres)	0.4	1.5	0.8
Home-consumed share (percent)	30.0	12.2	24.1
Production share of ripening varieties (percent)	36.6	78.4	50.4
Percentage of female-managed banana holdings	78.0	63.0	73.1
Percentage of farmers using manure	33.3	55.6	40.6
Percentage of farmers using farm chemicals	11.1	18.5	13.5
Percentage of farmers using irrigation	0.0	22.2	7.4
Plantation replacement (years)	13.7	13.9	13.8

[a] Western regions include Nyanza and Western Provinces.
[b] Central and eastern regions include Central, Eastern and Coast Provinces.

Source: Author's interview survey (1998).

are probably attributable to the more favorable soil and climatic conditions (e.g. better distribution of rainfalls throughout the year).

2.3.2 Farm Types

For the analysis of income distribution effects of the technology, the banana producers shall be subdivided into meaningful groups. In order to identify appropriate indicators for disaggregation, correlation coefficients of different farm variables collected in the interview survey are depicted in Table 3. Unsurprisingly, the total acreage of a farm is positively correlated with the size of the banana holding. Yet many other variables are correlated only weakly with the overall farm size. Rather than total farm size, the more appropriate indicator for distinguishing farm groups appears to be the banana area, which shows a statistically significant correlation with all the other variables considered. The larger the banana plantation of a farm, the lower are the subsistence orientation and the proportion of cooking type varieties, and the higher is the input intensity of production.

Given these linkages, we subdivided all Kenyan banana producers into three groups according to the following criteria:

- Small-scale farmers having a banana area of less than 0.5 acres,
- medium-scale farmers growing between 0.5 and 2 acres of bananas, and
- large-scale farmers having a plantation which is bigger than 2 acres.

Some characteristics of these three farm groups are given in Table 4. Significant differences in the individual groups' parameters can be observed. Nevertheless, the banana areas and home consumption shares indicate that even the large producers are mostly traditional peasant farmers. Large agricultural estates that exist partly in the export crop sectors are rare in Kenyan banana production. Hence, the expression large-scale is used here in a relative rather than in an absolute sense.

In terms of farm numbers, the small-scale producers clearly dominate the banana sector. Because of their small holdings and the lower yield levels obtained, however, their production share is smaller than that of the medium-scale farmers. Even the large-scale growers account for 22 percent of national production, notwithstanding that only 2 percent of all banana growers belong to this group. As anticipated, subsistence orientation and the share of cooking type varieties used decline with an increase in the banana area; for the input intensity (not shown here) it is *vice versa*. The prevalence of small-scale producers is higher in the western regions, whereas the large farms are mostly found in the central and eastern parts of the country.

2.3.3 Banana Production Intensity and Enterprise Budgets

Banana is a perennial crop associated with establishment investments at the beginning of the plantation cycle, recurrent annual expenditures and the costs of removing the old plants at the end of the cycle. Correspondingly, banana yields usually show a yield peak in the first and second ratoon (second to fourth year), before they gradually decline in subsequent years. Simple budget calculations based on one single year are not suitable to depict the time-dependent cost and income flows of a banana plantation cycle. It was shown before that the average longevity of such a cycle is 14 years in Kenya. In order to account for the time dimension of costs and revenues, we consider the complete plantation cycle. Table 5 shows in per acre terms the average cost that farmers incur for plantation establishment. Although the total banana area of many farmers is less than one acre, farmers' statements are extrapolated to a full acre for comparative purposes. This appears justified, since—except for the land preparation in few cases—little mechanization is used so that economies-of-scale are more or less negligible.

Plowing the soil is mostly done by hand; sometimes animal traction and in few cases a hired tractor is used. The planting holes are dug by hand, which can be a cumbersome task, depending on the soil conditions. The average plant spacing in a pure banana crop is 4 by 5 meters (203 plants per acre), with no systematic differences between the farm types. This plant density is quite low if compared to other banana-producing countries. The reason is that hardly any desuckering is practiced in Kenya. It is not rare that a single mat has 10 to 15 stems at a time. The amounts of farm inputs used by the banana growers are derived as the arithmetic mean values of the groups' sample farms. The deployed inputs and factors of production are valued at their observed farm-gate prices. The households' own, non-purchased resources are priced accordingly, because their allocation to the banana activity is associated with an opportunity cost that is approximated by the respective market value. It has to be kept in mind, therefore, that not all of the costs discussed here are associated with an actual monetary expenditure for farmers.

Table 3: Correlation matrix for different characteristics of banana farms

	Banana area	Home consumpt.	Ripening share	Male-managed [a]	Use of manure [a]	Use of chemicals [a]	Use of irrigation [a]
Total area	0.28*	-0.06	0.26*	0.23	0.16	0.10	0.23
Banana area	1.00*	-0.54*	0.42*	0.35*	0.29*	0.31*	0.50*
Home consumpt.		1.00*	-0.25	-0.23	-0.27*	-0.41*	-0.54*
Ripening share			1.00*	0.37*	0.03	0.34*	0.36*
Male-managed [a]				1.00*	0.14	0.11	0.30*
Use of manure [a]					1.00*	0.34*	0.42*
Use of chemicals [a]						1.00*	0.55*

Note: The given figures are based on Spearman's rank order correlation technique, which is also suitable for not normally distributed variables.
[a] These are dummy variables, which take the value 1 when the respective condition is met, and 0 otherwise.
* Significant on the 0.05 level.

Source: Author's interview survey (1998).

Table 4: Characteristics of banana farm types

	Small-scale	Medium-scale	Large-scale
Average banana holding (acres)	0.3	1.1	4.9
Average home-consumed share (percent)	37.1	24.6	4.0
Average ripening share (percent)	33.7	48.3	84.0
Share in terms of farm numbers (percent)	79.6	18.6	1.9
Share of national production (percent)	36.9	41.0	22.1

Source: Author's interview survey (1998).

Table 5: Banana plantation establishment cost by farm type (in 1998 KSh/acre)

	Small-scale	Medium-scale	Large-scale
Labor for land preparation	395	395	395
Labor for hole digging	2,212	2,212	2,212
Manure	1,680	2,649	5,685
Labor for manuring	553	790	1,185
Nematicides	45	99	450
Planting material	2,842	3,248	4,263
Labor for planting	869	869	869
Total	**8,596**	**10,262**	**15,059**

Note: 1 US$ = 59.7 KSh according to the official exchange rate in late 1998.

Source: Author's interview survey (1998).

The average labor rate is 79 KSh per day, including the in-kind wage component in form of provided meals. Farmyard manure costs 646 KSh per ton, and the average price of nematicides is 300 KSh per kilogram. Suckers taken from farmers' own banana plants are valued at 10 KSh per piece, to reflect the necessary labor cost of removing and handling them. Purchased suckers are rated at the prices that farmers stated—ranging from 10 to 80 KSh per piece according to the individual procurement sources. The use of farmers' own suckers is by far the most important origin of planting material for all three farm types. Still, there are slight differences in terms of purchase frequencies: the smaller farmers buy material from outside sources less often than the larger ones. Given these patterns, implicit sucker prices of 14, 16 and 21 KSh are derived for the small-, medium- and large-scale farmers, respectively. Table 6 shows the average cost of banana production that occurs annually on a regular basis over the whole length of the plantation cycle.

The per acre cost of plantation establishment is 75 percent higher, and the recurrent operation cost is 67 percent higher for the large-scale farmers in comparison to the smallholders. The medium-scale producers' cost lies in-between. Cost differences are mainly attributable to the more widespread use of farmyard manure among the larger farms and the more intense maintenance works. What is striking is that even the large-scale producers use hardly any inorganic fertilizers, and, except for some nematicides, chemical pest and disease control measures are not applied at all. The reasons for the low input levels in banana production vary, a few of them being:

- Farmers' knowledge and experience in using farm chemicals is rather low.
- Due to budget constraints, the scope of the Kenyan government's agricultural extension service is limited; moreover, specialized horticultural extension officers are rarely employed.
- Farmers are facing liquidity constraints, and access to formal credit is unavailable for banana production.[1]
- There are some superstitious beliefs that inorganic fertilizers have detrimental effects on the banana quality. Such beliefs are often spread by local banana traders.

Improving these institutional impediments could help to intensify production and increase banana yields substantially, even without the use of new technologies. However, as will be argued later, a new technology application—such as tissue culture plantlets—could induce institutional innovations and attitude changes, which might be harder to achieve without such a mechanism.

On account of nutrient deficiencies and high pressure from pests and diseases, banana yields in Kenya do not reach their potential maximum in the peak years. Moreover, the yield decline in subsequent years is more rapid than it would be without these stress factors. Given the different cultivation practices among farm types, it is not surprising that these features of the yield curve over the plantation cycle are more pronounced for the smaller than they are for the larger producers. Information on exact yield curves under Kenyan on-farm conditions is not available, and farmers themselves do not record their harvested amounts. The annual enterprise budget calculations shown in Table A1 (Appendix) build on yield profiles, which were estimated by the interviewed banana researchers (cf. Figure A1 in the Appendix). From the annual farm type-specific cost and income values per unit area, annuities are calculated, whereby in year 14, the cost of 51 labor-days for uprooting the old plantation is added equally for all producer groups. The cost and income annuities can be interpreted as the respective average figures for the whole plantation cycle. They are shown in Table 7.

The annuity of the net return per labor-day is also given in Table 7. This indicator is derived by subtracting all non-labor costs from the gross revenue, and dividing the residue by the amount of labor-days allocated to banana production on an annual basis. For the indicated per unit cost, no annuity can be calculated because there is no yield in the first year, which would lead to an unallowed division by zero. Instead the per unit cost is obtained by dividing the cost annuity by the yield annuity.[2]

The average yield is 29 percent higher for the medium-, and 74 percent higher for the large-scale farmers than it is for the small-scale producers. The corresponding income difference is 23 and 60 percent, respectively. Net returns per labor-day are fairly high for all three farm types. The figures suggest that many of the farm households are producing bananas under conditions of relative labor shortages. Employing more hired labor might be efficient from a profitability consideration. As was argued before, however, banana is often seen as a security crop, and resource-poor farmers in particular try to keep the monetary outlays as low as possible. This could also explain why the return on labor is highest for the small-scale growers. In terms of per unit costs, the medium-scale producers are slightly more efficient than the small and the large ones, even though the comparative figures show only little variation. This similarity is somewhat surprising, and it should be underlined that inaccuracies might originate from the valuation of non-monetary production inputs at regular market prices for all three producer groups. These uniform values might not exactly reflect the individual household's true opportunity cost

[1] The Agriculture Finance Corporation (AFC) and some of the cooperatives are offering agricultural credits. Yet they are mainly serving the larger producers and only support specified priority crops and activities.

[2] The yield annuity is preferred over the average yield shown in Table 7 because it takes better account of when the yields occur during the plantation cycle.

Table 6: Recurrent annual cost of banana production by farm type (in 1998 KSh/acre)

	Small-scale	Medium-scale	Large-scale
Cost of land	1,486	1,486	1,486
Labor for weeding	1,106	1,343	1,580
Manure	1,014	1,311	2,261
Labor for manuring	316	395	553
Inorganic fertilizers (NPK)	0	158	293
Labor for harvesting and handling	553	672	948
Other costs [a]	316	474	869
Total	**4,791**	**5,839**	**7,990**

Note: 1 US$ = 59.7 KSh according to the official exchange rate in late 1998.
[a] This item includes the operation cost of irrigation, labor for pruning, desuckering, supporting of plants etc.

Source: Author's interview survey (1998).

Table 7: Average banana cost and income figures by farm type (per acre)

	Small-scale	Medium-scale	Large-scale
Cost annuity (KSh)	5,996	7,248	9,992
Average yield (t)	4.35	5.62	7.57
Income annuity (KSh)	23,774	29,312	38,002
Return per labor-day (KSh)	929	904	858
Per unit cost (KSh/t) [a]	1,313	1,292	1,357

Notes: The annuity calculations are based on the annual cash flows shown in the Appendix (Table A1). A discount rate of 10 percent is used. 1 US$ = 59.7 KSh according to the official exchange rate in late 1998.

[a] The per unit cost is calculated as the cost annuity divided by the yield annuity.

Source: Author's calculations based on the interview survey (1998).

(scarcity) of own resources. On the other hand, there are also two arguments that could reasonably explain the close convergence of per unit costs across farm types:

- One reason why larger farms are generally often assumed to be more efficient than smaller ones is the possible realization of economies-of-scale. But, whereas different levels of variable inputs are used by the Kenyan banana farmers, the amount of fixed costs (e.g. through mechanization) is marginal for all producer types. Scale effects are therefore hardly existent in the considered production systems.
- Contrarily, one could also believe that the larger farmers have higher per unit costs. A neoclassical production function, for instance, implies diminishing returns on additional inputs, which would affect the large-scale growers, with their more intensive systems, to a higher degree than the smallholders. Yet the banana cropping intensity of all farm groups in Kenya is far below levels under which maximum yields could be obtained. Thus, cultivation takes place in the lower part of the production function, where there are still almost constant marginal returns on additional inputs.

2.4 Banana Marketing and Trade Channels

Unlike for major cash crops produced in Kenya, where marketing boards or cooperatives exist (e.g. tea, coffee, pyrethrum), banana marketing so far has been predominantly an individual business. Marketing channels often involve a number of private middlemen and traders before the end-consumer is reached (cf. Dijkstra and Magori, 1994). Price formation is not controlled administratively but follows the rules of supply and demand. It was mentioned before that around 24 percent of all Kenyan bananas are produced on a subsistence basis, i.e. they do not leave the producing farm household. The lion's share of commercialized banana production is sold locally by farmers in the form of complete bunches in their unripe stage. Most of the interviewed producers use more than one outlet on a regular basis. Sales are often made to local middlemen at the farm-gate. These middlemen either have their own all-terrain vehicles or they employ people who carry the bunches to the village markets or other collection points at a fixed rate. Local trade in many regions is predominantly a female affair, i.e. women farmers sell the crop to women middlemen. Sometimes, banana bunches are also sold directly by farmers in the local markets without the middlemen. But, especially for more remote farms, it can take a full labor day to market a single bunch due to poor road conditions and lack of transport facilities. In rarer cases, farmers also ripen the bunches on-farm and retail the single hands in their own small kiosks. Banana farm-gate prices slightly vary according to the season. Although harvesting takes place continuously throughout the year, supply usually peaks in the rainy seasons (spring and fall, with regional differences) entailing price decreases. Highest prices are usually obtained from December to February, when the dry spell coincides with rising banana demand in the hot season (ripening bananas are particularly popular in the hot summer months). Price differences also arise between the individual varieties. The cooking type bananas are often somewhat cheaper than the ripening ones, but even within these categories remarkable price differentiation is common. Among the ripening types, the highest prices are usually fetched by Gros Michel (Kampala), because of clear consumer preferences for this cultivar. For the present analysis, a single price is assumed across all varieties, which is derived as the mean value from the farm interview survey; it is 6518 KSh per ton.

Starting from the local banana collection points, there is substantial inter-regional banana trade in Kenya. Specialized traders with their own or hired trucks partly transport green banana bunches over long distances between production and consumption areas. Major targets of such transporters are the wholesale markets in Nairobi, Nakuru, Kisumu, Eldoret and Mombasa. From these wholesale markets, the bananas are sold to the retailers, where bananas are ripened before they reach the urban consumers. International trade with bananas is negligible in terms of exported or imported quantities, so that Kenya can essentially be regarded as a closed banana economy. The chances for opening up export markets in the future are fairly low for Kenya, due to cheaper competitors from Latin America, higher costs of transportation to reach the main importing countries, and barriers to banana trade in these countries, particularly in the European Union. Some potential could exist for exports into the Gulf Region, although there would be competition from Israel and South Africa. Nonetheless, increasing banana production in Kenya could easily be absorbed by national demand. Retail prices in the larger cities are often a multiple of the prices in rural areas, which demonstrates the high urban demand. Expanded outputs, however, would also require improved domestic marketing networks to efficiently connect the regions of supply and demand and to avoid local price downfalls. The recently established Banana Growers Association (BGA) could become instrumental in pooling and representing farmers' marketing interests vis à vis the traders under circumstances of increased commercialization.

3. Introducing Biotechnology in Banana Production

In Kenya, only 20 percent of the total area is suitable for cropping. The rest is arid and semi-arid land which receives too little precipitation to allow for intensive agriculture without irrigation facilities. Given the very high population growth rates in the country, technological measures are required that enhance agricultural productivity in the high-potential areas and enable a sustainable expansion of food production into the more marginal locations. Biotechnology has been identified by national authorities as a priority area to contribute to the solution of Kenya's food deficit problem (Obukosia et al., 1993). Although tissue culture techniques have been used in the country since the early 1980s, pyrethrum and to a lesser extent sugarcane and ornamentals are to date the only crops for which planting material is produced on a commercial scale using these techniques (Wafula and Falconi, 1998).

3.1 The Tissue Culture Project

As elaborated in the previous Chapter, the Kenyan farmers' practice of using pest and disease-infected sucker material for banana propagation is one of the main constraints for improving the crop's yield performance. Laboratory-based micropropagation techniques render pathogen-free planting material. Thus they could help to increase banana productivity substantially. Tissue culture is a comparatively simple technique. It has been used for commercial banana propagation since the mid-1980s in several subtropical producing countries, notably Israel, the Canary Islands, South Africa and Taiwan.

In 1995, Jomo Kenyatta University of Agriculture and Technology (JKUAT) began the micropropagation of banana in Kenya, partly funded by the World Bank. But JKUAT's current laboratory capacity is too small to reach all interested banana growers in the country's producing regions. The main objective of the biotechnology project launched by KARI in 1996/97 and facilitated by ISAAA is to improve the availability of in vitro planting material, especially to the small and resource-poor banana farmers. Specifically, the project intends to build and upgrade national banana tissue culture capacity and to establish viable biotechnology distribution channels. The first three-year phase of the project is financially supported by the Rockefeller Foundation and IDRC. Project funds also cover technical and managerial assistance from ITSC in South Africa, a service which is provided on a regular consultation basis. ITSC is closely cooperating with Du Roi, an experienced private company producing around 3 million in vitro banana plantlets per year for the South African market.

Tissue culture protocols for most of the Cavendish varieties are already available, and researchers at KARI's National Horticultural Research Center in Thika are working on the development of protocols for other widely used varieties.[1] Furthermore, KARI is conducting agronomic research with the TC material. This is important because some of the cropping recommendations from South Africa—a subtropical country—have to be adjusted to the tropical conditions of Kenya. On-station field trials for cultivar evaluation, for testing the optimal plant density and nutritional requirements have been carried out since 1997 in the Regional Research Centers of Kisii (Nyanza), Thika (Central), Embu (Eastern) and Mtwapa (Coast). In the same regions, on-farm field trials have also been started in 1997 in cooperation with selected banana producers to demonstrate the technology and to learn about farmers' requirements and attitudes. These on-farm and on-station field trials are ongoing, and were expanded in 1998 and 1999. The banana farmers involved are generally enthusiastic about the technology and are keen to obtain more in vitro material. In a further step, these farmers could play an important role in technology delivery to other growers, e.g. through the initiation of small banana nurseries as local distribution points.

KARI itself does not have the capacity to produce enough TC plantlets. Currently the material for the field trials is purchased on a commercial basis from Genetic Technology Limited (GTL), a private company in Nairobi. GTL was founded in 1994 and started its business with the in vitro propagation of pyrethrum and sugarcane. The company's diversification into banana tissue culture has essentially been encouraged through the KARI/ISAAA project. Explicit involvement of the private sector in multiplication and dissemination of the technology is regarded as an important strategy to ensure the efficient provision of high quality planting material to farmers, while minimizing the need for external financial support in the longer run. GTL is currently producing around 20,000 banana plantlets per year. For the production of enough material in the future, once the technology finds widespread adoption, there are generally three non-exclusive options. First, GTL itself could increase its production capacity. Second, other national public and private organizations could begin with banana tissue culture or upgrade their facilities (for instance, JKUAT is planning to increase its output), and third, small in vitro plantlets could be imported from Du Roi in South Africa. With more players involved, the market would become more competitive so that prices of TC plantlets would fall, to the benefit of farmers. On the other hand, economies-of-scale can be expected when there is only a single major supplier of TC plantlets.

For widespread technology adoption—especially among small-scale producers—the first project phase will have to be succeeded by another, with a main focus on institution-building and the creation of capacity for technology dissemination. It is also planned to extend the biotechnology project to neighboring countries, Uganda and Tanzania, where the problems of banana production are basically the same. In Uganda, bananas and plantains are the most important food crops, and national production exceeds Kenya's output by almost a factor of 10. Uganda has a good national banana program and maintains close partnerships with the International Institute of Tropical Agriculture (IITA), based in Nigeria but with a regional center in Uganda.

3.2 Advantages of Tissue Culture Plantlets

There are several—partly direct, and partly more indirect—advantages brought about by the use of banana in vitro plantlets in comparison to conventional sucker material. These advantages are:

- Tissue culture banana plantlets are free of the most important pests and diseases that exist in Kenya, notably weevils, nematodes and fungi. Without appro-

[1] For a widespread use of the technology among small-scale farmers it is particularly important to make available in vitro plantlets for cooking type cultivars.

priate care and field hygiene (especially if planted in contaminated soils) banana plants can still be infested at a later ex vitro stage. But it has to be kept in mind that unclean planting material is the main vector of pathogen dispersal in the country. Thus it can be expected that yield losses caused by these pests and diseases could be reduced substantially by starting plantation cycles with clean in vitro plantlets.

- Even when compared to the yield performance of clean conventional sucker material, TC plantlets show a considerable advantage. They usually experience a more vigorous initial growth, with a significantly larger root system, larger pseudostem circumference and larger functional leaf area after the first months of plant development (e.g. Eckstein and Robinson, 1995; Drew and Smith, 1990). This leads to shorter harvest-to-harvest periods, a higher bunch weight, and a higher annual yield. A study carried out with different Cavendish varieties in South Africa revealed that this yield advantage is around 20 percent in the first year, then slightly decreasing but still measurable after the third year (Robinson et al., 1993). Comparable experience with other varieties and under tropical conditions is much scarcer.
- Another frequently mentioned advantage of in vitro plants is their uniformity and more simultaneous plantation development as compared to conventional material (cf. Israeli et al., 1995). Thus orchard management is facilitated, and harvesting can be done over a short period, adjusted to market requirements. However, such uniformity is effective mainly in the plant crop (first cycle) and weakens in the subsequent ratoon harvests, so that this advantage is of less relevance in Kenya, where average plantation cycles are fairly long.
- Apart from the immediate yield gains, another major advantage associated with the use of TC plants is that superior new banana germplasm can be introduced and disseminated much faster. The reason is that large numbers of healthy in vitro banana plantlets can be produced in a comparatively short period of time in the laboratory, whereas the speed of conventional propagation depends on the number of suckers produced by the mother plant. Under farmers' conditions one plant produces only around six suckers per year. The quick introduction of new germplasm is of particular importance in case of an outbreak of a serious disease to which the traditional cultivars are susceptible so that complete banana holdings are destroyed. A case in point in Kenya is the variety Gros Michel (Kampala) with its high susceptibility to Panama disease.
- Experience with tissue culture and the establishment of efficient germplasm distribution channels are also preconditions for quickly realizing the progress of more advanced biotechnologies, e.g. transgenic banana varieties, as soon as they are at hand. Using tools of biotechnology in banana improvement is especially attractive, since combining resistance traits with desired quality characteristics based on conventional techniques proved to be a difficult task during the last 70 years of breeding (INIBAP, 1993). Transformation protocols for banana have already been developed (e.g. Sági et al., 1995), and it is expected that transgenic varieties with resistance to major pests and diseases will become available within the next 10 years (Frison et al., 1997).

3.3 Disadvantages of Tissue Culture Plantlets

Apart from the advantages that tissue culture banana plantlets unquestionably have, there are also certain drawbacks:

- The first limiting factor of using in vitro banana plantlets from the point of view of farmers is the higher price of the material if compared to conventional suckers. This implies a remarkably higher cash outlay for plantation establishment, which could constitute a constraint for the predominantly small-scale banana farming systems of Kenya. The current price of a TC plantlet sold by GTL is around 100 KSh, which—in the absence of suitable access to financial markets—is quite high for resource-poor farmers, regardless of the later benefits. Yet the prices for in vitro plants will definitely decrease when more skills in banana biotechnology are gained and when competition is created by other providers entering the market. Within 1998 alone, the price already fell by one-third. Du Roi in South Africa sells its plantlets at a price which is equivalent to about 35 KSh. Although a direct comparison is misleading due to dissimilar conditions in South Africa (e.g. a different growth stage of the plant at sale), this figure demonstrates that there is further scope for price reductions in the future. As mentioned earlier, imports of small in vitro plantlets from South Africa are an option as well. Mbwana et al. (1998) propose the use of split corm techniques (excavating the corm of available suckers and cutting it into slices to multiply scarce planting material) as a cheaper alternative to tissue culture. However, while split corm techniques prevent weevils and nematodes from being spread through the planting material, they do not remove diseases, which are also severely limiting banana production in Kenya.

- Another disadvantage of TC plants is that they require added care and improved management. Since they have no nutrient reserves when transplanted, external stress is particularly harmful in the first five months after plantation establishment (Robinson, 1993). Without proper fertilization, weeding and enough water supply during this phase, the growth performance of TC plants could be lower than that of traditional suckers. Likewise, transplanting in vitro plants into pathogen-infected soils can be more damaging than with conventional material. Kenya—in comparison to subtropical locations—has the advantage that climatic stress factors are less severe, especially when planting dates are chosen during the rainy season with enough precipitation to avoid irrigation. Nonetheless, it is obvious that the technology can only be successful in Kenya when farmers alter their traditional practices of neglecting the banana crop in terms of labor and input allocation.
- The occurrence of off-types (somaclonal variants) in in-vitro-propagated banana has frequently been reported (e.g. Israeli et al., 1995). These mutations are usually inferior and can lead to dwarfing or other undesired morphological features. Unfortunately, they are often only detectable at a certain growth stage of the plant, i.e. after transplanting into the field. The mutation rate in TC plants might reach levels of up to 50 percent, but can be reduced substantially (down to 1-3 percent) with improved laboratory methods, especially through limiting the number of multiplied specimen per explant. Therefore, special care has to be taken that the objective of lowering the price of in vitro plants is not at the cost of increased mutation rates.
- While most of the pathogens are removed from the banana plant in the tissue culture procedure, viruses can still be transmitted through in vitro plants. Although banana viruses so far do not constitute a problem in Kenya, there is a risk that they could be brought into the country via imports of in vitro material from infected areas of the world. Therefore, the source of the material should be unambiguously clarified before any transboundary banana germplasm transfer takes place.

4. Potential Technology Effects at the Farm Level

The potential income effects of the tissue culture technology in Kenya are analyzed by juxtaposing the banana enterprise budgets currently observed for the three farm groups (without the technology) with the projected ones using the new technology. This is not a straightforward procedure, because—as mentioned earlier—the exploitation of technology benefits requires the use of complementary instruments, notably more fertilizers and added care in terms of labor allocation. The use of the tissue culture technology, therefore, has to be understood as a technology package, comprising the TC planting material as well as the bundle of additional inputs and production factors. Although first evidence about tissue culture yields under the more or less optimal conditions of research stations is available for Kenya, there is still uncertainty associated with the question of to what extent farmers are able and willing to recapitulate these conditions, which are significantly different from their current farming practices. The on-farm field tests carried out so far offer initial insights, but as for demonstrating the advantages of the technology they were mostly managed by the researchers. Historical experience from Kenya and other countries demonstrates that farmers might adopt a certain component of a technology package, while refusing another component or adopting it at a later stage, according to subjective profitability and risk considerations (e.g. Parton, 1993; Byerlee and Hesse de Polanco, 1986). For instance, a banana grower could decide to buy TC plantlets without exactly following the recommendations for regular desuckering, or for the amount of manure and fertilizer to apply. Of course, such individual modifications of the package would influence the yield levels to be obtained. Indeed, given traditional banana cultivation practices in Kenya, it would be quite unrealistic to assume a sudden and complete adoption of all recommended components by the growers. Nevertheless, the interviews and hitherto field trial experience revealed that the farmers are generally keen on innovating within their banana enterprises. Against the backdrop of falling farm-gate prices for traditional cash crops, they consider the banana activity as a good cash-earning opportunity for the future. The main constraint to farmers fully realizing their intensification strategies will be resource shortages, particularly for the poorer and smaller producers.

The crop enterprise budget projections presented here are based on information from interview surveys with banana researchers, extension officers and farmers. They presume that—due to stronger liquidity constraints and risk aversion—smaller farmers adopting the TC technology would intensify their banana activity to a lesser absolute degree than the larger ones. As little is known so far about farmers' actual adoption behavior and long-term yield performance of in vitro banana plants under sub-optimal conditions, the calculations presented cannot provide more than a first and rough impression of likely effects of the biotechnology project at the individual farm level. As in Chapter 2, we proceed in a stepwise manner to cover the whole plantation cycle. We start with the consideration of crop establishment and recurrent production costs, before the technology's potential impact on banana incomes is analyzed. The plantation longevity is assumed to be 14 years for both the without and with-technology alternatives. It might be argued that, due to lower pest and disease problems with TC material, the crop could be used for a longer period. But experience from other banana-producing countries reveals that increasing intensification and commercialization often goes along with shorter plantation cycles for economic reasons.

4.1 Effects on the Cost of Production

4.1.1 Plantation Establishment Cost

The recommended plant spacing for tissue culture bananas in Kenya is 3 by 3 meters, i.e. 450 plants per acre, which is more than double the amount of mats per unit area compared to average traditional plant spacing (cf. section 2.3.3). The estimated establishment costs with and without the use of in vitro planting material is shown in Table 8. It has to be stressed that in the calculations it is build upon the supposition that all farm types would use the technology. This is done for examining the agronomic potential of the innovation. Possible adoption constraints are mentioned in this Chapter, and they will be incorporated into the market considerations in Chapter 5.

The largest cost item in the with-technology projection is by far the TC planting material itself, making up 76 percent of the small-scale farmers' total establishment investment. For the medium- and large-scale producers, the acquisition of the plantlets accounts for 73 and 67 percent of the overall establishment cost, respectively. The calculation assumes a price of 75 KSh per purchased plant. As seen in the previous Chapter, the current commercial price of in vitro plants in Kenya is 100 KSh, so that the assumed value would not fully compensate for today's cost of laboratory production. However, the price is a realistic reference in the medium-run, as increasing experience, economies-of-scale and/or competition are likely to lower the cost of producing TC plants substantially in the future.[1] At a price of approximately 75 KSh for farmers, plantlets could also be imported from South Africa, if the cost of transportation, import taxes and handling is accounted for (Z. de Beer, 1998, personal communication).

Owing to the higher plant density, the cost of manual labor for digging the planting holes is also much higher for the with-technology projection. A sufficient planting depth is important for the in vitro plants. If planted too shallow, the rhizome tends to climb above soil level because of the rapid and vigorous growth. Furthermore, the use of inputs, particularly farmyard manure, is considerably expanded in all farm types. But it is likely that the absolute production intensity will remain higher for the larger producers as compared to the smaller ones, who are facing more severe resource constraints. As in Chapter 2, the given cost figures are not inevitably connected to an equivalent monetary outlay, since the farm households' own resources are valued at their prevailing market prices. Including these opportunity costs in the considerations is important, for the availability of own means of production (e.g. labor and manure) is limited. Allocating more resources to the banana enterprise entails either foregone income from other activities or cash outlays for purchasing additional amounts. The incremental establishment cost associated with using TC material is substantial for all three farm types.[2] For the large-scale farmers, the projected cost is 334 percent of the currently observed conventional establishment cost. For the other groups, the corresponding ratios are even higher: 451 and 517 percent for the medium- and the small-scale producers, respectively.

Even though nothing has been said so far about the profitability of the additional investment, it has to be

[1] Moreover, the BGA—in addition to bundling the commercialization interests of farmers (cf. section 2.4)—could also assist in increasing the bargaining power of banana growers vis à vis the TC laboratories with respect to prices and qualities of the technology product.

[2] Especially for the large-scale farmers, the establishment cost could still be higher when bigger pieces of land are to be planted with TC material. This would create extra costs for sourcing enough in vitro plantlets of the desired varieties. Transaction costs of this kind are not taken into account in the calculations.

Table 8: Banana plantation establishment cost without and with the use of TC technology (in 1998 KSh/acre)

	Small-scale		Medium-scale		Large-scale	
	without	**with**	**without**	**with**	**without**	**with**
Labor for land preparation	395	395	395	395	395	395
Labor for hole digging	2,212	4,740	2,212	4,740	2,212	4,740
Manure	1,680	2,584	2,649	3,876	5,685	7,106
Labor for manuring	553	790	790	948	1,185	1,264
Nematicides	45	600	99	1,020	450	1,500
Planting material	2,842	33,750	3,248	33,750	4,263	33,750
Labor for planting	869	1,580	869	1,580	869	1,580
Total	**8,596**	**44,439**	**10,262**	**46,309**	**15,059**	**50,335**

Note: 1 US$ = 59.7 KSh according to the official exchange rate in late 1998.
Source: Author's calculations based on the interview survey (1998).

clearly seen that the comparatively high setup cost of using tissue culture plants will make it difficult for resource-poor farmers to adopt larger amounts of TC plants in the absence of available credit. Seen realistically, farmers would start testing the technology with a smaller number of plantlets. If correct field hygiene is practiced, it is even likely that suckers from the in vitro mother plants could be used for further conventional propagation, while still benefiting to a significant degree from the initial health and vigor of the basic material. This option is currently being tested in KARI field trials. It is evident that "own propagation" of the technology would reduce the plantation establishment cost substantially. We account for this alternative in section 4.2, by additionally analyzing a scenario in which a lower average price per TC plant is assumed.

4.1.2 Recurrent Production Cost

The recurrent annual cost calculations for banana production under traditional practices and under the conditions of tissue culture plants are compared in Table 9. Again, the costs for all three farm types are projected to be remarkably higher with the use of the technology. The provision of appropriate plant nutrients was mentioned to be an important factor for satisfactory growth and development of TC plants. So the expenditure for fertilizers (including manure) becomes the major component in the recurrent cost accounts for all producer groups. Moreover, the labor cost for care and management works increases to a noteworthy extent. This is due to the need for maintaining clean field conditions (e.g. weeding, desuckering, mulching), higher input amounts to be applied and higher yields to be handled, including the pre-harvest propping of stems (with wooden poles or ropes) that carry exceptionally heavy bunches.

4.2 Effects on Banana Yields and Incomes

As expected, the increased cost of production under tissue culture conditions will lead to sizeable yield gains. Estimated effects of the technology package on the yield curves over the whole plantation cycle are graphically depicted in Figure A1 in the Appendix. There are mainly three features that characterize the differences between the without and the with yield curves consistent for all farm groups. First, the time between planting and the first crop harvest is usually shorter under TC conditions, about 12 months in tropical areas as the field trials show (KARI, 1998). This offers the advantage that—in contrast to the traditional system—a positive income flow is generated in the first year, notwithstanding the high plantation establishment cost (cf. Table A2 in the Appendix). Second, the yield peak occurs earlier and reaches a significantly higher magnitude. And third, the yield decline in subsequent years is lower. These phenomena are attributable to the better growing conditions in the with-technology alternative, i.e. the pathogen-free planting material and improved management practices.

Given the described differences in the cropping intensities across farm types, it is not surprising that the absolute yield level is highest for the large-scale producers. On the other hand, potential yield gains in relative terms are most pronounced for the small-scale farmers. As shown in Table 10, the smallholders could increase their average yield by 150 percent (medium: 132 percent;

Table 9: Recurrent annual cost of banana production without and with the use of TC technology (in 1998 KSh/acre)

	Small-scale		Medium-scale		Large-scale	
	without	with	without	with	without	with
Cost of land	1,486	1,486	1,486	1,486	1,486	1,486
Labor for weeding	1,106	1,580	1,343	1,738	1,580	1,896
Manure	1,014	1,938	1,311	2,584	2,261	4,199
Labor for manuring	316	553	395	790	553	948
Inorganic fertilizers (NPK)	0	675	158	1,125	293	1,688
Harvesting and handling	553	1,185	672	1,264	948	1,343
Other costs [a]	316	632	474	790	869	1,106
Total	**4,791**	**8,049**	**5,839**	**9,777**	**7,990**	**12,665**

Note: 1 US$ = 59.7 KSh according to the official exchange rate in late 1998.

[a] This item includes the operation cost of irrigation, labor for pruning, desuckering, supporting of plants etc.

Source: Author's calculations based on the interview survey (1998).

Table 10: Average banana cost and income figures without and with the use of TC technology (per acre)

	Small-scale		Medium-scale		Large-scale	
	without	with	without	with	without	with
Cost annuity (KSh)	5,996	13,815	7,248	15,774	9,992	19,159
Average yield (t)	4.35	10.89	5.62	13.03	7.57	14.61
Income annuity (KSh)	23,774	60,853	29,312	71,744	38,002	78,388
Return per labor-day (KSh)	929	1,251	904	1,271	858	1,211
Per unit cost (KSh/t) [a]	1,313	1,206	1,292	1,175	1,357	1,280

Notes: The annuity calculations are based on the annual cash flows shown in the Appendix (Tables A1 and A2). A discount rate of 10 percent is used. 1 US$ = 59.7 KSh according to the official exchange rate in late 1998.

[a] The per unit cost is calculated as the cost annuity divided by the yield annuity.

Source: Author's calculations based on the interview survey (1998).

large: 93 percent). Holding prices constant, average per acre incomes for the small-, medium- and large-scale farms could rise by 156, 145 and 106 percent, respectively. This demonstrates the high profitability of the necessary incremental investment associated with adopting the technology package, and its general suitability for all farm types. Likewise, using the tissue culture technology would considerably increase the net return on labor for all producer groups, which is also an important criterion in the prevailing situation of relative labor scarcity at the level of the individual farm household.

Although potential yield and income effects are meaningful indicators with which farmers can evaluate the tissue culture technology, they are not the appropriate measures to assess the rate of technological progress induced by the innovation. Technological progress is defined as an upward shift in the commodity's production function, or as an increase in the total factor productivity. In monetary terms, the total factor productivity at the farm level is measured by the average cost that arises per unit of output. Thus, holding input prices constant, technological progress can be assessed by calculating the technology-induced savings in the per unit cost of production. The potential per unit cost reduction through the use of tissue culture technology is 8.1 percent for the small, 9.1 percent for the medium and 5.7 percent for the large-scale farmers. These values clearly demonstrate that the potential yield and income increases are only partly due to the shift in the production function itself. Considerable proportions of the gains are obviously attributable to an upward movement along this function, i.e. an adjustment of the previous input mix. This is not surprising because modifications of the traditional cropping intensities were mentioned as being a necessary condition for using the TC technology successfully.

Lower Price for TC Plants

So far, we have assumed a farm-gate price of 75 KSh per TC plantlet. Yet it is possible that the average cost will eventually be much lower. As argued before, it is likely that farmers will be able to multiply their own suckers from already acquired in vitro plants. It is not yet clear how many times this method can be practiced before completely losing the technology advantage. This will also depend to a great extent on farmers' cultivation practices. We take the possibility of such "technology self-propagation" into account by projecting additional with-technology enterprise budgets under a lower cost assumption for in vitro plants. Table 11 shows how different prices influence the technology-induced changes on the cost and income variables. The higher price scenario is just a summary of the calculations discussed above, i.e. with a price of 75 KSh for a TC plantlet. The lower price scenario utilizes an average price of 35 KSh per plant. This value was chosen more or less arbitrarily; it corresponds to the price that South African farmers have to pay for in vitro plants. Both scenarios take the without-technology calculations as the reference.

It can be seen that the cost of the plantlets is a critical variable in the calculation of tissue culture effects at the farm level. The additional cost associated with using the technology for all farm types shrinks sharply in the lower price scenario, and consequently the additional income is somewhat increased—provided that potential yield gains remain the same. It is not surprising that a decrease of the TC price would have the most conspicuous positive influence on the small-scale producers, whose cost accounting is more dominated by the outlays for the planting material than that of the other two groups. So, whereas the per unit cost reduction caused by the technology in the initial scenario was highest for the medium-scale farmers, in the lower price alternative the smallholders could realize the highest growth in the total factor productivity.

4.3 Institutional Aspects of Technology Dissemination

It has to be stressed that the potential technology advantage indicated in the previous sections can only be harnessed under the contingency that banana management is improved, as assumed in the calculations. Under the currently prevailing husbandry situation, where banana is rather a neglected crop in terms of input allocation, it is likely that the TC plants will not show any yield gains at all. Or more pessimistically, they could even perform worse than conventional sucker material. If banana producers were to buy in vitro plants without adjusting their input mix accordingly, they would suffer remarkable income losses. This illustrates the paramount importance of transferring the technology to farmers only in combination with the extension message of how to use it successfully. Otherwise farmers will experience disappointing results, which would be detrimental to their own income situation on the one hand, and to the general image and acceptance of the tissue culture technology on the other. Measuring the short-run project impact only in terms of numbers of distributed TC plants should, therefore, be avoided by all means.

Table 11: Technology-induced changes in cost and income figures under different price assumptions for TC plants (percent)

	Small-scale		Medium-scale		Large-scale	
	Higher TC price	**Lower TC price**	**Higher TC price**	**Lower TC price**	**Higher TC price**	**Lower TC price**
Increase of cost annuity	130	93	118	87	92	70
Increase of average yield	150	150	132	132	93	93
Increase of income annuity	156	165	145	152	106	112
Increase of return on labor	35	36	41	42	41	43
Per unit cost reduction	8	23	9	22	6	17

Note: The higher price scenario assumes a price of 75 KSh per TC plant; the lower price scenario is based on the assumption that the average cost per in vitro plant is 35 KSh.

Source: Author's calculations based on the interview survey (1998).

It must also be questioned whether it is realistic at all to expect that farmers would adopt a technology for which they are required to significantly change their traditional cropping practices. And whether remarkable yield and income increases could not be achieved even without biotechnology, simply by intensifying the prevailing banana systems. To get a better understanding of these issues, it is instructive to examine more closely the reasons behind farmers' current low-input behavior. The optimal production intensity for the individual farmer is a function of technical input-output relationships on the one hand, and of economic options and constraints on the other. While both aspects might be two sides of the same coin in a situation of perfectly competitive markets, this is not the case in a situation of market failures. From a mere technical standpoint, the low-input intensities observed in the Kenyan banana sector seem to be sub-optimal. But widening this narrow view, it becomes apparent that the prevailing production patterns are just a symptom of the imperfections in rural factor markets. As discussed before, the scope of the government's agricultural extension service is too limited to cover the banana crop effectively and, without such effort, knowledge of how to improve banana production remains limited. But even if farmers would like to intensify, they are often confronted with liquidity constraints, meaning that the marginal cost of raising output levels may be very high, even in situations where, technically, favorable returns on additional inputs could still be expected. Hence, the observed perpetuation of the low-input banana farming systems in Kenya is largely determined by failures of the markets to provide information and rural finance. Improving this situation is not an easy task, neither without nor with new technology. Yet the potential of an appropriately introduced technological innovation to bring about broader institutional innovation and a more comprehensive modernization of farming systems should not be underestimated. In connection with a tangible technological product (i.e. TC plantlets) it will be much easier, for instance, to transfer knowledge about improved management practices than without such a tool. Of course, this depends on an efficient organizational structure for technology dissemination. One of the KARI/ISAAA project's main objectives is to create new biotechnology and information distribution channels. A specific training of, and an additional resource allocation to, the government's extension service is one possibility. But other promising and innovative models of technology transfer are conceivable as well (ISAAA, 1997). Some related comments are given below.

As indicated in Chapter 3, local distribution points for in vitro plants will have to be established, in order to connect the supply from the laboratories (currently only in Nairobi) with the demand in the different rural areas of the country. Before the plantlets leave the initial supplier (laboratory) it is advisable that they are already acclimatized to ex vitro conditions so that the rate of later plant losses can be kept low. At the same time, they should still be small (around 5 cm) to minimize the cost of transportation. After the plantlets are transported, the task of the local distribution points is to harden them, under shaded nursery conditions, up to a height of about 30 to 40 centimeters before they can be handed over to the banana growers for field transplantation. So far, KARI itself has taken on this role, but expanding this service—once the technology leaves the stage of field trials—would go beyond the institute's mandate and capacity. A private contract is likely to be the more efficient alternative and would also foster the project's economic independence in the longer run. In particular, non-governmental organizations (NGOs), such as church or women's groups in rural areas, should be considered and encouraged to start small-scale banana nursery enterprises. Since such organizations are usually grassroots initiatives of the rural communities, they could not only retail the TC plantlets, but could effectively combine the sales with a participatory transfer of the important extension information. The initial investment required for establishing a nursery is comparatively low. Nonetheless, some financial and technical support should be granted to the implementing organizations in the beginning. After a certain learning phase, however, the business itself and the provision of extension services could well be financed out of the product sales. The possibility of involved NGOs managing a small-scale credit program, especially tailored to facilitating TC technology adoption for the resource-poor producers, should also be contemplated. We argue that a more explicit involvement of women's groups into technology demonstration and dissemination efforts is especially appealing because of several reasons (also see Qaim, 1999):

- These groups consist of female farmers, who are mostly engaged in banana growing anyway, so they know best the problems and constraints associated with cultivating the crop.
- The on-farm field trials should also be conducted with women's groups. Thus, the demonstration and extension message would immediately reach many more growers than the individual farmers' approach practiced so far. The collective commitment could

improve the trial results and could advance the groups' own initiatives for nursery establishment.

- Up to now, agricultural extension services in Kenya were mostly male-focused, even for semi-subsistence activities which are predominantly managed by women (RNE, 1994; Maarse et al., 1998). If women's groups were to organize nurseries for TC bananas and related extension services, there would be increased likelihood that the message reaches the female farmers who are responsible for the bulk of maintenance work in banana enterprises.
- Often, technological progress and increasing commercialization in developing country agriculture entails a situation where men take over traditional female responsibilities, which curtails the women's scope and freedom of decision-making (e.g. von Braun and Webb, 1989). An indication for such a trend in the Kenyan case of bananas is the positive correlation between the male-managed dummy variable and some of the input and technology parameters presented in Chapter 2. Explicitly involving women's organizations in the process of technology dissemination would hardly stop this trend, but could at least contribute to weakening it.
- Women's groups are officially registered organizations in the Social Services Department of the District Offices, and they are eligible to apply for formal funds from governmental and other sources. Although government funds are scarce in Kenya, the general international tendency toward empowerment of rural women should make it possible to access foreign development grants for gender-sensitive technology dissemination programs.

Notwithstanding these apparent advantages with women's groups, the efforts for creating viable biotechnology distribution channels should not focus only on one single approach. In Embu, for instance, a church group has recently established a link with GTL and has started to set up a local nursery for TC banana plantlets. In Central Province, a farmer who participated in on-farm field trials was immediately convinced of the technology advantages in such a way that she has already begun retailing in vitro material bought from KARI. These promising examples suggest that there should be enough flexibility in the project design to account for regional differences and to allow for participatory ideas and initiatives of the farmers and other stakeholders themselves.

5. Market Effects of Biotechnological Progress

Potential income effects of the tissue culture technology at the farm level have been investigated in the previous Chapter. However, while from the individual farmer's perspective the expected income gains are an important criterion, they do not constitute the appropriate instrument to evaluate the technology from an economic point of view. First, the income calculations assumed per se that farmers are using the technology, i.e. they abstracted from possible adoption constraints. Second, they reckoned with constant banana prices, even though it is expected that the technology itself will induce price decreases. Third, potential benefits to banana consumers caused by such price decreases were neglected. And fourth, the projected income gains overstated the increase in the total factor productivity, which is the standard measure for technological progress. This Chapter attempts to provide a more comprehensive picture of the technology's efficiency and equity implications by modeling likely effects of tissue culture bananas at the national market level.

5.1 Methodology

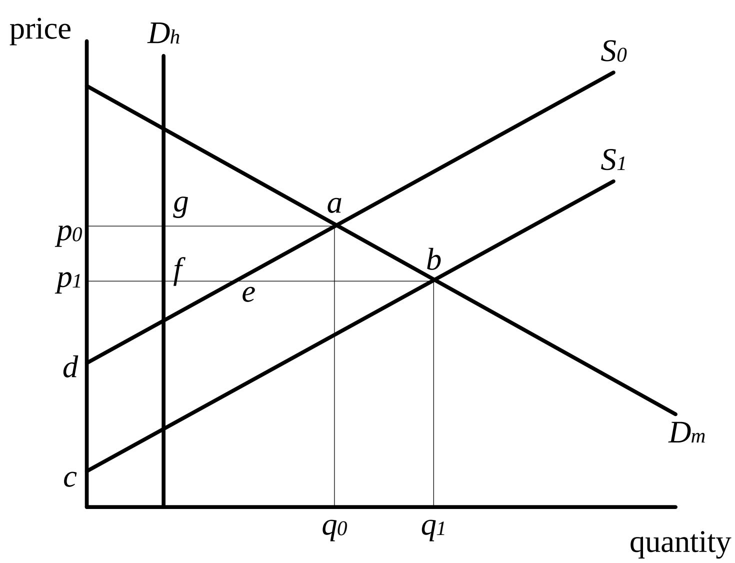
The biotechnological progress in the Kenyan banana sector is analyzed with a partial-equilibrium displacement model. Models of this kind are the most common approach used for evaluating returns on agricultural R&D, and they have been ranked as the best available method for that purpose by Alston et al. (1995). However, while they are suitable for the assessment of direct and immediate welfare effects of the technology for banana producers and consumers, more indirect and dynamic positive repercussions are not covered within the framework. Technological progress in tradable agricultural commodities augments rural incomes and can engender employment generation and broader regional growth via rising demand for locally produced goods. Noteworthy agricultural growth linkages have recently been proved empirically for various countries of Sub-Saharan Africa. Delgado et al. (1998) showed that initial income gains from increased crop production are doubled on average due to demand-driven growth multipliers. Unfortunately, it is hardly possible to attribute such effects to specific technologies, let alone within the *ex ante* considerations of the present study. Keeping in mind that our model results will probably underestimate the long-term benefits, we quantify the expected welfare gains of the tissue culture banana technology on the basis of changes in the producer and consumer surplus measures.

For a highly commercialized commodity, the differentiation between producers and consumers is clear. Many crops in developing countries, though, are produced on a semi-subsistence basis, as was shown to be the case for bananas in Kenya. This means that the general division between producer and consumer surplus is flawed. Hayami and Herdt (1977) developed a model in which they complemented the market demand curve of a semi-subsistence crop with an additional demand curve for home consumption. Nguyen (1977) represented subsistence demand accordingly. In general, home consumption of an own-produced crop is less price responsive than market demand for the same commodity. In the absence of more detailed information it might be a simplified but not unrealistic approximation to assume that the demand curve for subsistence consumption is vertical, i.e. it is completely price inelastic (Norton et al., 1987). A simple model of biotechnological progress in the Kenyan banana market—taking account of home consumption—is graphically depicted in Figure 2.

The initial banana supply curve without the use of tissue culture technology is S_0. D_m and D_h are the demand curves of market purchasers and of home consumption, respectively. The reference price and quantity equilibrium is given at point *a*. The biotechnology application will enhance the productivity of banana production. By lowering the cost per unit of output, it will cause the initial supply curve to shift downwards to S_1. The new equilibrium is characterized by point *b*. Hence, the change in consumer surplus for market purchasers is area *gabf*, and the change in producer surplus is area *ebcd* minus area *gaef*. Interestingly, the magnitude of the overall technology-induced change in economic surplus (area *abcd*) is exactly the same as if there were no home consumption. The only difference occurs in benefit partition between producers and consumers. Whereas, in a completely commercialized market, consumers would additionally capture the rectangle p_0gfp_1, in the semi-subsistence setting producers retain that benefit due to home consumption.

Although the model appears suitable to depict the Kenyan banana market, it is so far not apt to identify distribution effects of the technology between different producer groups. To do so, the aggregate supply curve of all domestic producers needs to be disaggregated into the individual supply curves of the constituent

Figure 2: Biotechnological progress in the Kenyan banana market



farm types, so that the technology shifts are modeled separately for each group. Assuming spatial market integration and thus a single national demand curve, price formation after technological progress becomes a joint function of these independent shifts. An equilibrium displacement model with a supply disaggregation for *n* producer groups has recently been described by Qaim (1998), based on linear functions of supply and demand, and a parallel shift of the supply curve. The technology-induced reduction of the equilibrium price (*p*) has been derived as:

$$\frac{dp}{p} = \frac{\sum_{i=1}^{n}\left(ss_i \cdot e_{s,i} \cdot K_i\right)}{e_d - \sum_{i=1}^{n}\left(ss_i \cdot e_{s,i}\right)} \qquad (1)$$

where ss_i is the production share, $e_{s,i}$ is the price elasticity of supply, and K_i is the downward shift factor of producer group *i*. e_d is the price elasticity of demand. Using the same model and additionally accounting for home consumption, we obtain the following equations for the changes in consumer surplus (*CS*) and producer surplus (*PS*) for producer group *i*:[1]

$$\Delta CS = -p \cdot q_d \cdot \frac{dp}{p} \cdot \left(1 + 0.5 \cdot e_d \cdot \frac{dp}{p}\right) - \left(-dp \cdot q_d \cdot \sum_{i=1}^{n}\left(h_i \cdot ss_i\right)\right) \qquad (2)$$

$$\Delta PS_i = p \cdot q_{s,i} \cdot \left(\frac{dp}{p} + K_i\right) \cdot \left(1 + 0.5 \cdot e_{s.i} \cdot \left(\frac{dp}{p} + K_i\right)\right) + \left(-dp \cdot q_{s,i} \cdot h_i\right) \qquad (3)$$

where q_d is the total quantity demanded (market plus home-consumed), $q_{s,i}$ is the total quantity produced by producer group *i*, and h_i is the average proportion of home consumption by the same group. The technology downward shift factor *K* for producer group *i* in a given year *t* is defined as:

$$K_{i,t} = C_{i,pot} \cdot A_{i,t} \qquad (4)$$

with C_{pot} the group-specific potential per unit cost reduction through the biotechnology application, and *A* the group and time-specific technology adoption rate.

Based on this model, the analysis is carried out from 1999 to 2020. There had been no significant technology application before 1999. And even though the tissue culture technology might still produce benefit flows after 2020, the discounting procedure will prevent these benefits from significantly changing the results after the considered 22-year period. Given the comparatively high population growth in Kenya—and thus rising food demand—technology benefits derived on the basis of a constant demand curve over time would underestimate the true benefits. Therefore, a little refinement to the described model is made as proposed by Norton et al. (1987): we let the demand curve exogenously shift rightwards by the extrapolated annual population growth rate observed in recent years, which has been 2.6 percent on average (World Bank, 1999). A substantial additional expansion in banana demand due to income growth is not expected, as average per capita growth of GNP has been almost zero in Kenya during the last decade. The model is run for two different sce-

[1] Whether the technology-induced shift of a crop's supply curve shall be modeled as a parallel or a pivotal one has been extensively discussed in the literature without general agreement. A pivotal shift is appropriate if it is expected that farmers with high marginal costs of production would realize technological progress which is different from that of the low-cost producers. Such evidence could not be traced within the considered banana farm types in Kenya. Remember that the shifts are modeled separately for each individual group. Rose (1980) argued the use of a parallel shift, whenever a clear empiric justification for a pivotal shift is lacking. This argument has been reinforced again by Alston et al. (1995).

narios: (i) the assumed higher price for TC material (75 KSh), and (ii) the lower price (35 KSh) per plantlet (see section 4.2).

Data

The quantities of banana production and consumption used for the model computations are taken from the official Kenyan agricultural statistics (MALDM, 1996, 1997). Subsistence amounts are already included in these statistics because they are based on area estimates rather than on marketed production. In order to subside annual output fluctuations, an arithmetic mean of the 1996/97 figures has been calculated. The average banana farm-gate price was obtained from the farm interview survey in the different banana-producing regions. Because of the exogenous shift in demand, the reference price and quantity equilibrium changes during the period of consideration. Production shares and proportions of home consumption for the individual farm types have already been discussed in Chapter 2. Unfortunately, estimates on banana price elasticities of supply and demand for Kenya could not be found in the literature. For some of the export-oriented banana-producing countries of Latin America, supply elasticities are presumed to be quite high, up to a level of 3.0 (Hallam, 1995). For the semi-subsistent farming systems of Kenya, the values should be far below that. In the absence of better information, supply response parameters for agricultural crops in developing countries are often approximated with a value near to one (cf. Alston et al., 1995). Owing to the somewhat more commercialized and input-intensive conditions of large-scale farmers, their production is expected to be more price responsive than that of the smaller farms. We assume banana supply elasticities of 0.8, 1.0 and 1.2 for the small-, medium- and large-scale farmers, respectively. An average price demand parameter for bananas across various industrialized countries has been estimated with a value of around –0.4 (Islam and Subramanian, 1989). Given that in developing countries the price responsiveness of demand is usually remarkably higher, for Kenya a demand elasticity coefficient of –0.8 is assumed.[1] The technology-related data to determine the group-specific supply curves' shift factors is based on the primary data collection within the interview surveys. The potential per unit cost reductions (C_{pot}) for the three farm types have been presented in Chapter 4. Estimated technology adoption rates (A) are discussed in the following section.

5.2 Technology Adoption

The adoption of tissue culture technology is one of the key variables determining the shift of the farm types' banana supply curves, and thus the economic benefits to producers and consumers. Technology adoption for the purpose of this study is defined as the share of all Kenyan bananas produced under tissue culture conditions. Due to the divisibility of planting material this implies that adopting the technology for the individual farmer is not only a dichotomous (using/not using) decision. It is rather expected that banana growers start purchasing TC plantlets for a small portion of their land and expand adoption according to the personal advantage experienced. Likewise, aggregate adoption over all farms will be a gradual process. Most of the studies about the diffusion of agricultural technology assume that the cumulative rate of adoption over time follows an S-shaped logistic function (CIMMYT, 1993), i.e. a slow start, followed by a phase of progressive adoption, before turning into an asymptotic convergence toward the maximum level. We follow this approach for the tissue culture bananas. The technology adoption profile is defined as:

$$A_t = \frac{A_{\max}}{1 + e^{(-a - b \cdot t)}} \qquad (5)$$

where A_t is the cumulative adoption in a given year t, A_{max} is the long-term upper bound of adoption, and a and b are constants describing farmers' adoption behavior. The adoption behavior, of course, is not yet known in the *ex ante* framework applied here. It should mainly be influenced by factors such as the expected private profitability of the innovation, the complexity of using it and its compatibility with the farming systems, farmers' individual risk perception, and resource constraints, as well as by the effectiveness of the institutions in the dissemination framework. Obviously, the relevance of these partly inter-related factors differs across

[1] Differences in the demand elasticities for the ripening banana varieties and the cooking types might be expected, because the latter are used as a staple food. However, cooking bananas are not the most important staple commodity in Kenya, so that substitution effects are relevant, and it is realistic to assume a demand parameter significantly different from zero.

farm types so that adoption behavior will differ, too. As argued in Chapter 4, it is likely that more severe resource constraints and concomitantly higher risk will lead to a slower technology adoption by the smaller farms. This is in accordance with international experience related to the diffusion of agricultural innovations that are associated with relatively high setup costs (cf. Feder et al., 1985).

In an *ex ante* study of agricultural biotechnology diffusion in the USA, Lesser et al. (1986) obtained predictions for certain adoption parameters directly from the potential users of the innovation to be introduced, i.e. from the farmers themselves. In Kenya, most of the banana growers found it difficult to imagine the advantages of tissue culture planting material and to anticipate their own adoption behavior, without encountering the technology first. For the present analysis it was, therefore, decided to elicit related information from the interviewed banana experts and extension workers, who based their projections on existing knowledge about tissue culture and past experience with other technologies. The interviewees were asked to estimate A_{max} and cumulative adoption rates after 5, 10 and 20 years, respectively, for the three farm types under different assumptions for the price of TC plants. The median results of these estimates for the two scenarios to be analyzed are shown in Table 12.

On account of the substantial cost outlay for the tissue culture material itself, it is not astonishing that, under the lower price assumption, technology diffusion would be much faster than in the higher price scenario for all farm types. Besides, the upper limit of adoption is anticipated to be significantly higher, and the differences between the farm types' adoption patterns would shrink with lower TC prices. For specification of the logistic adoption profiles we applied a technique proposed by Griliches (1957).[1] Equation (5) can be transformed to obtain the following linear relationship:

$$\ln\left(\frac{A_t}{A_{\max} - A_t}\right) = a + b \cdot t \qquad (6)$$

Using the figures from Table 12, we identified the parameter values for a and b which yielded the best fitting straight line. These values were inserted in equation (5) to attain the farm type-specific logistic adoption curves. The resulting profiles for the two scenarios are graphically shown in Figure A2 in the Appendix. These profiles delineate for each individual year the projected cumulative adoption rates, which are employed to determine the technology shift factor K according to equation (4).

5.3 Welfare Effects for Banana Producers and Consumers

On the basis of the described data and information, the economic surplus model outlined in section 5.1 is run for the two TC price scenarios. The obtained annual changes in producer and consumer surplus induced by the technology are presented in Table A3 in the Appendix. The results are summarized in Table 13. We use the annuity to describe the average annual benefit that accrues to producers and consumers in the 1999-2020 period. Moreover, the benefit distribution among the different producer groups is shown in percentage terms. For the evaluation of equity effects, the benefit shares can be compared with the farm groups' initial production shares.

It becomes evident that tissue culture technology is likely to bring about a substantial aggregate welfare growth in the Kenyan banana sector, regardless of the underlying assumptions about the costs of in vitro plants. What is striking, however, are the major differences in the absolute amounts for the two scenarios analyzed. Whereas it could have been expected that—due to the higher per unit cost reductions and the accelerated technology adoption—the lower TC price scenario would produce the greater benefits, the dimension of the scenario differences is quite surprising. The average annual change in total economic surplus with the higher TC price is around 94 million KSh; assuming the lower price it multiplies by more than the factor 8, to 764 million KSh.

[1] A similar approach has also been used by Lemieux and Wohlgenant (1989) in a study on the future impacts of biotechnology-derived growth hormones in the US pork industry.

Table 12: Estimated technology adoption rates under different price assumptions for TC plants (percent)

	Small-scale		Medium-scale		Large-scale	
	Higher TC price	**Lower TC price**	**Higher TC price**	**Lower TC price**	**Higher TC price**	**Lower TC price**
Maximum adoption rate	25	60	50	80	80	95
Adoption after 5 years	1	5	2	8	5	10
Adoption after 10 years	5	40	15	65	25	85
Adoption after 20 years	15	60	45	80	70	95

Note: The higher price scenario assumes a price of 75 KSh per TC plant; the lower price scenario is based on the assumption that the average cost per in vitro plant is 35 KSh.

Source: Author's interview survey (1998).

Table 13: Benefits and distribution effects of the technology for different scenarios

	Producers			
	Small	**Medium**	**Large**	**Consumers**
		Higher TC price		
Annuity of surplus change [a]	0.8	34.9	17.3	41.4
Share of producer surplus (percent)	1.5	65.9	32.6	43.9 [b]
Initial production share (percent)	36.9	41.0	22.1	–
		Lower TC price		
Annuity of surplus change	128.4	222.3	89.9	323.3
Share of producer surplus (percent)	29.1	50.5	20.4	42.3 [b]
Initial production share (percent)	36.9	41.0	22.1	–

Note: The higher price scenario assumes a price of 75 KSh per TC plant; the lower price scenario is based on the assumption that the average cost per in vitro plant is 35 KSh.

[a] The annuity of the changes in producer and consumer surplus is calculated over the 1999-2020 period. A discount rate of 10 percent is used. The annuity figures are given in million 1998 KSh. 1 US$ = 59.7 KSh according to the official exchange rate in late 1998.
[b] The share given for consumers refers to the proportion of the overall economic surplus change attributable to banana consumers.

Source: Author's calculations.

Furthermore, the distribution effects deviate significantly. In the higher price scenario, the small-scale farmers would receive only a marginal fraction of the total benefits. As can be seen from Table A3, in a number of years they would even suffer welfare losses, driven by the technology-caused price decrease being more pronounced than their own realized productivity growth. The largest share of the additional producer surplus goes to the medium-scale banana growers, whose supply function shifts the most on average. The benefit portion attributable to the large-scale farmers is also higher than their initial production share. This shows that—notwithstanding the aggregate advantages—the technology would considerably reinforce the income disparities among Kenyan banana growers. The main reason for this would be the laggard adoption of the innovation by the smallholders. In spite of the notable benefit potentials of TC bananas for this group of farmers, the barriers to using the technology are high: First, the recommended adjustment of the input mix and thus the required change of the traditional behavior is biggest for the small producers. Second, and more important, the relative cost increases are highest for them and constitute a serious adoption constraint.

The model results of the lower TC price scenario demonstrate how critical the cost of the planting material itself is in this connection. With the reduced price, the smallholder benefit portion would still be slightly below their initial production share. But the distribution effects would improve tremendously in comparison to the higher TC price scenario. Both the medium- and the large-scale banana growers would hand over some of their relative benefits to the smaller farms. It should be kept in mind that the price of 35 KSh is just an arbitrary figure. If own-sucker propagation of purchased in vitro plantlets should prove successful to some extent, the average cost per plant to farmers could even be lower, which would benefit the poor producers more than the rich ones. These improved distribution effects are due to the fact that a TC price decline influences the per unit cost reduction and the technology adoption rates of the small-scale growers more than the respective variables of the other two farm types. Any alternative measure particularly targeted to improve these parameters of the smallholders would engender similar results.

Another interesting feature, which is often neglected in producer-oriented evaluations of farm technology, are the advantages for food consumers. The productivity gains in production cause the banana price to decline. This improves the real income situation of purchasers and thus their welfare. Table 13 reveals that consumers would capture over 40 percent of the total economic surplus gains in both scenarios. In section 5.1, it was elaborated that the methodological approach accounts for subsistence consumption of producing households. Without that refinement of the model, the consumers' benefit share would even be higher, around 55 percent in both scenarios. Noteworthy in this context is also that the small-scale producers' average surplus change would be negative in the higher TC price scenario if neglecting home consumption.

5.4 Contrasting Costs and Benefits

So far, only the benefits of the tissue culture technology within the Kenyan banana sector have been analyzed. This has been abstracted from the costs associated with the biotechnology project. In order to get a better understanding of the overall profitability, it is necessary to assemble these costs and contrast them to the derived benefits.

Tissue culture techniques for bananas were internationally available free of charge so that no direct cost accrued for acquiring that basic tool. Costs arise, however, in the context of adaptive research, development, demonstration and diffusion of the technology product. Such cost data were collected within the interview survey, whereby the future costs were estimated. The data are discussed in the following with respect to the different involved organizations. An overview of the financial flows is presented in Table A4 in the Appendix.

- **Rockefeller Foundation and IDRC:** These donor organizations provide funds for the three-year starting phase of the biotechnology project (1997-1999). The major part of this budget is being used by KARI for laboratory equipment, purchases of in vitro plantlets from GTL, training and communication activities, wages for assistance personnel, travel allowances and overhead costs. The donor funds also cover part of the ISAAA facilitation work and the costs that accrue in connection with the consultation from South Africa through ITSC.
- **KARI:** As the implementing organization, KARI is carrying the salary cost for its banana researchers working with the project. Furthermore, the institute supplements the donor funds for laboratory expenditures and related supplies. It is estimated that KARI's project costs gradually decline after the starting phase. From the year 2002 onwards, it is assumed that there is only one full-time-equivalent researcher (including overheads) active in maintenance research as well as in training and monitoring of local extension services.
- **ISAAA:** ISAAA facilitates the biotechnology project. This embraces the establishment and maintenance of the network of involved national and international organizations, including the donors, as well as the monitoring and evaluation of the project's success. Furthermore, capacity building and institutional support is provided to KARI and other national organizations through ISAAA's regional center in Nairobi. It is anticipated that the ISAAA cost within this project gradually shrinks, and fades out after the year 2003. ISAAA's effort to transfer the project to neighboring countries is not considered here.
- **Other costs:** It is likely that external financial assistance will still be needed after the first three-year phase of donor support from the Rockefeller Foundation and IDRC. In the succeeding phase, the project focus will more and more shift from R&D over to capacity and institution building activities in connection with biotechnology dissemination. In particular, the establishment of local distribution points for in vitro plants, that should be combined with extension services to farmers, will require initial funding. This is crucial in order to guarantee access to the technology, especially for the resource-poor producers. Appropriate donors will have to be identified. It is reckoned that such external funds would be needed until 2005. After that,

the activities by the local organizations should be able to financially sustain themselves.

The total estimated costs are weighed against the aggregate welfare gains caused by the technology on an annual basis, starting from 1997 until the year 2020. Based on this, the internal rates of return (IRRs) for project investments are calculated. The IRR for the higher TC price scenario is 42.0 percent. This is a reasonable profitability for a technology project. For the lower TC price scenario, the IRR more than doubles to 91.3 percent. This high value is attributable to much higher benefits in the absence of cost increases. Remember that it was assumed that farmers would be able to derive a number of own-suckers for propagation from their purchased in vitro plants. The tremendous growth in the project's profitability through lower TC prices for farmers suggests that—if "technology self-propagation" should prove unsuccessful—the plants could even be subsidized for resource-poor producers without jeopardizing the overall efficiency.

5.5 Sensitivity Analysis

In this section, the sensitivity of the above presented welfare and profitability results shall be tested with respect to changes in those parameters that are particularly subject to uncertainty. The calculations for the two scenarios already revealed that modifications in the two variables responsible for the determination of the farm type-specific supply shift factors—i.e. the per unit cost reduction (*C*) and the technology adoption rate (*A*)—have a substantial impact on the dimension of aggregate benefits. To a large extent, these technology-related variables refer to future events so that their exact values are still unknown. The used figures were average estimates derived from the interview survey. Deviations from these average values could occur, for instance, through an unexpected long-term yield performance of TC plants under farmers' conditions, or through unforeseen developments in factor and input markets. In order to improve the reliability of the model calculations, we examined the consequences of extreme upward and downward parameter variations. Percentage changes of both variables, *C* and *A*, influence the aggregate welfare effects exactly in the same direction and magnitude, because they determine the shift factor *K* in a multiplicative fashion. Parameter increases lead to proportionally higher overall benefits and *vice versa*, with a concomitant outcome for the project's economic profitability. However, even under a 90 percent reduction of either *C* or *A*, the IRR is still above 10 percent, which is considered to be the profitability's cut-off point: 14.5 percent in the higher TC price scenario, and 40.1 percent in the lower TC price scenario. These variations have no influence on the distribution effects of the technology, assuming that they are performed in equal percentage terms for all farm types.

Moreover, the sensitivity with respect to the price elasticities of supply and demand was tested, as no exact parameter estimates were available. A variation of the respective coefficients in realistic dimensions has hardly any influence on the aggregate welfare effects and the IRRs.[1] But the distribution effects of the tissue culture technology change remarkably. A reduction of the supply elasticities shifts more benefits from banana consumers to producers and slightly improves the equity effects between the different farm types, i.e. the smallholder share increases to some extent. For higher values the opposite holds true and, for a 50 percent increase in the price responsiveness of banana growers, the small-scale farmers would suffer welfare losses under the higher TC price assumption. A decline of the demand price elasticity's absolute value leads to a growth in the consumer surplus to the detriment of farmers and *vice versa*. Given the higher price for in vitro plants, a coefficient of—0.65 (instead of—0.8 as initially assumed) would entail negative results for the smallholders. This is an important finding because, although urban demand for bananas in Kenya is surely unsaturated, a significant production increase could lead to flooded local markets associated with a low price responsiveness of demand, if the transportation and marketing infrastructure is not appropriately adjusted. Therefore, the successful introduction of the tissue culture technology not only depends on bettering the conditions of factor and input markets, but also depends much on the improvement of infrastructure within banana outlets. The mentioned modifications of supply and demand price elasticities influence the equity outcomes in the lower TC price scenario to a much lesser extent than in the higher price scenario.

Summarizing the findings of the sensitivity analysis, it has to be stated that a certain cautiousness is appropriate in interpreting the model results in their absolute values. However, the direction of the statements is fairly robust in all parameter variations, and the pivotal role of the cost of in vitro plants for the technology's effective distribution is even strengthened.

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[1] A reduction of both the price elasticity of supply and demand in absolute terms, tends slightly to expand the growth in economic surplus, whereas for an increase of the coefficients, it is the other way around. Still, even for a doubling or halving of the parameters, the changes in aggregate welfare measures are less than 10 percent.

6. Conclusions

One of the main reasons for the low yield levels currently obtained in Kenyan banana production is severe crop infestation by pests and diseases. Among other ways of transmission, all of the economically important pathogens are being spread through infected suckers. Therefore, the widespread use of suckers from questionable sources for plant propagation perpetuates and aggravates the problem. Kenyan farmers still carry on this unfavorable practice for mainly two reasons: First, the lack of availability of clean planting material, and second, the low degree of better knowledge among farmers. The introduction of tissue culture techniques for plant propagation undoubtedly has the potential to improve this situation. The analysis shows that if farmers were to use in vitro plantlets instead of conventional suckers for plantation establishment, the yield and income gains could be remarkable. This holds true for all three of the analyzed farm types, i.e. the small-, medium- and large-scale producers. The potential relative gains are even higher for the smaller than they are for the larger farms.

It should not be overlooked, however, that the successful use of the technology requires a significant change in farmers' current cultivation methods. So far, banana in Kenya is mostly seen as a security crop, which renders a continuous in-kind and in-cash income flow also under very low input regimes. Thus, in terms of resource allocation, banana growing is a rather neglected enterprise within the farming systems. In vitro planting material is quite delicate and demands optimal growing conditions with respect to field hygiene and nutrient and water availability. Consequently, adopting the TC technology without improving and intensifying the traditional management practices could worsen the yield and income situation of farmers instead of improving it. This demonstrates the great importance of disseminating the technology only in combination with the analogous extension message.

Field observations reveal that farmers are generally inclined to alter their cultivation habits. Against the background of diminishing terms-of-trade for other marketable crops, many of them even consider increased banana production and commercialization as a promising alternative for partly compensating lost cash revenues. But the realization of related intensification strategies is complicated through serious institutional impediments, particularly imperfections in rural markets for information and credit. If appropriately introduced, the technological innovation in the form of tissue culture plantlets could bring about the needed institutional innovation. It is planned to involve NGOs for the creation of viable biotechnology distribution channels. Such community-based organizations (e.g. women's groups) should already be integrated one step earlier, namely into the initial stages of TC demonstration, to stimulate participatory initiatives and to foster demand-driven technology dissemination.

The successful adoption of the TC technology is associated with a significant increase in the production cost per acre of bananas. On the one hand, this is attributable to the necessary adjustment of the input mix. But on the other hand, the incurred expenditure for the in vitro planting material itself causes this cost expansion to a noteworthy extent. Although these additional outlays are more than offset by the expected gains in revenues, higher monetary expenditures imply higher risks for the farmers, which will curb the speed of technology adoption. The relative cost increase was shown to be highest for the small-scale farmers, i.e. the group with the lowest resource endowment. It is likely, hence, that the smaller producers will take up TC bananas much more slowly than the larger ones. Assuming a realistic price of 75 KSh per purchased in vitro plantlet, the model calculations reveal a substantial aggregate advantage for banana producers and consumers. But the benefit share of the small-scale growers would be only marginal due to their laggard technology adoption. The highest proportion of the benefits would accrue to the medium-sized farms.

How important the cost of acquiring TC material is for the welfare and distribution effects of the technology is demonstrated by the alternative scenario, where a price of 35 KSh per plantlet is presumed. Compared to the higher price assumption, the absolute benefits would rise substantially for all considered groups, whereby the relative gains for the smallholders would be greatest. Cost reductions for in vitro plants could, for instance, be achieved by scale-effects in the laboratory production process, albeit attention has to be paid to maintain certain quality standards, especially a low rate of somaclonal variants. Targeted price subsidies to small-scale producers are conceivable as well. But the most notable cost reduction would be achieved if farmers could "propagate the technology" on their own, by using suckers from once-acquired in vitro mother plants. Although it is not yet exactly clear to what extent this might be possible without completely losing the TC yield advantage, it is likely that there will be least some carry-over effect to the following sucker generations. Apart from TC price reductions, other strategies to improve the smallholder benefit share should particularly be targeted to lower their perceived risk, thus speeding up their adoption of the innovation. Possible instruments—which have already been partly discussed within the organizations involved in the project—could include:

- Creating awareness and improving the information flow among small-scale farmers. This should start with technology demonstration in a group approach (e.g. women's groups) instead of dealing only with individual farmers. Thus, a larger number of persons would be reached with only little additional effort by field researchers and extensionists. Target group members should be trained in an intensive way, so that they would be able to transfer the improved management information to other farmers in a second step.
- Suitable existing farmers' groups should also be encouraged to organize cooperative banana marketing. The piloting efforts of the Banana Growers Association (BGA), for instance, constitute a promising starting point. Cooperative marketing could improve the bargaining power of farmers vis à vis banana middlemen. Moreover, it would decrease the transaction costs for transporters and traders, making the transport to urban consumption points more efficient. Thus the risk of local price downfalls due to technology-induced increases in supply would be reduced.
- The provision of micro-credits under conditions that are tailored to the needs of small-scale banana farmers (e.g. timely availability of loans at recommended planting dates, access for women farmers etc.). Such credits should be tied to the purchase of in vitro plantlets and, after a certain starting phase, they could be managed by the same community-based organizations acting as local biotechnology distribution and information dissemination points. Short-term credits would be sufficient because positive income flows are already expected in the first year after plantation establishment.
- Extending the range of varieties for which in vitro material is available. Although tissue culture protocols for most of the ripening type clones have already been developed, effective micropropagation methods for many popular cooking varieties are still missing. TC technology only associated with ripening bananas would impose the additional risk of necessary variety replacement on small-scale farmers, whose preference for cooking varieties is usually higher than that of the larger ones.

In general, it can be concluded that banana biotechnology is likely to produce important welfare gains for producers and consumers, while significantly modernizing banana farming systems in Kenya. The innovation is not inherently biased against the poorer producers. Nonetheless, public support will be needed to tackle market imperfections and to facilitate the resource-poor farmers' access to the technology. Comparing tissue culture with crops that have been genetically engineered for stress resistance, it is emphasized that the accomplishment of an equitable benefit distribution among producer groups of different farm sizes and resource endowments requires more institutional effort for the former biotechnology application. While yield advantages in case of transgenic crops can even be realized without any other additional inputs, tissue culture requires a substantial adjustment of the input mix and of traditional smallholder farming practices. Furthermore—at least for open-pollinated and vegetatively propagated crops—transgenic germplasm can be reproduced by farmers themselves without losing the technological advantage. Tissue culture plants, on the other hand, are not genetically improved; they are free from pathogens in the beginning, but can be infected by pests and diseases at a later stage just like conventional material. Thus, whereas yield advantages might be carried over to some extent to the suckers, own-technology reproduction in its actual sense is not possible with TC material.

Yet tissue culture and transgenic technologies are not mutually exclusive. On the contrary, the development of genetically engineered crops builds upon expedient tissue culture techniques, and the quick and successful dissemination of transgenic varieties requires efficient biotechnology distribution channels in a country. Therefore, a too static notion of banana tissue culture and its direct effects alone neglects the dynamic benefit prospects associated with the project. The gained tissue culture capability and experience in the Kenyan agricultural research system and the institution-building component of the project open up promising new avenues for biotechnological innovation. So far, transgenic banana varieties are not internationally available, but their release is expected in the near future. Based on hitherto and upcoming project achievements, a speedy and successful transfer of such improved banana cultivars to Kenyan farmers will be facilitated enormously.

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Table A1: Annual cost and income flows of banana production without the use of TC technology (in 1998 KSh/acre)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Small-scale farmers														
Cost of establishm./uprooting	8,596	0	0	0	0	0	0	0	0	0	0	0	0	4,029
Recurrent production cost	4,791	4,791	4,791	4,791	4,791	4,791	4,791	4,791	4,791	4,791	4,791	4,791	4,791	4,791
Total cost	13,387	4,791	4,791	4,791	4,791	4,791	4,791	4,791	4,791	4,791	4,791	4,791	4,791	8,820
Total labor-days	80	29	29	29	29	29	29	29	29	29	29	29	29	80
Yield (t)	0.00	4.51	9.02	7.38	6.15	5.33	4.92	4.51	4.10	3.69	3.28	2.87	2.67	2.46
Net income	-13,387	24,605	54,001	43,312	35,295	29,950	27,278	24,605	21,933	19,260	16,588	13,916	12,580	7,214
Medium-scale farmers														
Cost of establishm./uprooting	10,262	0	0	0	0	0	0	0	0	0	0	0	0	4,029
Recurrent production cost	5,838	5,838	5,838	5,838	5,838	5,838	5,838	5,838	5,838	5,838	5,838	5,838	5,838	5,838
Total cost	16,100	5,838	5,838	5,838	5,838	5,838	5,838	5,838	5,838	5,838	5,838	5,838	5,838	9,867
Total labor-days	91	37	37	37	37	37	37	37	37	37	37	37	37	88
Yield (t)	0.00	4.51	9.43	8.20	7.38	6.97	6.56	6.15	5.74	5.33	4.92	4.72	4.51	4.31
Net income	-16,100	23,558	55,627	47,610	42,265	39,592	36,920	34,248	31,575	28,903	26,230	24,894	23,558	18,193
Large-scale farmers														
Cost of establishm./uprooting	15,059	0	0	0	0	0	0	0	0	0	0	0	0	4,029
Recurrent production cost	7,989	7,989	7,989	7,989	7,989	7,989	7,989	7,989	7,989	7,989	7,989	7,989	7,989	7,989
Total cost	23,048	7,989	7,989	7,989	7,989	7,989	7,989	7,989	7,989	7,989	7,989	7,989	7,989	12,018
Total labor-days	109	50	50	50	50	50	50	50	50	50	50	50	50	101
Yield (t)	0.00	6.56	10.66	9.84	9.43	9.02	8.61	8.20	7.79	7.59	7.38	7.18	6.97	6.77
Net income	-23,048	34,769	61,493	56,148	53,476	50,803	48,131	45,458	42,786	41,450	40,114	38,777	37,441	32,076

Note: The banana farm-gate price is uniformly assumed to be 6518 KSh per ton of production.

Source: Author's calculations based on the interview survey (1998).

Table A2: Annual cost and income flows of banana production with the use of TC technology (in 1998 KSh/acre)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Small-scale farmers														
Cost of establishm./uprooting	44,439	0	0	0	0	0	0	0	0	0	0	0	0	7,900
Recurrent production cost	8,049	8,049	8,049	8,049	8,049	8,049	8,049	8,049	8,049	8,049	8,049	8,049	8,049	8,049
Total cost	52,488	8,049	8,049	8,049	8,049	8,049	8,049	8,049	8,049	8,049	8,049	8,049	8,049	15,949
Total labor-days	145	50	50	50	50	50	50	50	50	50	50	50	50	150
Yield (t)	10.66	13.94	13.94	13.12	12.30	11.48	11.07	10.66	10.25	9.84	9.43	9.02	8.61	8.20
Net income	16,994	82,812	82,812	77,467	72,123	66,778	64,106	61,433	58,761	56,088	53,416	50,744	48,071	37,499
Medium-scale farmers														
Cost of establishm./uprooting	46,309	0	0	0	0	0	0	0	0	0	0	0	0	7,900
Recurrent production cost	9,777	9,777	9,777	9,777	9,777	9,777	9,777	9,777	9,777	9,777	9,777	9,777	9,777	9,777
Total cost	56,086	9,777	9,777	9,777	9,777	9,777	9,777	9,777	9,777	9,777	9,777	9,777	9,777	17,677
Total labor-days	155	58	58	58	58	58	58	58	58	58	58	58	58	158
Yield (t)	11.48	15.58	15.58	14.76	14.35	13.94	13.53	13.12	12.71	12.30	11.89	11.48	11.07	10.66
Net income	18,741	91,774	91,774	86,429	83,757	81,084	78,412	75,739	73,067	70,395	67,722	65,050	62,378	51,805
Large-scale farmers														
Cost of establishm./uprooting	50,335	0	0	0	0	0	0	0	0	0	0	0	0	7,900
Recurrent production cost	12,665	12,665	12,665	12,665	12,665	12,665	12,665	12,665	12,665	12,665	12,665	12,665	12,665	12665
Total cost	63,000	12,665	12,665	12,665	12,665	12,665	12,665	12,665	12,665	12,665	12,665	12,665	12,665	20,565
Total labor-days	168	67	67	67	67	67	67	67	67	67	67	67	67	167
Yield (t)	12.30	17.22	17.22	16.40	15.99	15.58	15.17	14.76	14.35	13.94	13.53	13.12	12.71	12.30
Net income	17,171	99,575	99,575	94,230	91,558	88,885	86,213	83,540	80,868	78,196	75,523	72,851	70,179	59,606

Note: The banana farm-gate price is uniformly assumed to be 6518 KSh per ton of production.

Source: Author's calculations based on the interview survey (1998).

Table A3: Annual technology-induced changes in producer and consumer surplus (in thousand 1998 KSh)

	Higher TC price				Lower TC price			
	Producers				Producers			
Year	Small	Medium	Large	Consum.	Small	Medium	Large	Consum.
1999	490	847	1,008	1,806	1,796	1,787	175	2,534
2000	581	1,292	1,409	2,543	3,288	3,878	652	5,381
2001	674	1,958	1,961	3,579	5,920	8,326	2,028	11,438
2002	759	2,949	2,718	5,030	10,411	17,564	5,713	24,183
2003	822	4,409	3,743	7,053	17,760	35,972	14,773	50,170
2004	841	6,536	5,117	9,849	29,358	70,096	34,262	99,559
2005	787	9,588	6,930	13,673	47,608	126,297	67,788	181,719
2006	626	13,884	9,279	18,824	76,578	203,907	109,173	293,326
2007	327	19,781	12,255	25,627	118,958	289,411	143,751	413,457
2008	-130	27,624	15,928	34,386	170,446	364,539	164,451	519,772
2009	-729	37,654	20,326	45,311	221,614	421,055	175,245	603,494
2010	-1,401	49,904	25,425	58,441	265,449	461,786	181,964	667,248
2011	-2,016	64,110	31,134	73,579	300,303	492,836	187,881	717,383
2012	-2,388	79,705	37,310	90,291	327,830	519,003	194,196	759,584
2013	-2,310	95,929	43,769	107,981	350,462	543,140	201,181	797,767
2014	-1,601	112,011	50,318	126,022	370,229	566,762	208,809	834,323
2015	-147	127,338	56,786	143,883	388,532	590,639	217,000	870,638
2016	2,075	141,555	63,038	161,202	406,258	615,163	225,685	907,501
2017	5,006	154,558	68,997	177,800	423,947	640,542	234,823	945,370
2018	8,524	166,434	74,638	193,646	441,927	666,895	244,392	984,520
2019	12,478	177,375	79,975	208,802	460,397	694,300	254,386	1,025,129
2020	16,710	187,617	85,055	223,388	479,486	722,819	264,809	1,067,325

Source: Author's calculations.

Table A4: Financial cost of the biotechnology project\by involved organizations (in thousand 1998 KSh)

Year	RF and IDRC	KARI	ISAAA	Other	Year	RF and IDRC	KARI	ISAAA	Other
1997	6,377	2,700	2,985	0	2009	0	597	0	0
1998	5,232	2,700	1,791	0	2010	0	597	0	0
1999	4,742	2,025	1,791	0	2011	0	597	0	0
2000	0	2,025	1,194	2,985	2012	0	597	0	0
2001	0	1,350	597	2,985	2013	0	597	0	0
2002	0	597	597	2,985	2014	0	597	0	0
2003	0	597	597	1,194	2015	0	597	0	0
2004	0	597	0	1,194	2016	0	597	0	0
2005	0	597	0	1,194	2017	0	597	0	0
2006	0	597	0	0	2018	0	597	0	0
2007	0	597	0	0	2019	0	597	0	0
2008	0	597	0	0	2020	0	597	0	0

Note: Values given in US$ have been converted to KSh by the official 1998 exchange rate (1 US$ = 59.7 KSh).

Source: Author's interview survey (1998).

Figure A1: Estimated banana yield curves over a 14-year plantation cycle without and with the use of TC technology

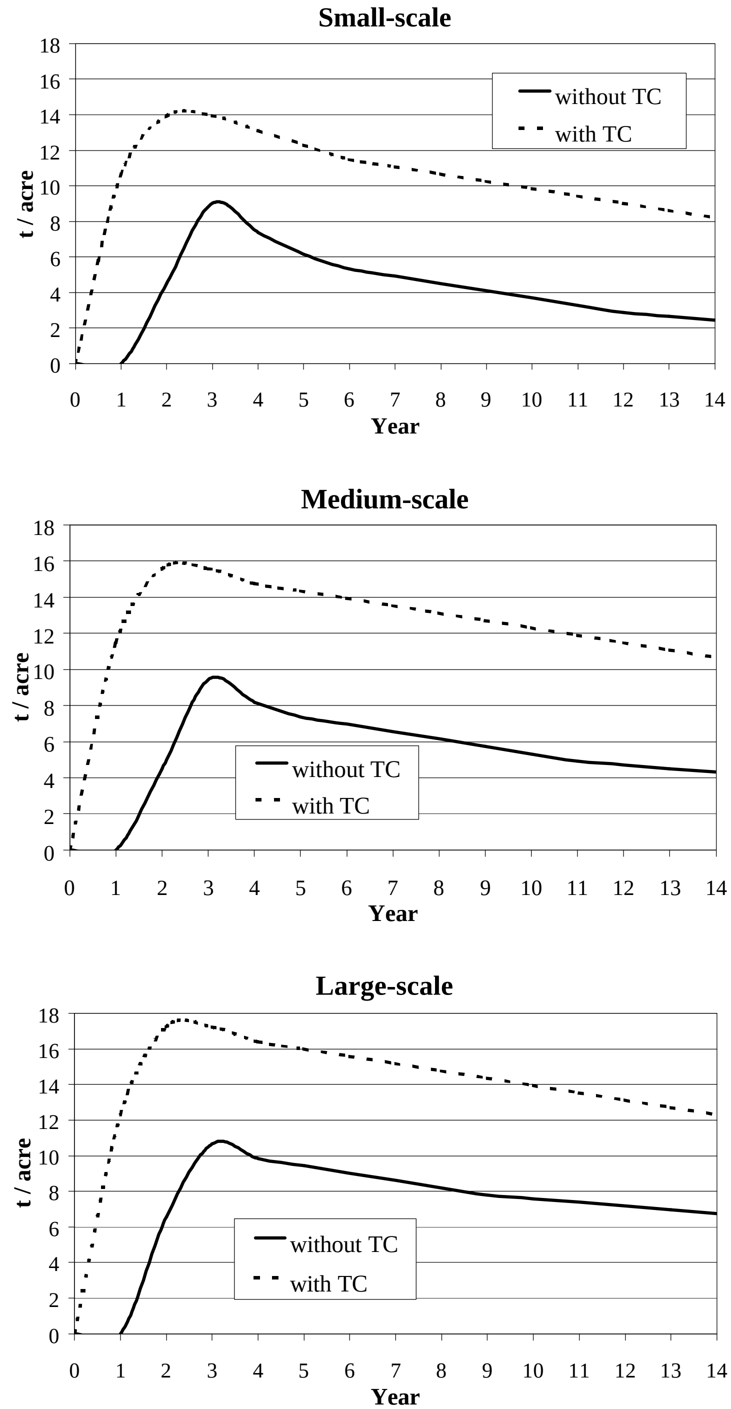
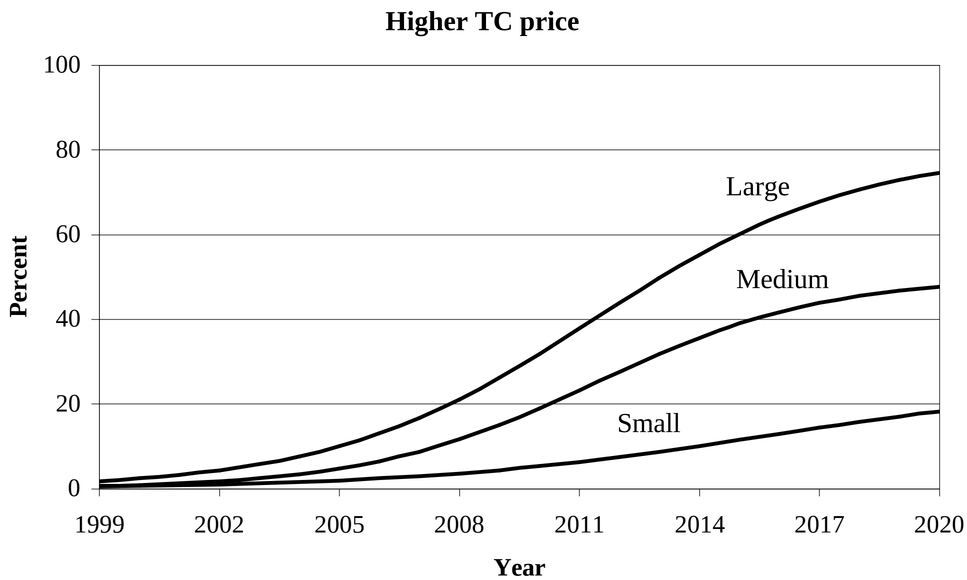
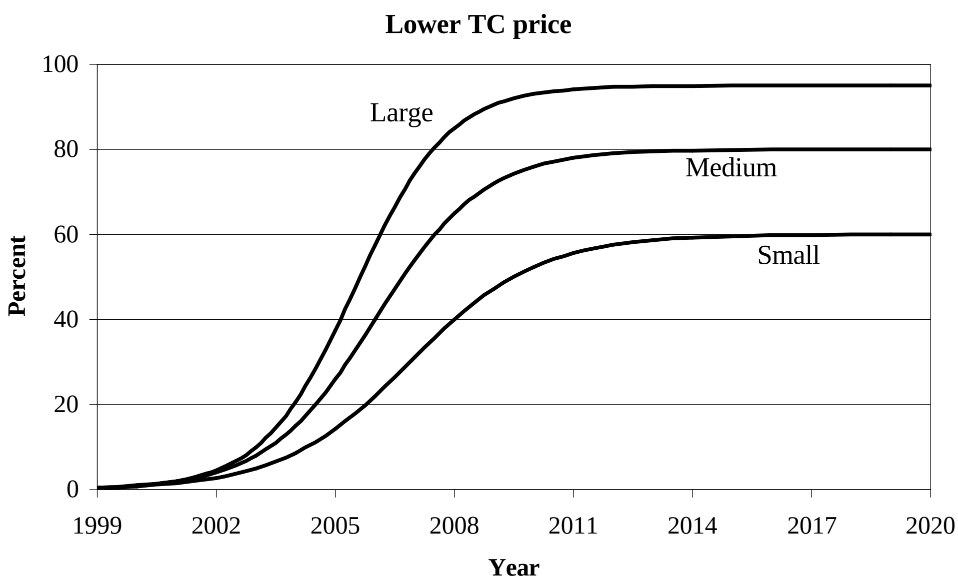


Figure A2: Estimated technology adoption profiles under different price assumptions for TC plants





Note: The higher price scenario assumes a price of 75 KSh per TC plant; the lower price scenario is based on the assumption that the average cost per in vitro plant is 35 KSh.