Innovation Dynamics and Agricultural Biotechnology in Kenya

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Acronyms

AABNF	African Association of Biological Nitrogen Fixation
AATF	African Agricultural Technology Foundation
ABSF	African Biotechnology Stakeholders Forum
ABSP	Agricultural Biotechnology Support Programme
ACMV	African Cassava Mosaic Virus
ACTS	African Centre for Technology Studies
AGRA	Alliance for a Green Revolution in Africa
AIS	Agricultural Innovation Systems
ARDAP	Appropriate Rural Development Agricultural Programme
ARF	Agricultural Research Fund
ASAL	Arid and Semi-Arid Lands
ASARECA	Association of Agricultural Research in Eastern and Central Africa
BAT	British American Tobacco
BNF	Biological Nitrogen Fixation
Bt	Bacillus thuringiensis
CBOs	Community Based Organizations
CD&W	Colonial Development and Welfare Fund
CGIAR	Consultative Group on International Agricultural Research
CIAT	International Centre for Tropical Agriculture
CIMMYT	International Maize and Wheat Improvement Centre
CIP	International Potato Centre
CRF	Coffee Research Foundation

CRIFC	Central Research Institute for Food Crops
DGIS	Director-General for International Cooperation/ Dutch Ministry of International Cooperation
FAO	Food and Agriculture Organization of the United Nations
FFS	Farmers Field Schools
FGDs	Focus Group Discussions
FORMAT	Forum for Organic Resource Management and Agricultural Technology
GM/GMO	Genetic Modification/Genetically Modified Organism
GoK	Government of Kenya
GR	Green Revolution
HSHC	Help Self Help Centre
IARCs	International Agricultural Research Centres in Africa
ICIPE	International Centre on Insect Physiology and Ecology
ICRAF	International Centre for Research on Agroforestry
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
IK	Indigenous Knowledge
ILRI	International Livestock Research Institute
IPM	Integrated Pest Management
IPPC	International Plant Protection Convention
IPRs	Intellectual Property Rights
IRMA	Insect Resistant Maize for Africa
IS	Innovation Systems
ISAAA	International Services for the Acquisition of Agri-biotech Applications
ISNAR	International Service for National Agricultural Research
JKUAT	Jomo Kenyatta University of Agriculture
KACE	Kenya Agricultural Commodity Exchange
KARI	Kenya Agricultural Research Institute
KBL	Kenya Breweries Limited

KEBS	Kenya Bureau of Standards
KEPHIS	Kenya Plant Health Inspectorate Services
KFA	Kenya Farmers Association
KIOF	Kenya Institute of Organic Farming
KIPI	Kenya Industrial Property Institute
KNFU	Kenya National Farmers Union
KTRF	Kenya Tea Research Foundation
MAB	Marker Assisted Breeding
MDGs	Millennium Development Goals
MIRCEN	Microbiological Resources Centres Network
MNCs	Multinational Corporations
MoA	Ministry of Agriculture
MSC	Mumias Sugar Company
MSU	Michigan State University
MTA	Material Transfer Agreement
MVs	Modern Varieties
NACBAA	National Advisory Committee on Biotechnology Advances and their Applications
NARIs	National Agricultural Research Institutes
NARP	National Agricultural Research Project
NARS	National Agricultural Research Systems
NBC/A	National Biosafety Committee/Authority
NCST	National Council of Science and Technology
NES	National Environment Secretariat
NGOs	Non-Governmental Organizations
OMMN	Organic Matter Management Network
PBK	Pyrethrum Board of Kenya
PBRs	Plant Breeders Rights
PPPs	Public/Private Partnerships
R&D	Research and Development
RENESA	*Rhizobium* Ecology Network of East and Southern Africa
S & T	Science and Technology

SA	Sustainable Agriculture
SACAR	Southern Africa Centre for Agricultural Research
SAPs	Structural Adjustment Programmes
SI	Systems of Innovation
SPFMV	Sweet Potato Feathery Mottle Virus
SPVD	Sweet Potato Virus Disease
SRA	Strategy for Revitalizing Agriculture
SSA	Sub-Saharan Africa
TAC	Technical Advisory Committee
TAD	Technology and Agrarian Development Group
TBSF	Tropical Soil Biology and Fertility
TC	Tissue Culture
ToT	Transfer of Technology
TRF	Tea Research Foundation
TRIPs	Trade Related Intellectual Property Rights
UNESCO	United Nations Educational, Scientific and Cultural Or ganisation
UoN	University of Nairobi
UPOV	International Union for the Protection of New Varieties of Plants
USA	United States of America
WEMA	Water Efficient Maize for Africa
WTO	World Trade Organization

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During my fieldwork, I interacted with many people with diverse knowledge and divergent interests including policy makers, expert advisors, researchers and advocacy groups. I also spent many days with smallholder farmers and local leaders in Nyeri and Busia Counties to learn their experiences with new and existing agricultural technologies. The dynamics of the perceived potential of biotechnology and the actual needs of smallholder farmers are difficult to concretise given the diversity of people and issues. I want to give special thanks to all people I interviewed during my fieldwork for all the knowledge they freely shared with me and the time we spent together. I also want to thank Macdonald Wesonga of Appropriate Rural Development Agriculture Program (ARDAP) in Busia County; and Juma Odongo, the former agricultural officer in Kieni East sub-county for their assistance.

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Hannington Shemawa Odame

Abstract

Modern agricultural biotechnology is being flaunted in global policy debates as a powerful technology for improving agricultural productivity and food security in Africa. These debates often conveniently lump together the controversial GMOs and the less contentious traditional biotechnology, also known as 'non-transgenic biotechnology'. The controversial debate on GMOs encompasses the influence of biotechnology companies, governmental regulators, non-governmental organizations, scientists and consumers. The contentious issues on GM food and crops include labelling, health and environment, pesticide resistance; impacts of GM crops on farmers, feeding the world population; and the role of government in all these issues. The overall policy debate is whether and how GMOs can contribute to sustainable agricultural productivity and new inputs for African smallholder farmers.

Most African governments are cautious of modern biotechnology and especially about GMOs because the role of this technology in African agriculture is not well understood. Today, there are few transgenic crops that have been developed and successfully introduced to African smallholder farmers. This situation raises the question: Can agricultural biotechnology be harnessed to improve sustainable agricultural productivity and food security of smallholder farmers in Kenya?

This study employed the Agricultural Innovation Systems (AIS) framework as a potentially useful tool for identifying and analysing strengths and weaknesses in harnessing biotechnology for smallholder farmers. This analysis helps understand how the NARS has evolved and to examine whether biotechnology will be useful to the people or not.

Empirical research was conducted within selected NARS at the national level, and among the target smallholder farmers in Busia and Nyeri Counties. The national level institutional analysis focused on poli-

cy and institutional contexts in which biotechnology is being developed and deployed in the country's smallholder agriculture. Data collection on the innovation capacity of selected Kenyan NARS and status of agricultural biotechnology used five information sources including secondary data, news clippings, key informant interviews and a feedback workshop. Fieldwork involved five stages: 1) key informant interviews with project leaders to reconstruct histories of agricultural biotechnology projects; 2) farmer focused group discussions (FGDs) on past and present production practices; 3) technology access and use through surveys; 4) farmer feedback workshops to discuss the initial findings and provide an opportunity for farmer input into data analysis and interpretation; and 5) dissemination workshops to share findings.

The status of agricultural biotechnology and 4 case projects were analysed and discussed within the components of AIS conceptual framework: i) agricultural research and education systems, ii) bridging institutions, iii) business and enterprise, iv) policy and institutions, and v) coordination and linkages. The first two biotechnology projects were based on detailed fieldwork: a traditional agro-biotechnology (*Rhizobium inocula*) had reached farmers but in an unsystematic way while modern agro-biotechnology (Transgenic sweet potato) was (and is still) yet to reach farmers. As a result, its impacts are yet to be realized in view of the initial project objectives. The second set of agro-technology projects (i.e. Tissue culture (TC) banana and StrigAway maize projects) that have systematically reached farmers were based on secondary data, key informant interviews and FGDs.

Five key findings are discernible: Firstly, agricultural biotechnology applications in Kenya are being introduced into largely failed systems to meet needs, capacities and priorities of smallholder farmers irrespective of the technology types or characteristics. Secondly, agri-biotechnology projects are influenced by particular actors and organizations which may not be guided by local realities. Thirdly, most agri-biotechnology R&D initiatives in Kenya are taking place in the poorly-financed public research sector, with only a few initiatives conducted through donor-funded public-private partnerships (PPPs). Fourthly, agri-biotechnology interventions have contributed to some technical and legal/regulatory capacity building in Kenya. However, this capacity does not stimulate creativity, and is confined to upstream research networks and not extended to downstream networks. Fifthly, limited application of systems approach to agricultural development leads to fragmented biotechnology programmes with indeterminate effect on smallholder farmers in the country.

This study has made several contributions relevant to agricultural policy in general and agricultural innovation policy in particular. One, the study has attempted to apply the framework of innovation systems to the Kenyan agriculture sector to identify weaknesses in the country's agricultural development. The analysis has led to an important conclusion that technological answers cannot be achieved independently of the contemporary land issues. The research has pointed out that biotechnology could be made part of the answer if there is policy action in support of easing some of the contemporary agricultural development challenges including soil infertility, marginal land use and those obstacles faced by agricultural youth. Two, based on evidence from case materials, the study has also brought back evolutionary thinking into the Innovation Systems (IS) approach by reconstructing dynamic innovation histories. For example, the study shows that TC banana and StrigAway maize projects were not just about developing and deploying biotechnology applications, but also learning processes by bringing together scientific and local knowledge on production of bananas and maize. But the interactions between the scientific knowledge and traditional knowledge needed market mediation for farmers to change their practices and begin to use improved seed, gain access to credit to buy fertilizer or pay for hired labour and markets.

Three, it is now becoming increasingly evident that there is a generic problem with capacity development approaches that focus solely on physical infrastructure and competencies of researchers to produce knowledge. The failure to develop complementary capacities to put the existing knowledge into use, and the need to make scientific resources respond to the rural economy and society as a whole is now a major concern in the STI debate. Four, innovation governance entails managing the influence of international actors in modern biotechnology R&D funding priorities and legal and regulatory regimes (including IPRs and biosafety regulations). Thus, developing countries such as Kenya need capacity to negotiate and manage legal and regulatory frameworks in response to local realities. Five, while coordination of diverse actors and their interests is difficult, the art of managing agri-biotechnology innovation as it evolves is creating space, opportunity and incentives to bring in relevant actors at different stages of the processes.

A major limitation of this study is that research has been carried out for more than a decade. The long duration has some disadvantages but could also be advantageous. The main disadvantage is out-dated field data and information. It is advantageous because the detailed case studies have captured important and instructive processes of biotech innovation attempts in the past, from which much can be learned. The intervening time period has provided the opportunity to observe any further developments, although without the level of detail achieved in the original field studies. Therefore, an important area for future research is devising and implementing a methodology for updating agricultural biotechnology projects and assessing how they interact with local and (inter)national innovation processes because it is difficult to sustainably deploy biotechnology when such knowledge is not joined up with the existing innovation systems, which are also trying to address the agricultural development challenges facing African smallholder farmers.

Samenvatting

Moderne biotechnologie wordt wereldwijd in beleidsdebatten opgevoerd als een krachtig wapen om de productiviteit van de landbouw en voedselzekerheid in Afrika te bevorderen. In deze debatten worden de controversiële genetisch gemodificeerde organismen (ggo's) en de minder omstreden klassieke biotechnologie, die ook wel 'niet-transgene' biotechnologie genoemd wordt, vaak gemakshalve op één hoop gegooid Bij het debat over ggo's zijn veel partijen betrokken: biotechnologiebedrijven, overheidsinstanties, niet-gouvernementele organisaties (ngo's), wetenschappers en consumenten. De onderwerpen die centraal staan in het debat over genetisch gemodificeerd voedsel en gengewassen zijn onder andere etikettering van levensmiddelen, milieu en gezondheid, resistentie tegen bestrijdingsmiddelen, gevolgen van genetisch gemodificeerde gewassen voor boeren, het voeden van de wereldbevolking, en de rol van de overheid op al deze gebieden. De algemene vraag in het beleidsdebat is in hoeverre en hoe ggo's kunnen bijdragen aan duurzame landbouw en een nieuwe impuls kunnen geven aan kleineCha Afrikaanse boeren.

De meeste Afrikaanse overheden staan terughoudend tegenover moderne biotechnologie en vooral tegenover ggo's omdat men de rol van deze technologie in de Afrikaanse landbouw nog niet goed begrijpt. Er zijn nu slechts enkele transgene gewassen ontwikkeld en met succes geïntroduceerd op kleinschalige Afrikaanse boerderijen. Hierdoor rijst de vraag: kan biotechnologie op kleinschalige boerderijen in Kenia worden ingezet om duurzame landbouw en voedselzekerheid te bevorderen?

Dit onderzoek is uitgegaan van het principe van Agricultural Innovation Systems (AIS; een systeem waarbij individuen, organisaties en bedrijven samenwerken om voedselzekerheid en duurzame economische ontwikkeling te bevorderen) als een mogelijk nuttig instrument om de voor- en nadelen van het toepassen van gentechnologie voor kleine boeren te onderzoeken. Deze analyse draagt bij aan een beter begrip van

hoe het NARS (National Agricultural Research System: systeem voor nationaal landbouwonderzoek) zich heeft ontwikkeld en hiermee kan de vraag beantwoord worden of moderne biotechnologie nuttig is voor de bevolking.

Het empirisch onderzoek is uitgevoerd bij een aantal NARS-instellingen op landelijk niveau en onder kleine boeren in de districten Busia en Nyeri. De institutionele analyse op nationaal niveau was gericht op de beleids- en institutionele context waarin biotechnologie wordt ontwikkeld en ingezet in de kleinschalige landbouw. Bij de verzameling van data over de innovatiecapaciteit van de Keniaanse NARS-instellingen en het gebruik van gentechnologie in de landbouw zijn vijf informatiebronnen gebruikt waaronder secundaire data, krantenknipsels, interviews met sleutelpersonen en een feedbackworkshop. Het veldonderzoek omvatte vijf stadia: 1) interviews met projectleiders (sleutelpersonen) om de historische ontwikkeling van biotechnologieprojecten in de landbouw te reconstrueren; 2) groepsdiscussies in focusgroepen van boeren (farmer focused group discussions: FGD's) over vroegere en huidige productiemethoden; 3) survey-onderzoek naar toegankelijkheid en gebruik van technologieën; 4) feedbackworkshops met boeren om de voorlopige onderzoeksresultaten te bespreken en boeren de gelegenheid te geven om bij te dragen aan de analyse en interpretatie van de onderzoeksgegevens; en 5) workshops om de onderzoeksresultaten bekend te maken.

De stand van zaken rond het gebruik van biotechnologie in de landbouw en vier projecten zijn geanalyseerd en besproken aan de hand van de componenten van het AIS: 1) landbouwonderzoek en -opleidingssystemen, 2) een brug slaan tussen verschillende instellingen, 3) bedrijven en ondernemingen, 4) beleid en instellingen, en 5) coördinatie en dwarsverbanden. De eerste twee biotechnologieprojecten zijn bestudeerd in uitgebreid veldonderzoek. De boeren hadden kennisgemaakt met een klassieke vorm van biotechnologie (*Rhizobium inocula*), zij het niet op systematische wijze, maar een moderne vorm van biotechnologie (transgene zoete aardappel) had de boeren nog niet bereikt (ook nu nog niet). Daarom moeten de oorspronkelijke doelen van deze twee projecten nog gerealiseerd worden. De andere twee biotechnologieprojecten (het verbeteren van de bananenteelt door weefselkweek en het gebruik van het bestrijdingsmiddel StrigAway in de maïsteelt) zijn op een systematische manier ingevoerd op kleine boerenbedrijven en deze zijn onderzocht door middel van de analyse van secundaire data, interviews met sleutelpersonen en FGD's.

Op grond van het onderzoek kunnen vijf belangrijke conclusies getrokken worden. Ten eerste worden biotechnologieprojecten in Kenia ingevoerd in grotendeels mislukte systemen om te voldoen aan de behoeften, capaciteiten en prioriteiten van kleine boeren en daarbij wordt niet gekeken naar het type technologie of de kenmerken. Ten tweede worden biotechnologieprojecten beïnvloed door bepaalde actoren en organisaties waarbij niet altijd rekening gehouden wordt met de lokale omstandigheden. Ten derde vinden de meeste R&D-initiatieven op het gebied van biotechnologie in Kenia plaats in de noodlijdende door de overheid gefinancierde onderzoekssector, en zijn er slechts een paar initiatieven die door publiek-private samenwerkingsverbanden waarbij donoren betrokken zijn gefinancierd worden. Ten vierde hebben biotechnologische interventies in de landbouw tot op zekere hoogte bijgedragen aan het opbouwen van technische en juridische kennis en regelgevingscapaciteit in Kenia. Dit is echter geen stimulans voor creativiteit, en het blijft beperkt tot upstream-onderzoeksnetwerken (productontwikkeling) en heeft geen invloed op downstream-netwerken (toepassing en commercialisatie). Ten vijfde leidt een beperkte toepassing van een systeembenadering in de landbouwontwikkeling tot gefragmenteerde biotechnologieprogramma's met een onduidelijk effect op kleinschalige boerderijen in het land.

Dit onderzoek draagt op een aantal manieren bij aan landbouwbeleid in het algemeen en landbouwinnovatie-beleid in het bijzonder. In de eerste plaats is in het onderzoek gekeken naar innovatiesystemen in de Keniaanse landbouwsector in een poging om zwakke punten te ontdekken in de landbouwontwikkeling van het land. Een belangrijke conclusie van het onderzoek is dat bij het vinden van technologische oplossingen ook gekeken moet worden naar de huidige problemen op het gebied van het gebruik van grond. Het onderzoek wijst erop dat een deel van de oplossing te vinden is in beleid dat gericht is op het aanpakken van een aantal van de huidige problemen in de landbouwontwikkeling, waaronder onvruchtbare grond, marginaal gebruik van landbouwgrond en problemen waar jonge agrariërs tegenaan lopen. Ten tweede is op basis van de resultaten van de casestudy's het evolutionaire denken teruggebracht in de innovatiesysteem-benadering door het reconstrueren van dynamische innovatieprocessen uit het verleden. Uit het onderzoek blijkt bijvoorbeeld dat het in het weefselkweek-project in de bananenteelt en het project met het gebruik van StrigAway in de maïsteelt niet alleen ging om het ontwikkelen en toepassen van gentechnologie, maar ook om een leerproces waarin wetenschappelijke en lokale kennis over de productie van bananen en maïs samengebracht werden. Maar er was ook nog marktwerking nodig om te zorgen dat boeren hun werkwijze veranderden en verbeterde zaden gingen gebruiken, krediet probeerden te krijgen om kunstmest te kopen of betaalde arbeidskrachten inhuurden.

In de derde plaats wordt steeds duidelijker dat benaderingen van capaciteitsontwikkeling die uitsluitend gericht zijn op de fysieke infrastructuur en het vermogen van onderzoekers om kennis te produceren niet voldoen. Het onvermogen om aanvullende capaciteit te ontwikkelen om de bestaande kennis te kunnen gebruiken en de behoefte aan wetenschappelijke kennis die nuttig is voor de plattelandseconomie en voor de maatschappij als geheel zijn nu belangrijke onderwerpen in het debat over STI (Science, Technology and Innovation). Ten vierde behelst innovatiebeleid ook het omgaan met de invloed van internationale actoren bij het stellen van prioriteiten voor de financiering van R&D op het gebied van moderne biotechnologie en het rekening houden met internationale rechtssystemen en regelgeving (waaronder regelgeving op het gebied van intellectuele eigendom en biologische veiligheid). Daarom moeten ontwikkelingslanden als Kenia de capaciteit hebben om te onderhandelen en om de juridische randvoorwaarden en regelgeving toe te kunnen passen in de lokale situatie. In de vijfde plaats is het weliswaar moeilijk om verschillende actoren met hun verschillende belangen op één lijn te brengen, maar is het bij innovatie in de landbouw de kunst om de ruimte, de gelegenheid en de juiste prikkels te bieden om de relevante actoren er in verschillende stadia van het proces bij te betrekken.

Een belangrijke beperking van dit onderzoek is dat het verspreid over een periode van ruim 10 jaar is uitgevoerd. Deze lange duur heeft nadelen, maar er zitten ook voordelen aan. Het belangrijkste nadeel is dat onderzoeksgegevens en informatie verouderen. Een voordeel is dat er in de gedetailleerde casestudy's belangrijke informatie over biotechnologische innovatieprojecten uit het verleden naar voren is gekomen waar veel van te leren valt. In de tussenliggende tijd was er de gelegenheid om verdere ontwikkelingen te observeren, ook al gebeurde dat niet zo gedetailleerd als in het oorspronkelijke veldonderzoek. Een belangrijk onderwerp voor verder onderzoek is dus het ontwikkelen en implementeren van een methode om biotechnologieprojecten in de landbouw te actualiseren en na te gaan hoe ze passen binnen lokale en (inter)nationale innovatieprocessen. Het is namelijk moeilijk om biotechnologie duurzaam in te zetten als deze kennis niet gekoppeld wordt aan bestaande innovatiesystemen die ook gericht zijn op de uitdagingen op het gebied van de ontwikkeling van de landbouw waarvoor Afrikanen met een klein boerenbedrijf staan.

1 Introduction

1.1 Introduction

Consider this: you have been closely following the debate on whether introducing biotechnology into existing national agricultural research systems (NARS) would result in sustainable productivity and food security for smallholder farmers. Fascinated by this narrative of old systems problem versus challenges of new technology paradigm; you wonder: what does this debate inform us on the dynamic view of innovation systems in developing and introducing a new technology into an existing system? Do modern and traditional biotechnology applications present similar opportunities and challenges to smallholder farming? Looking at how agricultural biotechnology policy and programmes have evolved in Kenya, and what worked and what didn't, should provide insights into the dynamics of innovation processes.

The central argument of this dissertation is that there are fundamental problems with existing systems in the diffusion and utilisation of available agricultural technologies irrespective of technology types and characteristics. There are two closely linked storylines to this central argument with respect to the issues of innovation capacity for sustainable utilisation of biotechnology in Kenya's smallholder farming.

The first storyline highlighted in this dissertation is that land reform as a basic resource for production cannot be separated from agricultural technology utilisation in Kenya. Thus, biotechnology may be needed because the demand for political and institutional solutions to extreme poverty is greater today than ever before. The easy option would be to continue flaunting technology as the answer. Yes, biotechnology can be made part of the answer if there are efforts to integrate the technology with the rest of the rural economy and also respond to larger societal concerns including the contemporary agricultural development challenges of soil fertility, marginal land use and agricultural youth in Kenya.

The second storyline, which is the focus of much of the empirical work in this dissertation, is around harnessing agricultural biotechnology for sustainable productivity and food security of smallholder farmers in Kenya. In this narrative, the study employs the Agricultural Innovation Systems (AIS) approach to examine the capacity of NARS and smallholder farmers in Kenya to innovate given technical, institutional and policy challenges posed by modern agricultural biotechnology.

Modern agricultural biotechnology, with focus on applications in genetic engineering or genetically modified organisms (GMOs), is being flaunted in global policy debates as a powerful technology for improving agricultural productivity and food security in Africa.

These debates often conveniently lump together the controversial GMOs and the less contentious traditional biotechnology, also known as 'non-transgenic biotechnology', which focuses on conventional applications such as fermentation, bio-fertilisation, tissue culture, and *in vitro* techniques.

There is controversy on the distribution and consumption of GM foods and other goods as opposed to conventional crops and other uses of biotechnology applications in food production. The controversial debate encompasses biotechnology companies, governmental regulators, non-governmental organizations (NGOs), scientists and consumers. The contentious issues on GM food include: labelling of food, the effect of GMOs on health and the environment, the effect on pesticide resistance, the impact of GM crops for farmers, the role of GM crops in feeding the world population, and the role of government (e.g. regulators) in all these issues.[1] Overall, the on-going policy debate is whether GMOs are transformatory; specifically, whether and how they can contribute to sustainable agricultural productivity and new inputs for African smallholder farmers.

Most African governments are cautious of modern biotechnology and there is confusion about GMOs because the role of this technology in African agriculture is not well understood. Today, there are few transgenic and non-transgenic crops (viz. virus-resistant sweet potato; IRMA, Insect-Resistant Maize for Africa; insect-resistant cotton; insect-resistant maize; transgenic cassava; DTMA, Drought-Tolerant Maize for Africa;

WEMA, Water-Efficient Maize for Africa; biofortification) that have been developed for and/or introduced in Africa, but so far, with mixed impact on food and income security of smallholder farmers. In fact, some of these biotechnology projects have faced intractable technical obstacles. Moreover, for many commentators, African farming systems are unique (small-scale, heterogeneous) and faced with many institutional and policy challenges. Thus, there is need for a more thorough examination and discussion of GM technology potential in this context.

1.2 Green Revolution and African Smallholder Agriculture

The context analysis of African smallholder agriculture is important because the original Green Revolution (GR) in agriculture largely bypassed Africa. While the introduction and deployment of improved crop varieties and the adoption of modern agronomic practices enabled food production to outstrip population growth in Asia and Latin America, agricultural productivity actually declined in Africa. According to Cooke and Downie (2010) "on a per capita basis, Africa's farms produced almost a fifth less in 2005 than they did in 1970."[2] Factors explaining Africa's low agricultural productivity include: low soil quality; scarcity of water; shortage of inputs; weak access to markets, credit and finance; variability of climate and the effects of climate change; inadequate government support to policy and infrastructure; and barriers to international trade (ibid).

In responding to some of these challenges several initiatives such as the Alliance for a Green Revolution in Africa (AGRA) aim to transform Africa's agricultural sector by making sure smallholder farmers are productive, profitable and food secure. AGRA's strategic approach states:

> AGRA's strategy is to transform today's rural poverty into tomorrow's prosperity by increasing the productivity of smallholder farmers. It is grounded in Africa's very diverse and largely rain-fed agriculture; wise use of science and technology; and in learning from previous Green Revolutions. AGRA's strategy focuses on smallholder farmers while working for change that strengthens the entire agricultural system and focuses on high-potential breadbasket areas and countries. It aims at strengthening critical links in a chain of activity that extends from farmers' fields to agricultural research organizations, from Africa's new seed companies and food processors to regional markets…[3]

Within AGRA, Program for African Seed Systems activities are focused on technology transfer via market-based models with mainly private seed companies and networks of local small entrepreneurs (also known as agro-dealers). The few exceptions where informal seed systems are supported include vegetative-propagated materials such as cassava and sweet potato where multiplication and delivery is by farmer groups facilitated by government research institutions and NGOs/CBOs. However, there are considerable challenges in promoting purely market-based approaches in an environment of imperfect markets, characterised by monopolies in seed production and distribution. Government interventions (viz. Farm Input Subsidy Programs) often bypass or undermine the profit-driven agro-dealers who are willing to deliver new technologies to new areas and small farmers in rural areas (Odame and Muange 2010, Scoones and Gover 2009). As a result, there is often a large shortage of good quality seeds for many crops, with the bulk of seed supplied through the informal sector.

AGRA recognises the importance of a 'diverse and dynamic seed system' and acknowledges the crucial role of the informal sector (AGRA, 2013). But it has not provided support for the informal systems or the Quality Declared Seed systems, which can provide seed quality assurance for locally traded seeds of smallholder farmers in Africa.

Smallholder farmers dominate Kenya's agricultural production structure. A small-scale farmer is one who lives and farms an average of 2 ha of land, especially in high potential agricultural regions of the country. The definition is however changing because about 80% of smallholder farmers are now living on less than 2 ha of land.

Despite the small farm sizes, this sub-sector accounts for 75 per cent of total agricultural production and over 60 per cent of gross marketed output. Many of these farmers practice mixed farming (including trees, crops and livestock) as well as petty trade to supplement their farm incomes. Women farmers predominantly manage this sub-sector. Women farmers are able to access neither assets such as land nor services such as credit and collective action (see, for example, World Bank 2007). The definition of small scale is quite different in the dry land areas of the country where land is relatively abundant. In this situation, the number of livestock they raise often defines small-scale farming. In this study "small-scale farmers" and "rural traders" are rolled into one concept referred to as "smallholders".

According to Odhiambo et al. (2004), Kenya's agricultural productivity growth has shown a marginal increase in aggregate cereal yields from 1.3 tonnes to 1.7 tonnes per hectare in the period from the 1960s and 1970s to 2000. In the early years following independence, the rapid growth was attributed to the expansion of production areas largely due to support provided by the Government in terms of extension, access and use of modern agricultural inputs such as seed and chemical fertilizers as well as investment in agricultural research.

Nyoro and Ariga (2004) stated that: from the late 1980s through the early 1990s, the government adopted policy reforms that reduced its involvement in economic activities. They further mentioned that the policies were however unable to bring about the expected increase in agricultural productivity. Cereal yields declined from an average of about 1.6 tonnes/ha to 1.4 tonnes/ha in the late 1990s before rising steadily to 1.6 tonnes/ha in 2005. This turn of events did not only raise the risk of food insecurity in Kenya but also limited the country's ability to fight against poverty.

The National Development Plan (2002-2008) reported that several factors play a role in contributing to food insecurity: poor choice of crops, droughts, increasing cost of inputs such as fertilizers amongst others. These in turn limit the ability of the agricultural sector to realize its full potential. In response to declining agricultural production and productivity, the Government developed a Strategy for Revitalising Agriculture (SRA). This 10-year plan was launched in 2004, and later entrenched in the Vision 2030.[4]

But consider this: the steady decline in the growth of yields and rate of poverty could not be reduced by the original GR which was guided by the R&D agenda of NARS. This raises the question: is biotechnology the answer?

1.3 Biotechnology as the Proposed Answer

The question whether biotechnology can provide the answer to the problem of agricultural productivity and food security in Africa has been at the forefront of international agricultural policy discussions and in the politics of international trade (Glover 2003). The polarity of US and European opinion on the societal impacts of biotechnology, specifically genetic modification, has equally shaped the biotechnology and biosafety debates in developing countries (Odame and Muange 2011).

In Kenya, the biotechnology policy debate began in 1990 following the report of the National Committee on Biotechnology Advances and their Applications (NACBAA) (NACBAA 1991). NACBAA was appointed by the government to prepare a roadmap to gradually apply and advance biotechnology in the country. In recent years, this debate has assumed some urgency as a result of rapid developments in biotechnology R&D and increasing commercialisation of GM technology at the global level. Other factors include increasing food insecurity in Africa and the growing activities and influence of global and local environmental activists. For instance, the enactment process of the Biosafety Bill in Kenya progressed slowly as proponents and opponents of modern biotechnology argued over processes and mechanisms of regulating GMOs (Oikeh 2009).

The most important concern to both proponents and critics of modern biotechnology is the regulation of the potential risks of GM technologies to the environment or health. However, the review of global-local biotechnology policy debates should also be concerned with dynamics of upstream research concerns (including investments, partnerships, intellectual property rights [IPRs], and biosafety concerns in the deployment of GM technology [ibid]). For instance, while the development and deployment of GR crop varieties were largely carried out by the public sector, the gene revolution, with its focus on GM plants, is conducted by the private sector or through public-private partnerships (PPPs) for commercial purposes (Odame and Muange 2011). This raises policy challenges with respect to how modern biotechnologies would be disseminated to poor smallholder farmers in order to realise the envisaged productivity growth (ibid).

Proponents of modern biotechnology argue that its adoption by farmers could help address the problem of food production. But they also caution on the broader developmental challenges including economic growth, agricultural sustainability, environmental protection and poverty alleviation. Several concerns have been raised on the potential risks of GM crops on the health of consumers and the environment. This situation creates uncertainty for politicians in developing countries to decide on whether or not to approve the plantings of GM crops. The key concern is who is likely to benefit from the introduction of GM crops (Mechlem 2010).

According to Paarlberg (2009) and James (2008), biotechnology will benefit both large and small-scale farmers. This view is however contested by many critics of the technology who argue that it allows multinational corporations (MNCs) to exploit poor farmers and threatens to disrupt other forms of agricultural systems (Action Aid 2003). Scoones and Glover (2009) further posit that placing too much hope in the technology will shift attention from other important socio-economic issues that underlie malnutrition and poverty.

For instance the GM crops and traits deployed, so far, target the needs of large-scale commercial farmers particularly in North America. Only recently are crops grown by smallholder farmers in developing countries being targeted. Also less targeted and funded are marginal conditions, including poor access to fertile land as an agricultural resource, drought, declining ground water levels, high temperatures and salinity (Odame and Muange 2011). A majority of the resource poor live in marginal areas and rely on agriculture for their livelihoods. But the technical problems they face are related to drought water stress, salinity, etc. which require multiple genes unlike the current GM crops, which have single genes or traits like *Bacillus thuringiensis* (Bt) technologies and herbicide tolerance (ibid).

These concerns have contributed to the debate on the need to look for alternatives to transgenic biotechnology. These include existing non-biotechnology (or conventional) technologies such as efficient irrigation, fertilizer use, modern high yielding varieties and hybrids as well as non-GM biotechnology applications such as bio-fertilizers, tissue culture, StrigaAway technology, marker assisted breeding (MAB), organic agriculture, integrated pest management, and participatory plant breeding. These non-transgenic biotechnologies are considered cost effective and proponents argue that they do not involve controversies including on IPRs and biosafety regulations (Odame and Muange 2011, Odame and Kangai 2013). In the words of Rosegrant (2012): "... traditional approaches are to be preferred to transgenics if they solve important problems, attract investment (public or private) and are cost efficient."

Unsurprisingly, there seems to be sharp divisions in opinions when it comes to finding the most suitable ways of identifying and managing the risks and uncertainties underpinning the implementation of GM crops – with respect to issues such as transparency, participation and accountability in decision-making. Specifically, these concerns are about the capacity of Kenyan NARS to learn, adapt and innovate given the challenges of GM technology. However, the focus on governance concerns has tended to limit the national debates on biotechnology to the narrow agenda of controlling and managing biophysical risks rather than the broader social, economic and ethical issues. These broader issues include asking hard questions: What kinds of investment in biotechnology should be made, and for what kind of reasons? How should successful technologies be deployed, scaled-up and/or scaled out?

Interestingly, these debates at the national level reflect global governance efforts towards a uniform pattern of capacity building in technology development and transfer to developing countries. But is this approach that enhances compliance to international regimes realistic or even desirable? Or should biotechnology policy and programmes be creatively designed and implemented in response to local contexts and needs?

1.4 Research Questions

In view of the issues raised above, this study attempts to answer the broader question: "Can agricultural biotechnology be harnessed to improve sustainable agricultural productivity and food security of smallholder farmers in Kenya?" The two specific research questions are:

1. Does the National Agricultural Research System in Kenya have the capacity to innovate in harnessing agricultural biotechnology for smallholder farmers given the challenges posed by modern biotechnology?

2. Does the innovation capacity of NARS influence the dynamics of success and failure of agricultural biotechnology policy and programmes in response to needs of smallholder farmers?

To address these research questions, this study employs the Agricultural Innovation Systems framework to Kenyan agriculture as a potentially useful tool for identifying and analysing strengths and weaknesses in harnessing agricultural biotechnology for smallholder farmers.

1.5 Agricultural Innovation Systems

1.5.1 Overview

The Agricultural Innovation Systems (AIS) approach was employed by this study due to its focus on a continuous process of innovation. Borrowed from business and industry, AIS concept signifies a change from technology delivery approach to one on capacity to innovate.

According to Hall (2007), several approaches to promote innovation in agriculture have emerged. They include: transfer of technology (TOT), farming systems research/extension (FSR/FSR&E), Farmer First (FF)/Farmer Participatory Research (FPR), and Interactive Learning for change (IL4C /Innovation Systems (IS).

The transfer of technology (ToT) paradigm was a widespread approach since the 1960s, and was predominantly used by National Agricultural Research Organisations. The implementation of the Farming Systems Research (FSR) approach in the 1970s and 1980s led to the formation of national agricultural research systems (NARS) to strengthen research at national level and support technology transfer and invention (see World Bank 2009).

Starting in the 1990s, the dominant paradigm was Farmer First (FF)/Farmer Participatory Research where the NARS were part of a pluralist Agricultural Knowledge Information Systems (AKIS) approach including agricultural extension service and public agricultural universities. AKIS emphasised greater participation of clients and their financing; adoption and adaptation of technologies; and knowledge learning and sharing.

More recently, in what Andy Hall (2005) refers to as 'Work in Progress', there has emerged a paradigm of Interactive Learning for Change

(IL4C) /Innovation System (IS) in which NARS are part of the Agricultural Innovation System approach (Rajalahti 2008).[5] The World Bank (2012:2, 2006: xvii) defines innovation in Agricultural Innovation Systems as follows: "Innovation is the process by which individuals or organizations master and implement the design and production of goods and services that are new to them, irrespective of whether they are new to their competitors, their country, or the world."

The AIS approach was developed to broaden the knowledge base of the agricultural sector of any particular country and to establish better ways to use new knowledge whilst designing other interventions that go beyond investments in research. Thus, AIS aims to create better opportunities for small farmers to innovate instead of trying to only introduce innovations (Hall and Dijkman 2006). It entails an interactive process that goes beyond the farmer and researcher to involve the private sector, technology delivery agencies and other players in the wider institutional and policy environment. Therefore, AIS encompasses all forms of interactions, including participatory rural approaches, public-private partnerships (PPP), local innovation, etc.[6]

As mentioned earlier, the concept of AIS is borrowed from the Systems of Innovation (SI) approach, especially following the seminal work by Freeman (1987), Lundvall (1992) and Nelson (1993).[7] Their work was however largely based on business and industry studies of *firms* in the newly industrialising countries. Hence, in adapting the IS approach to agriculture in general and smallholder *farms* in particular, it is important to define and delimit the following key concepts for developing an appropriate AIS conceptual framework.

1.5.2 Key Concepts Relevant to AIS

System

One of the early scholars of systems analysis, Churchman (1968)[8], still gives us one of the clearest explanations: A system is firstly defined by its Objectives (and concrete performance measures). It can then be described by its Environment, Resources, Components and Management means. This research recognizes that there is a hierarchy of systems and subsystems which are interconnected in the generation, adaptation, dissemination and utilization of knowledge. These include agricultural research education systems, bridging institutions and production systems, along with policies, institutions, linkages and systems. For example, the components of banana innovation system include: developing disease-free tissue culture (TC) banana planting material, making it available to farmers, getting farmers to use the plantlets, using market information, assembling, and ripening the bananas for market in response to price and marketing. These sub-systems relate to innovation.

Innovation

Innovation refers to the application of 'knowledge' to social and economic use. This entails knowledge creation, dissemination and use as opposed to mere knowledge creation. In other words, it involves both new knowledge and novel combinations of existing knowledge. There are different forms (codified/tacit) of knowledge, sources (scientific/indigenous) of knowledge, and types of knowledge including technical, institutional, organizational, managerial, service delivery, etc. Knowledge is necessary but not sufficient for innovation. It has to be combined with other components of the system for social and economic use. For instance, an invention system deals with knowledge generation while an innovation system combines invention and adaptation, dissemination and utilization of knowledge generated. This is the context in which the concept of innovation systems is defined.

Innovation System

Hall and Dijkman 2006) define Innovation Systems (IS) as follows:

> Networks of organizations, enterprises, and individuals that focus on bringing new products, new processes, and new forms of organizations into economic use, together with the institutions and policies that affect their behaviour and performance (see also World Bank 2008).

Given that innovation is about the application of new or re-discovered knowledge to create new levels of performance (following Drucker 1969), the innovation systems framework should be useful to a discussion of how information becomes knowledge becomes innovation in institutions, organizations and technology to be used by real people.

Institutions and organizations

Institutions are the 'rules of the game' which facilitate or impede or require certain actions. According to North (1990:359):

> Institutions are humanely devised constraints that structure human interaction. They are made of formal constraints (e.g. rules, laws, constitutions), informal constraints (e.g., norms of behaviour, conventions, self-imposed codes of conduct), and their enforcement characteristics. Together they define the incentive structure of societies, and political and economic institutions, in consequence, are the underlying determinants of economic performance.

Members of the community generally recognize and follow institutions regardless of their formal or informal status.[9] Institutions contrast with organizations which are 'entities' created by individuals or a group of individuals to support their collaborative goals. Formal organization is a kind of cooperation that is conscious, deliberate, and purposeful. Quoting extensively from Charles Edquist's book (Edquist 1997), the term 'institutions' in the context of national systems of innovation is used in two main senses. Institutions in the perspective of Nelson and Rosenburg (1993) are basically different kinds of organisations and they seem to include technology policies. For Lundvall (1992), institutions refer to 'things that pattern behaviour like norms, rules and laws. Thus, for Edquist (1997): 'The Nelson and Rosenburg's perspective could gain from stronger emphasis on things that pattern behaviour and Lundvall could give more weight on organisations in his historical elaboration.' Together organisations and institutions define the incentive structure of innovation system (AIS) in a specific country.

Technical change and innovation

Technical or technological change entails change in the production function that modifies input-output relationships. Normally, it is understood to be an improvement in technology for economic growth.[10] This understanding by most of the neo-classical and Keynesian theories fails to take account of the changing technology in each historical period (Freeman and Perez 1988:5-6):

> …it is true that almost alone among twentieth-century economists Joseph Schumpeter did attempt to place technical change at the heart of his system and did also address problems of social and institutional change.

Josef Schumpeter, however, paid little attention to the taxonomy of technical change (see, for example, Freeman (1988:5-6). Taking a cue from Freeman and Perez (1988), Lundvall (1992:57-59) made a distinction between four different forms of technical change: i) stationary technology, ii) incremental innovation, iii) radical innovation and iv) technological revolution. This study attempted to focus on incremental and radical aspects of innovation. The former is often associated with improving efficiency in the use of factors of production, whereas the latter is associated with the development[11] of new products because they often occur as a result of purposive R&D activity in enterprises and/or university or government laboratories. The mainstream economic theory assumes technical change is confined to incremental or process innovation aimed at achieving high productivity.

Nelson (1987, Nelson and Rosenberg 1993) proposed an evolutionary process as an alternative to understanding technical change which seeks to maximise profits. They concluded that change in technology is a process that is highly flexible and path-dependant. Nelson and Rosenberg (1993) considered innovation to be narrow in the sense that technical change is limited to technical modes of innovations.[12],[13]

The innovation concept is, however, not always restricted to technical innovations. Schumpeter, for example, conceived innovation in a much broader way when compared to the innovation concept used by Nelson and Rosenberg (1993) in Edquist (1997:9):

> Recalling that production in the economic sense is nothing but combining productive services; we may express the same thing by saying that innovation combines factors in a new way, or that it consists in carrying out New Combinations. (Schumpeter 1939: 87-8)

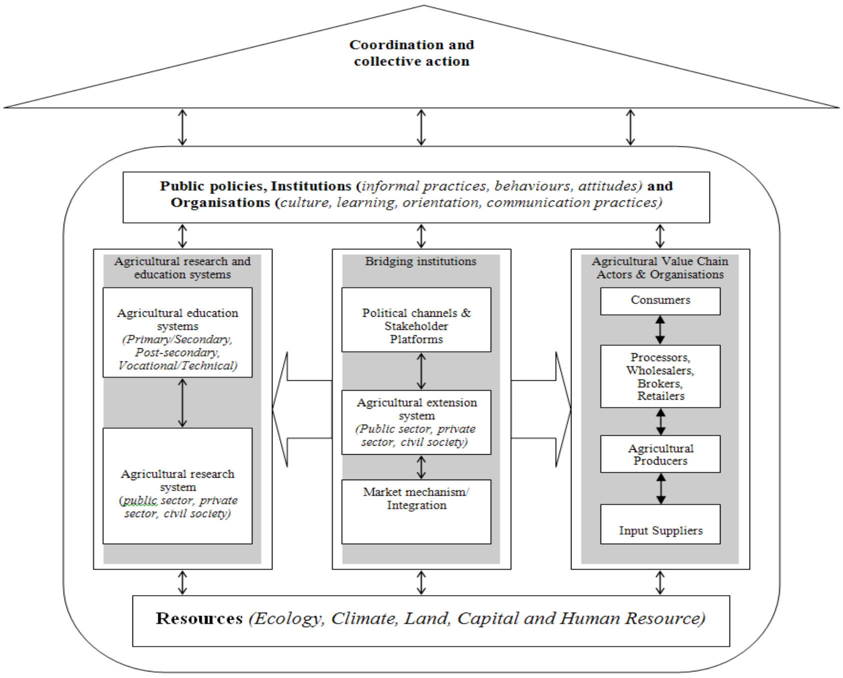
Edquist (1997:10) further explains that 'New creations' tend to be associated with product innovations whereas 'New combinations' are associated with process innovations. Product innovation seems to be the more important part of technological innovation (Lundvall 1992:8). This is probably the reason why they are including them in their concept of innovation. Lundvall (1992) mentions 'new forms of organization' and 'institutional innovations', in addition to technological process and product innovations.[14] Arguments favouring organizational change are persuasive (ibid).

The organizational form for a department of R&D for instance, does influence the design of technologies of a particular product, a number of which are later converted to process technologies. The study of organizational innovation has received little attention as compared to that of technological innovations[15]. In this dissertation, the new organizational forms, their dissemination as well as the communication between these models and technological innovations are conceptualized within the Agricultural Innovation Systems (AIS) approach.

1.5.2 Agricultural Innovation Systems Framework

Following an adaptation of the generic concept of National Systems of Innovation (Spielman and Kelemework 2009), our conceptual framework of Agricultural Innovation Systems comprises the following five domains: 1) agricultural research and education, 2) bridging institutions, 3) business and enterprise, 4) policy and institutions, 5) coordination and linkages (see Figure 1.1 below).

Figure 1.1
Conceptual Framework for Agricultural Innovation System



Source: Adapted by author from Spielman and Kelemework (2009)

Agricultural research and extension

Agricultural research is internationally aimed at unlocking agricultural potential, a goal that is quite relevant in the economies of developing countries. For this goal to be realised, there is a need for effective linkages between scientists and farmers and also coordination of the entire agricultural technology system.

Agricultural education systems such as institutions of higher learning are mandated to create, generate and manage knowledge. Knowledge produced in these institutions is viewed as a public good. However, educational institutions have been challenged to extend their mandate of knowledge generation to include knowledge use. The USA took up this challenge by encouraging university-industry linkages which would ensure knowledge diffusion either through formal or informal arrangements. Consequently, it leads in university-industry linkages in the provision of consultancy services to industries, university professors sitting in companies' scientific advisory boards or facilitating direct contractual agreements (Lam 2004). In Kenya, the participation of agricultural educational systems in adaptive research is exemplified in this study by the Nairobi MIRCEN (Microbiological Resources Centre Network) project at University of Nairobi (see Chapter 4).

Agricultural research systems occur mainly in three sectors namely; public, private, and the third sector comprising NGOs, CBOs and the civil society. However, the motivation for undertaking agricultural research varies across the sectors although they sometimes converge. For instance, Schumpeter (1939) posited that competition for small profits induced entrepreneurs to innovate. This describes the motive of the private sector's engagement in agricultural technology research.

Some agricultural technology innovations involve partnerships between the public and the private sector, a concept referred to as Public-Private Partnerships (PPPs). PPPs have been widely used as a means for capacity building as well as an enabling international transfer of modern biotechnologies to developing countries. The international transfer of technology has in some cases left the greater public ignorant of the motive[16]. In contrast, proponents of such arrangements argue that since the public sector in developing countries has been reducing its expenditure in agricultural research while the private sector has a pool of resources to engage in technological innovations, PPPs offer a platform to advance agricultural research (Spielman et al. 2007).

Evaluating a country's public expenditure in agricultural research is today considered 'out-dated' since it does not place a country's agricultural R&D efforts in a context that can be internationally analysed and evaluated. Hence, measures other than absolute levels of expenditures and numbers of researchers are needed. These include measures such as the intensity of investments in agricultural research (Beintema and Gert-

Jan Stads 2008). The relevant indicators mentioned by Spielman and Kelemework (2009) are: public investment in agriculture R&D infrastructure; investment in human resources; public and private funding for policy and programmes; quality of scientific research institutions and the education system (based on expert opinions); research collaborations and partnerships, technological readiness (in terms of use of ICT, scientific publications in peer-reviewed journals, membership in scientific bodies or networks); development and registration of crop varieties, patents; brain-drain engagement with farmers and public accountability.

This study seeks to analyse the success and failure of agricultural research and educational systems through a review of innovation capacity of NARS and case studies involving educational systems, the private sector, the public sector and PPPs in agricultural research. It will seek answers on the following issues: efforts aimed at moving beyond the generic form of capacity-building (Hall and Dijkman 2006); linking knowledge creation to its use by integrating knowledge and practices of farmers and other actors in the value chains; and communicating scientific knowledge to the non-scientific community and to the public. The study will draw lessons learnt from agricultural biotechnology development through to diffusion.

Bridging institutions

Bridging institutions comprise a variety of formal and informal organizations which link technology developers with the end users. These institutions offer various services which directly or indirectly ensure technologies move from laboratories to farmers' fields. They include political institutions, agricultural extension systems and market mechanisms. Services offered by bridging institutions include technology delivery and advisory services and other use requirements such as fertilizer, irrigation facilities, safety equipment, financial services and legal advisory services.

These services are offered either by the public sector, private sector or the third sector that includes local traders, NGOs, farmer groups, consumer groups, environmental groups, private companies, and Community Based Organizations (CBOs). The expansion of spaces between bridging institutions reflects a shift from depending on the government to other service providers.

Spielman and Kelemework (2009) mention the following indicators of bridging institutions: the presence of agricultural extension service to make it accessible to poor farmers; investment in agricultural extension as an indication of government commitment to extension service; and the importance of university-industry linkages to channel research findings to industries for the development of beneficial products to farmers and other users.

McNamara (2008) and Jones (2008) emphasize the role of modern ICT in extension systems.[17] They argue that through ICT, farmers can acquire current market information, be effectively linked to service providers, express their needs/views and give feedback to service providers regarding their services or products. Through ICT, farmer-scientist linkages will be two-way and this will facilitate development and diffusion of appropriate technologies.

Business and enterprise

Spielman and Kelemework (2009) provide useful indicators for evaluating business and enterprise domain. These include: performance of business, quality of institutions and infrastructure that impact on the performance of smallholders, potential for technology transfer (through Foreign Direct Investments and PPPs); use of fertiliser and machinery as a sign of commercialisation (and hence differentiating between subsistence and commercial production); access to production assets (land, water, tools and equipment owned or leased by smallholders) and quality of institutions and infrastructure that support smallholder farmers (e.g. roads, information flows, seed supply system, etc); conditions for accessing financial services; and level of farmer aggregation (farmer groups) to achieve economies of scale in accessing inputs, information, credit and product markets and commodity lobby groups for policy change.

The transformation of inputs to output through a production process is an important aspect of the business and enterprise domain. Farmer characteristics/attitudes including level of awareness, age, experience, risk attitude, tastes and preferences determine what, when and how to produce. If the farmer is constrained by one or more factors within the economic environment, the production is also constrained. A production system is unique in terms of its input system (acquisition and use), organisation system and farmer characteristics and practices. The organisation system refers to membership in farmer organisations or institutions which influence decision-making in regard to farm activities. Farmer characteristics encompass the socio-economic conditions under which farm decisions are made while farmer practices are a result of cultural inclination or farmer habits which influence uptake of a new technology and its use.

Alston et al. (1995) defined developing countries' agriculture as characterised by a small number of dominant crops/livestock and numerous minor crops and/or livestock. The authors also argued that a farming system observed in a region or farm represents long-term adjustments to the prevailing conditions. Farmers' decisions are guided by the existing exogenous and endogenous conditions which in turn explain the choice of one production system over another. Land, water access and use along with gender relations as part of the agro-ecosystem domain are the major constraints to agricultural production, especially in developing countries. Land tenure arrangements in these countries include production on rented pieces of land or on small land parcels which are in some cases uneconomic units. The constraints of land, water and gender erode the possibility of productivity improvement and output expansion. It also explains why efforts to improve efficiency of agricultural production and increasing average yields/ha remain at the top of the development agenda for developing countries (ibid).

Policy and institutions

Public action in designing and implementing target policies including: priority setting, legal matters and regulations, taxes and subsidies influence innovations on both the supply and demand sides. Edquist (2000) argued that technical changes are affected by different types of innovations. The procurement of public technology is an important policy on the demand side in the sense that it determines how agencies in the public sector make orders on products *a priori* to stimulate innovation.

Innovation policy is especially important for emerging technologies such as biotechnology. The public sector is involved in technology development, and in technology transfer through the extension departments of Ministries of Agriculture. It is also involved in policy formulation and implementation based on pertinent issues such as biosafety, IPRs, licensing, import and exports of technology.

The private sector in this study refers to privately owned biotechnology laboratories, private research firms, private companies involved in biotechnology development, diffusion and use and private researchers. Non-governmental organizations also intervene in agricultural technology to facilitate technology adoption and use by marginalized farmers. Farmers receive technologies (either new or improved) from the public and the private sector and in turn communicate their needs to the suppliers of technology. However, weaknesses in this feedback mechanism are blamed for the poor diffusion of technologies especially to small-scale farmers who are targeted in this study.

Coordination and linkages

Coordination and linkages whether undertaken by individual or organisational agencies play a facilitation role for the public sector to support effective interaction between small-scale farmers (particularly those not reached by extension and markets) and other actors, because the market alone is not sufficient to make those links. Coordination is also required to manage the diversity of knowledge competences and vested interests including those of donors, policy-makers, scientists, government regulators, extension workers, local traders, farmers, etc. The complexity of the innovation process means that it needs to be facilitated (Spielman et al. 2009). The facilitator can be networked individuals and/or influential organizations, also known as innovation brokers (Klerkx and Leeuwis 2009).

Lobbying is another important factor in determining the policies of innovation. This is done by private firms, state agencies and civil society organisations. These actors lobby for the design and implementation of innovation in pursuit of their interests (Edquist 2001). Lobbyists have political and/or economic power positions, and they often work to maintain the status quo; but they can also work for and against deployment of emerging technological innovations.

This study is interested in exploring the influence of societal forces in the design and implementation of biotechnology policy and programmes in Kenya. The AIS framework presents a potentially useful tool for understanding innovation dynamics in agricultural biotechnology and smallholder farming. It can complement the market economy dimension of industrial innovation with the non-market or sociological dimension of farmer participation in order to describe the changing landscape of agricultural research, extension and local production. Following an analytical framework employed by Edquist (2001) and Ikiara (2004), this dissertation attempts to make empirical generalisations or create (appreciative) theories about what drives agricultural biotechnology innovation policy. It also identifies and explains functions that are missing or inappropriate and which lead to deficient functions or 'system failures'.

1.6 Study Approach

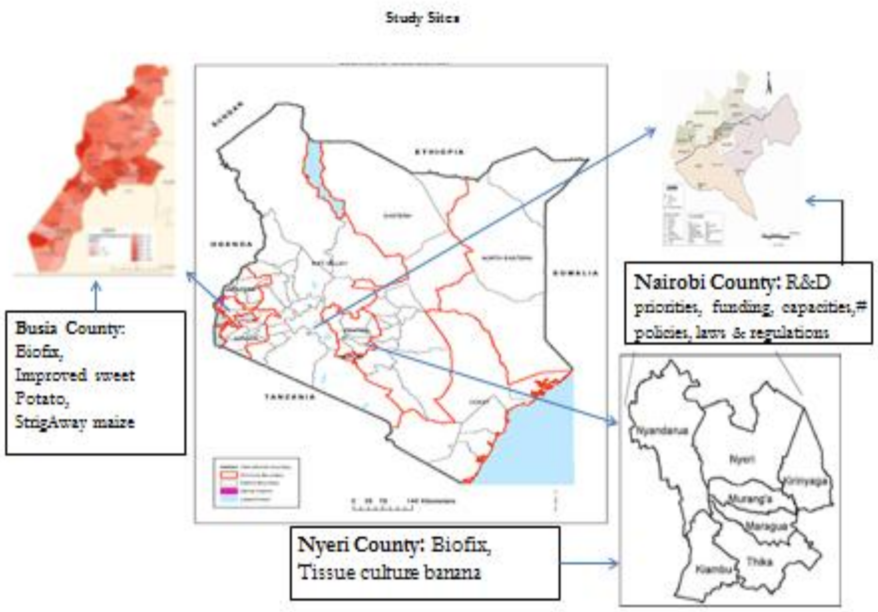
In attempting to answer the question of harnessing agricultural biotechnology for smallholder farmers, the study employed a two-pronged approach: a national institutional analysis and case studies (see Kitay and Callus 1998). The national institutional analysis was largely conducted in Nairobi County where most of the NARS head offices are located; while data and information on farmer experiences with the cases of agricultural biotechnology applications (viz. Biofix, improved sweet potato, tissue culture banana and StrigAway technology) were collected from Nyeri and Busia counties (see Figure 1.2).

1.6.1 National Institutional Analysis

The national institutional analysis aimed to describe the science and technology (S&T) policy and institutional environment in which biotechnology is developed and introduced in Kenyan agriculture; especially which agricultural biotechnology options are supported, by whom and in whose interest?[18] This description was intended to capture the global-local trends in agricultural biotechnology policy processes. In doing so, we used five main types of data sources: secondary data, news clippings, key informant interviews, questionnaire survey interviews and a feedback workshop.

First, the fieldwork drew heavily on data obtained from secondary sources, particularly the report by International Service for National Agricultural Research (ISNAR) (Wafula and Falconi, 1998). Information on statistics and data was derived from the report. The data was collected via surveys of indicators of research intended for agricultural biotechnology policy and programme activities in Kenya.

Figure 1.2
Study sites



Source: Author

Second, news clippings were used to obtain information on the current research activities and the implementing agencies. This source was critical because all major and minor policy pronouncements on agricultural biotechnology are made through the local press. Third, the two sources mentioned above enabled the author to identify respondents for key informant and survey interviews.

Fourth, the author obtained some feedback from the participants of a workshop organised by the African Centre for Technology Studies

(ACTS) in December 2000. The workshop on 'Building biotechnology innovation systems: Innovating institutions and financial mechanisms' provided the author with an opportunity to present and receive feedback on his preliminary report on the status of biotechnology in Kenya.

Fifth and finally, since these activities were all undertaken some time ago, the author has continued to update information on the status of agricultural biotechnology policies and regulations through media platforms and interactions with different stakeholders.

The author began primary data collection on the status of agricultural biotechnology in Kenya by conducting interviews with policy makers and scientists in the targeted research units (or departments, as units of analysis) in the Kenyan NARS. These respondents in turn assisted in identifying and compiling a list of research projects and contact persons.

The NARS in Kenya comprises universities, national agricultural research institutes (NARIs), private sector, international agricultural research institutes (IARCs) and state regulatory agencies. Apart from two universities (i.e. Egerton University and Moi University), many of these organisations are either located or have their head offices in Nairobi.

Data collection focused on organisations involved in agricultural research policy and programmes in Kenya. I received a letter of introduction from the African Centre for Technology Studies (ACTS)[19], which facilitated interviews with scientists in IARCs located in Nairobi. However, the letter was less useful in facilitating interviews with research scientists/managers in the Kenyan NARS because ACTS (as an intergovernmental organisation) has limited influence over the NARS. Hence I relied on personal contacts to facilitate data collection on the status of agricultural biotechnology in the country.

At the national level, International Service for Acquisition of Agri-Biotech Applications (ISAAA), Kenya Agricultural Research Institute (KARI), African Agricultural Technology Foundation (AATF), Agricultural Biotechnology Stakeholder Forum (ABSF), National Council of Science and Technology (NCST), University of Nairobi, and seed companies were considered crucial organisational contacts because of their leadership in the agricultural biotechnology policy and programmes in the country.

As Table 1.1 shows, the 32 respondents represented 62 departments of 20 national and international research organizations in Kenya. Depending on the size (i.e. number of departments), the respondents ranged from 1 to 5 in a given organization. The International Livestock Research Institute (ILRI) had the highest number of respondents. The questionnaire survey consisting of open and closed questions addressed the following areas: scientific infrastructure, human resources and funding, institutional linkages, national policies and laws. Therefore, Chapter 3 presents the main findings on availability, level of use and constraints to full use of existing national capacities.

Table 1.1
Sample data on NARS respondents in Kenya

Organization Category	Population (N)	Sample (n)
Academic/university	12	5
NARIs[a]	15	6
NGOs	5	3
Private	8	4
International	16	11
Government	6	3
Total[b]	62	32

Notes: a= KARI (N=7 and n=5), whereas Other NARIs (N=8 and n=2)
b=Of the 32 respondents, 24 completed questionnaires with formal interviews and 8 with informal ones.
Source: Author's compilation

1.6.2 Case studies

The main empirical case studies involved Rhizobium inocula of University of Nairobi's MIRCEN project (Chapter 4) and transgenic sweet potato project (Chapter 5), an initiative of KARI and Monsanto, among others. The data collection on Tissue Culture Banana Technology and StrigAway Maize Technology in Chapter 6 (which complemented the main case studies) were based on literature review and key informant interviews.

Rhizobium inocula

Although the Rhizobium inocula project has existed for over two decades, there was inadequate data to quantitatively assess its field performance in yields of dry beans. The project was not effectively targeted in terms of type of farmers and regions of the country. In other words, the project was largely implemented in an unsystematic manner. As a result, the author used an exploratory approach based on secondary data and 'snow-balling' to identify areas of the country and farmers that had systematically used the technology.

The primary data collection involved key informant interviews and a questionnaire survey of smallholder farmers. The author held one unique interview with Professor Keya, a founder of the University of Nairobi's MIRCEN and at the time the Executive Secretary TAC/CGIAR/FAO[20] in Rome, who provided useful insights on the origin and growth of Rhizobium research in Kenya. He also drew insights on the performance of inocula in Kenya from one key survey report on the distribution of *Rhizobia* associated with important agricultural legumes in the East and Southern Africa region, which was conducted under the auspices of Rhizobium Ecology Network of East and Southern Africa (RENESA) by Dr. Paul Woolmer and Nancy Karanja (Woolmer et al. 1996).

The Woolmer-Karanja study was based on 60 households in the Central Highlands of Kenya –an area where the original Rhizobium inocula (or Biofix) had been promoted through District Agricultural Shows and by some local NGOs for several years. The objective of their survey was to assess perceptions of farmers in the areas where legume inocula were available through the not-so-distant University of Nairobi MIRCEN (ibid).

However, the author's exploratory visits to the same areas especially in Kiambu, Nyeri, Kakamega and Busia districts in early 1998 revealed that only a few farmers in Nyeri and Busia districts had used the inocula.[21] Therefore, apart from secondary data, this chapter relies on the information obtained from 25 key informants from University of Nairobi, NGOs, CGIAR and FAO offices in Nairobi; and a questionnaire survey of 70 farmers from Mathira and Kieni East divisions in Nyeri District, and Butula division in Busia District. As it shall be discussed later, these are the regions of the country where, through particular local NGOs, some farmers had accessed and used Biofix and Prep-pack at least for one season.

Transgenic sweet potato

At the time of this study (as still is today), transgenic sweet potato research was still confined to KARI research stations, and it was yet to reach farmers' fields. Consequently, we used secondary and primary data sources on existing and anticipated sweet potato innovation in Kenya. The national level data collection involved key informant interviews with scientists at International Potato Centre (CIP) and KARI. The local level data collection was primarily an *ex ante* evaluation of the transgenic sweet potato technology based on the existing production system of traditional and improved (non-GM) sweet potato varieties. A key source of field data was a study on a collaborative research project, which involved Kenya Agricultural Research Institute (KARI), International Potato Centre (CIP), Ministry of Agriculture extension staff, NGOs/CBOs and farmers.

The latter was implemented under the Competitive Grant project in three districts namely Siaya, Busia and Teso in western Kenya. It employed participatory approach involving local NGOs/CBOs and 12 farming groups to conduct on-farm conservation of planting material and utilization of traditional and improved (non-GM) sweet potato varieties. Thus, it provided the foundation on which the study conducted fieldwork.

The field data collection for this study was based on 12 key informant interviews[22] and 160 survey farmers in Bukhalalire division, Busia District in western Kenya. In particular a local NGO, Appropriate Rural Development Agricultural Programme (ARDAP), assisted to identify and interview 120 farmers who had directly or indirectly participated in a Competitive Research Grant project on sweet potato between September 1997 and November 1999. The survey covered three categories of farmers namely:

i.) Trained and received new planting materials;
ii.) Not trained and received new planting materials, and
iii.) Not trained and did not received new planting materials.

The objective of using these categories was to obtain views from representative samples of farmers who were differentiated on the basis of access to training and/or new technology through supporting organizations such as ARDAP in Butula Division. The first two categories were randomly selected from 360 members of 12 farming groups mentioned above. The third category comprising 40 farmers was randomly selected from distant areas (15-25 km) from the project. The latter involved the use of 'snow-ball' technique (see Table 1.2 below).

Tissue culture banana and StrigAway maize

The author employed recent secondary literature and key informant interviews to review the introduction of tissue culture (TC) banana and StrigAway Maize biotechnologies to smallholder farmers in Kenya. The review was about interactive learning processes of bringing together scientific and local knowledge about production of bananas and maize. TC banana and StrigAway Maize were considered two of the few available examples of non-GM biotechnologies which had reached smallholder farmers in Kenya.

An extensive literature review was conducted from the relevant published reports over a period of 11 years, and more recently websites of key organisations were examined to update data and information on national institutional analysis and case studies.

In addition to key informants, focus group discussions (FGDs) involving farmer groups were also held in parts of Kenya where Rhizobium inocula technology (central and western Kenya) and improved sweet potato, Tissue Banana, IR-Maize technologies have been deployed and data/information on farmer experience could be collected. (See also Table 1.2 which summarises data collection on Rhizobium inocula and transgenic sweet potato).

Key informant interviews and farmer FGDs were important sources of information on descriptions and explanations of past and current production practices, especially with respect to common beans, sweet potato, bananas and maize. As mentioned earlier, two farmer surveys were conducted. One involving 70 farmers was carried out in three districts where Rhizobium inocula was introduced and used by farmers: Mathira and Kieni East in Nyeri County; and Butula district in Busia County. The other farmer survey involving 160 farmers was conducted in Butula district. These surveys assessed the farmers' experiences with the traditional biotechnology innovation -including Rhizobium inocula – and their perceptions concerning transgenic sweet potato, which was being anticipated in the area.

Table 1.2
Data collection on Rhizobium inocula and transgenic sweet potato

Case study/Variable	Rhizobium inoculum		Sweet potato
Division[a]	Mathira/Kieni East	Butula	Butula
Year[b]	1998/2000	2000	2000
Number of:			
- farmer key informants	3	2	5
- farmer focus groups	3	3	3
- farmer group membership	76	40	130
- farm households surveyed[c]	44	26	160
- farmers participating in the feedback workshops	15	10	25

Notes[23]:
a: Mathira and Kieni East divisions, Butula division, Nyeri district and Busia district.
b: Update of data was done over time.
c: Through focus group discussions, a number of farm households were chosen from members of participating farming groups. From a group of 160 respondents, 40 in the sweet potato study were selected from non-participating groups.
Source: Field data

Further insights into these issues have, over time, been obtained through discussions held with participants during feedback workshops in 2000 and dissemination workshops in 2004 when we presented the study findings in the form of reports or published papers on the Biotechnology Policy in general and four individual case studies in particular.

It is important to point out that this study has been carried out for more than a decade. The long duration has some disadvantages but could also be advantageous. One key disadvantage is the outdated data on the national institutional analysis and Rhizobium inocula and transgenic sweet potato case studies. At the national level, there is limited analysis of current status of scientific infrastructure (viz. laboratory facilities, human resources, funding) and research (re)-organisation. Although transgenic sweet potato research was still confined to KARI research stations and it had yet to reach farmers' fields at the time of the field study, there are now several initiatives resulting in increased adoption of improved (non-GM) sweet potato varieties by smallholder farmers. A new PPP initiative on Rhizobium Inoculant (BIOFIX) fertilizer was started in 2008 in an effort to build on the original Rhizobium inocula project to support increased accessibility of low-cost organic fertilizers to smallholder farmers in Kenya.

The two case studies, thus, do not capture the recent experience of farmers. However, the detailed case studies have captured important and instructive processes of biotech innovation attempts in the past from which much can be learned. The intervening time period has provided the opportunity to observe further developments. For instance, the original Rhizobium inocula technology in Chapter 4 and transgenic sweet potato in Chapter 5 did not work because they did not effectively reach the target smallholder farmers due to challenges along the innovation process (technology generation, dissemination and use) and linkages within the national system. I have attempted to update the original case study chapters and other chapters through secondary data, key informant interviews and FGDs. Using the latter methods, I have introduced TC Banana Technology and StrigAway Maize Technology in Chapter 6 as examples of biotechnologies which reached farmers in a systematic way. I have also used data and information obtained from consultancy assignments and projects to update the study material, especially on policy and regulations. The following publications are key sources of such updates: "Agro-Dealers and the Political Economy of Agricultural Biotechnology Policy in Kenya" (Odame and Muange 2011); "A country report on Agribusiness Public Private Partnerships in Kenya" (Unpublished report prepared for FAO and Economic Commission for Africa [Odame and Kangai 2013); and "Biosafety Regulation: Opening Up the Debate – Lessons from Kenya and Philippines. Proceedings of the International Workshop, held at African Institute for Capacity Development, Jomo Kenyatta University of Agriculture and Technology (JKUAT), Nairobi, Kenya, 15-16 November 2010" (Odame and Okumu 2010).

1.7 Organisation of the Thesis

The thesis consists of 7 chapters. This introduction chapter has identified the research problem and questions informing the study, the conceptual framework and the methodology and organisation of the dissertation. Chapter 2 presents a review of literature on the changing landscape of agricultural development in Kenya. It examines the history of agricultural technology systems (explaining why and how these technologies have developed, diffused, or failed to do so in society), along with an extensive communal structure where firms, knowledge and bridging institutions are embedded. The chapter then highlights key challenges that may influence biotechnology development in the country.

Chapter 3 examines the status of biotechnology policy and programmes in Kenya. It reviews the global and local trends to identify actors, their networks and R&D agenda. The chapter then uses empirical data on plant biotechnology projects developed and deployed in Kenya to assess the status, prospects and emerging challenges of agricultural biotechnology policy and programmes in the country.

Turning to the case studies, we focus on the innovation process within four agricultural biotechnology projects (Chapters 4-6) to better understand the dynamics of successes and challenges along the innovation process (viz. technology generation, diffusion, utilisation) and linkages within the national system with respect to smallholder farming.

The four case studies are the Rhizobium inoculum (Chapter 4) examines an attempt by a public university to move Biological Nitrogen Fixation (BNF), a non-GM technology, from the laboratory to smallholder farmers targeting the production of common beans for the purpose of nitrogen replenishment. This is followed by the Transgenic Sweet potato project (Chapter 5), which highlights public-private partnership (PPP) in modern agricultural biotechnology (or GMO) advancements in the country and allocation of disease-resistant sweet potato varieties to Kenyan farmers.

The case studies of Tissue Culture (TC) Banana and StrigAway Maize initiatives (Chapter 6) are based on interviews with key informants and a review of secondary literature to exemplify technologies that reached smallholder farmers. Chapter 7 provides a synthesis of the findings of the study in relation to the AIS conceptual framework and the research questions and analytical issues that rose in Chapter 1, and concludes the thesis.

Notes

[1]See also http://www.globalchange.umich.edu/globalchange2/ current/ labs/gmfood_video/gm%20review% 202010.pdf >Accessed 16th July 2012

[2]Cited in Robert Paarlberg, Starved for Science: How Biotechnology Is Being Kept Out of Africa (Cambridge: Harvard University Press 2009).

[3]See also http://www.agra.org/who-we-are/-strategy--for-an-african-green-revolution/ seed development programs in sub-saharan Africa; a review of experiences.pdf
'the future of agriculture status report 2013- AGRA' >Accessed on 10th July, 2013
[4]See also http://www.safaricomfoundation.org/fileadmin/template/

main/downloads accessed on 5th July, 2012/ Kenya_VISION_2030-final_report-October_2007.pdf >Accessed 31st July 2010

[5] See also http://www.future-agricultures.org/farmerfirst/files/D1_Hall.pdf >Accessed on 21st September 2010).

[6] FAC CAADP Policy Brief 07 | March 2012

[7] See also www.druid.dk >Accessed on 20th April 2011

[8] Churchman, C. West. The Systems Approach (1968)

[9] www.ifpri.org >Accessed 25th July 2012

[10] This refers to technological progress that increases output for any given input.

[11] Classical models deal with product innovation and the emergence of new products.

[12] Nelson and Rosenberg (1993) count process and product innovations as technical innovations.

[13] www.tema.liu.se >Accessed 5th October 2012

[14] www.unido.org >Accessed 5th November 2012

[15] Edquist (1993)

[16] For instance, Monsanto's initial funding of Transgenic sweet potato project was viewed as an entry point for Bt crops, see section 5.5.2

[17] http://www.ifpri.org/sites/default/files/publications/oc59.pdferry >Accessed 15th May 2013.

[18] We gained important insights from the report of the ISNAR entitled Agricultural Biotechnology Research Indicators in Kenya (Wafula et al. 1998).

[19] The African Center for Technology Studies (ACTS) is an inter-governmental organization located in Nairobi, Kenya. It is a leading science and technology policy organization in Africa

[20]TAC/CGIAR/FAO stands for Technical Advisory Committee(TAC)/Consultative Group on International Agricultural Research(CGIAR)/Food and Agriculture Organisation (FAO) of United Nations

[21] In particular, the first generation Rhizobium Inocula (or Biofix) was used in Nyeri district, whereas, its new variant (or Prepack) was used in Busia district

[22] The interviews involved scientists from CIP/KARI, Monsanto, KABP, extension workers, NGOs, etc.

[23] See also www.sls.wau.nl >Accessed on 3rd December 2012

2 Evolution and Context of the National Agricultural Research System

2.1 Introduction

The changing context of National Agricultural Research Systems (NARS) in which biotechnology is developed and introduced to farmers in Kenya is drawn from the country's history of agricultural development. The change can further be linked to the imperatives of modernisation strategies of the post-World War II period. Scholars such as Beynon et al. (1998: 57-80), noted that before and after independence, the Kenya NARS, previously known as the National Agricultural Research Institutes (NARIs) assumed a highly political role.

The state, for example, provided legal frameworks for some commodities and founded NARIs to support them. Upon gaining independence in 1963, the new government retained policies and institutions of the colonial era, while trying to balance between liberal and social state development models. It embraced both growth and redistribution policies as ways and means of modernising the subsistence sub-sector. A major constraint faced by the NARIs in modernising subsistence agriculture is the historical role of the state policies in influencing participation of different actors in agricultural research and extension processes.

In the mid 1970s, there was a rapid expansion in public agricultural research and extension programmes in response to the increase in smallholder production. This was mainly due to increased public investment from bilateral donors. Since mid 1980s, World Bank and IMF's prescription for Structural Adjustment Programmes (SAPs) influenced the performance of agriculture in Kenya. There was a shift from state-dominated NARIs to the much wider concept of NARS. In the contemporary era, the improved performance of NARS is a priority in addressing high incidences of rural poverty amid the changing landscape of science and technology (S&T) policy (Rukuni et al. 1998).

This chapter reviews agricultural policies and institutions, knowledge bases and production structures characterising the evolutionary contexts and environment of NARS in Kenya during the following three periods: Pre-colonial/colonial era, Post-independence era, Structural Adjustment Programmes/contemporary era. The review provides useful lessons on the dynamics of introducing biotechnology (see Chapter 3) within NARS – which faces challenge in harnessing existing technologies for smallholder farmers in Kenya.

2.2 Pre-colonial Era

The pre-colonial era was characterised by mixed farming practised by indigenous Kenyans. A key feature of the production structure was shifting cultivation. Under this system, farmers left one piece of land to lie fallow while the other piece was in use. Many local communities also engaged in pastoralism. They kept large herds of cattle, which they grazed by moving from one place to another (Lubembe 1968:17).

Production was basically for subsistence purposes though there was barter trade between communities. Due to poor soil and weather conditions in some areas, many African people experienced repetitive periods of droughts, pestilence and famine. In addition, because of population pressure, the search for new grazing land in Africa led to massive human migrations. The Luo of present day Kenya, for instance, migrated from Sudan to western Kenya due to an unsustainable increase in human and livestock populations. Also, the Kikuyu expanded into the Maasai area. The inter-ethnic geographical and cultural proximity influenced African agriculture and land-use options. Production knowledge evolved over time and was mediated by local culture. Apart from barter trade, most knowledge and plant materials were exchanged freely. However, scholars consider the advent of colonialism as the main turning point for changes in land tenure and knowledge systems in Kenya (Cohen and Odhiambo 1989:15-22).

2.3 Colonial era: 1902-1963

This period is regarded by many students of agrarian change in Kenya as characterized by the emergence of two farming systems: that of indigenous communities and that of the European settlers. The two systems were differentiated by proportion of factors employed in production (i.e. input use, production practices and social stratification). For instance, in 1905, an average size of the European settler farm was 5,488 acres, whereas it was estimated that the average farm size of a Kikuyu farmer was conceivably less than 40 acres (Bates 1989).

The period from the mid 1930s was characterised by expansion of the formal agricultural technology system along the lines of the British commercial agricultural model. Apart from expanding commercial agriculture in the country, it confined relevant agricultural innovations in the white settler farms and excluded African farms. In its informality, the organisation of indigenous knowledge in the African farms included a multiplicity of relations and practices, while the British model limited agricultural knowledge organisation to agricultural professionals. It was also more hierarchical and exclusive. The absence of mechanisms for mediating land conflict between the two systems left Africans subject to the goodwill of the white settlers, leading to spontaneous protests by the affected population. Therefore, the spate of agrarian unrest in the country was a geographic-specific phenomenon, especially in the areas occupied by the Kikuyu.

White settler agriculture expanded in the production of coffee, maize, sisal, tea and improved cattle. The dairy industry responded to increased demand for milk (due to urbanization) by introduction of European breeds of cattle, which made the business more profitable. However, the exotic breeds of cattle were susceptible to tropical diseases. The government responded by imposing quarantine measures against squatters and their indigenous livestock herds to curb disease spread. Following these measures, some squatters were sent back to African Native Reserves.

The colonial government acquired land forcefully from the indigenous community and moved them to African reserves. The African reserves served as pools of labour for European farms. The majority of the labourers were squatters in the sense that apart from being paid a subsistence wage, they were also allowed use rights to cultivate land and raise livestock. The colonial government favoured the settler community[1] by allocating them large tracts of land in the 'White Highlands'.

African farmers continued their subsistence production practices in the colonial era although they were limited by the colonial government's policies on land use and land ownership rights. The exclusion from producing certain crops resulted in protests against the feeling of being alienated from land and production (Sorrenson 1967). This led to the emergence of the Mau Mau group, which rebelled against the colonial administrators.

After the emergence of Mau Mau in 1952, Mr Swynnerton was appointed in 1953 to come up with recommendations for advancing African Agriculture in Kenya. The plan, which was popularly known as "Swynnerton Plan", published in 1954, significantly shaped the history of agricultural development in Kenya. For instance, it revealed that there was a regrettable absence of consultative and arbitration machinery to address land problems in the country. Therefore, the Plan recommended the establishment of a programme for settling squatters, enactment of land laws for guaranteeing free land transactions, compulsory consolidation and registration of parcels, and establishment of a land department responsible for solving land ownership issues.[2]

During World War II, the government's need for increased agricultural produce was immense, especially following a directive to supply raw materials in South East Asia and food for the British military forces in North Africa and the Middle East. This was a big challenge because the bureaucrats lacked skills, information and techniques to manage agricultural production. Also, the war effort had led to reduction in size of the administrative apparatus, as public servants were re-deployed to military assignments. The settlers were directed to develop mechanisms for safeguarding production targets. In so doing, the state handed economic power to settlers in exchange for services during the war.

The result was the creation of new institutions that were to enhance the capacity for collective action on the part of the settlers. The acquisition of the ability to act collectively transformed the significance of the structure of property rights. The settlers took advantage of the government's need for increased agricultural production by transferring to the state a portion of the risk of commercial farming. For instance, they produced commodities that they sold to the state at controlled prices.

The production and market exchange required the formation of new institutions as settlers formed agencies to monitor, police and control their own economic conduct. For instance, in 1927, three settler organisations (i.e. Maize Growers' Association, The Plateau Maize Growers' Association and the Kenya Wheat Growers' Association) merged to form the Kenya Farmers Association (KFA).[3] The terms of the new economic order were embedded in the provisions of increased crop ordinance[4] and defence. Based on this ordinance, farmers submitted to the state inspectorate a farm production plan with target acreage of specific crops, and an outline of intended production practices. When approved by an oversight committee, the production plan became a contract to purchase the pledged quantity of production at a fixed price. In the event of a natural disaster, the government guaranteed the farmer a rate of return commensurate with his production plan. On the basis of these guarantees, a farmer could secure from state agencies advances of farm inputs at controlled prices. He could also employ the guarantee as collateral for private loans (Bates 1989). The institutional linkages between farmers and the state aimed to smoothen and secure market relations.

The immediate post World War II period was characterised by attempts to integrate Africans into European agriculture. For instance, the British government, through the Colonial Development and Welfare Fund (CD&W), actively encouraged the colonial Kenya government to accelerate the spread of cash cropping.

The period was also characterised by strengthening of research-state alliances. One of the features of research systems in many former colonial regions is their close association with the state. In 1955, the Government of Kenya initiated a maize improvement program in Kitale, western Kenya to respond to the needs of farmers. The government hired an expatriate breeder, M.N. Harrison, who worked with some Kenyan researchers to develop late maturing hybrids for the wet highlands. By the late 1950s, there was a growing middle cadre of indigenous Kenyan scientists who eventually replaced expatriates in the post-independence era.

In summary, agricultural development strategies pursued by the colonial government before the nation gained independence in 1963 protected the white settler farming and undervalued African smallholder farming. Smallholder farming was based on subsistence production practices. There was free exchange of agricultural knowledge and planting materials through a communal network of neighbours, friends and relatives and between neighbouring communities. Attempts by African farmers to adopt settler farming practices were met with restrictive measures. Inevitably, the African subsistence farmers and settler large-scale agriculture were polarised. Marketing, pricing, infrastructure development, credit, research and extension favoured white settler farmers and neglected the African smallholders. Antagonistic relations also existed between the formal and informal knowledge systems but only the former was recognised and supported. Even at the household level, colonialism introduced a dichotomy of privileges benefiting more men than women (Boserup 1970).

2.4 Post-independence Era: 1978

After independence, the new Kenyan government embarked on redressing some of the imbalances created by the colonial government. One of the initiatives was formulation of policies such as land reforms, agriculture development and macro-economic policies.

2.4.1 Land Reform Policies

Land reform was fundamental to the newly formed government, since it was perceived to eliminate social inequality and generate growth by reforming the former White Highlands areas. According to the Sessional Paper 10 of 1965,[5] 'Implementation of the Settlement Schemes' was a major agricultural development strategy aimed at addressing the political concerns over land crisis and redistributing land to relieve population pressure on arable land. Land resettlement was also envisioned to improve the production base of the rural people and increase incomes and living standards. This led to the establishment of the 1-million settlement scheme aimed at improving accessibility to land. However, the scheme is estimated to have settled only 13 per cent of the estimated 100,000 squatters in the early 1960s (Herbeson 1973:3). The government used the rest of the land to set up state farms for continued production of elite seeds and livestock breeds. However, the area under plantation producing of coffee, tea, sisal and ranching remained the same because of the need to maintain the production of export crops. Also, few Africans could afford to buy land (Townsend 1993).

Kenya's land reform failed to achieve acceptable land redistribution and to increase agricultural productivity for impoverished smallholders and landless households. The initial benefits of land reforms favoured large-scale farmers, export crop producers and high potential agro-ecological areas. In essence, the government shifted its policies from agrarian development to agricultural development.

2.4.2 Agricultural Development Policies

In the second Five-Year Development Plan (1969-1973) formulated by the Republic of Kenya, the government supported smallholder agriculture to achieve high targets of production and exports. A policy framework to elicit the necessary response was established. This development strategy was based on the neo-classical foundation of rapid economic growth by modernising the subsistence or traditional agricultural sub-sector.[6] The government adopted a 'developmental state' approach based on the mixed economy model. This required a balance between growth and social development models by trying to attract foreign investment through favourable taxation and business policies on the one hand and implementing redistribution policies on the other. The government designed and implemented the mixed economy model because of its belief that this development strategy would lead to access to productive assets, which was meant to increase yields in selected agricultural commodities such as maize, coffee, tea, wheat and horticulture.

This strategy was based on increased public investments in the agricultural sector via research, extension, credit, infrastructure and human resources. For instance, in the 1964-1974 period, real public expenditure on maize research rose by 200 per cent, from K£100,000 to K£200,000 million (Hassan and Karanja 1997:5). As a result, there was an immediate significant increase in rates of farmer adoption of hybrid maize (see Table 2.1). Large-scale farmers in high potential areas rapidly adopted the new maize hybrids[7]. Over 50 percent of these farmers also adopted seed and inorganic fertilizer, which significantly contributed to the growth of maize yields.

During this period only 16 and 5 per cent of smallholders respectively in high potential and low potential zones adopted the new maize variety. A large proportion of large-scale farmers adopted modern varieties (MVs), followed by smallholders in high potential zones, and lastly by smallholders in areas that produced low yields (Hassan and Karanja 1997). The poor adoption rates of small-scale farmers in the low production regions were attributed to government neglect of the sub-sector. In particular, the government was criticised for abandoning agrarian reform and adopting a mixed economy approach (ibid).

Table 2.1
Kenya: Growth in maize area, yield and production and trends in adoption of improved maize seed and fertilizer, 1963-1991

	1963-1974	1975-1984	1985-1991	Total 1963-1991
Growth				
▪ Area (%/yr)	2.8	-4.3	0.2*	0.7
▪ Yield (%/yr)	0.8	1.5	0.3*	1.6
▪ Production (%/yr)	3.6	-2.8	0.5*	2.3
Number of new varieties released	13	2	6	21
Percentage of farmers adopting seed				
▪ Large-scale farmers, high-potential zones	48	72	94	94
▪ Small-scale farmers, high-potential zones	16	58	95	95
▪ Small-scale farmers, low-potential zones	5	17	57	57
Percentage of farmers adopting fertilizer				
▪ Large-scale farmers, high-potential zones	42	60	83	83
▪ Large-scale farmers, high-potential zones	11	35	63	63
▪ Small-scale farmers, low-potential zones	2	5	11	11

* 1985-1995

Source: Hassan and Karanja 1997:83; Table 6.1

Marginalisation of smallholders and indigenous knowledge (IK) has also been cited by Warren (1992), who points out that the local government adopted the top-bottom approach to technology development started by the colonial masters. He argues that despite the fact that IK is excluded from the formal information systems, rural communities apply IK as a basis for decision-making.

2.4.3 Macro-economic Policies and Politics

The 1973 oil crisis severely affected the government. A significant amount of the country's foreign reserves was spent on oil imports. Suddenly the state had much less resources with which to support its massive development agenda, which included expanding agriculture. Consequently, the state expanded its borrowing from external sources, especially the World Bank and other bilateral donors.

In 1974-75, Kenya experienced a dual crisis of rapid increase in inflation and decline of 2.8 per cent in the GDP growth rate, the lowest since independence. The government's strategy for coping with the crisis was laid out in the Sessional Paper No. 4 of 1975 on 'Economic prospect and policies. However, the idea of restructuring the economy was temporarily abandoned as a result of income growth from agriculture relative to industry. By the end of 1978, the coffee boom which explained income growth had ceased, forcing the government to consider alternative policies.

Politics and economic development are inseparable, hence politics has always determined the economic growth of Kenya. For instance, the politically elite large-scale farmers through Kenya National Farmers' Union (KNFU) influenced the direction of research. KNFU leaders supported the dominance of agricultural research and extension systems over other knowledge systems in the country. It was also a political strategy of Kenyatta's government to reward leaders with political appointments and land allocations. This led to the neglect of a core sector of the country's economy, the smallholder farmers.

Agricultural research system

This period was marked by bilateral and multilateral donors' investment in agricultural development. There was also notable proliferation of international research organisations in the country with Kenya having the highest number of international agricultural research centres that conduct agricultural research in Africa. The government also established the National Council of Science and Technology (NCST), and its duty was co-ordinate activities of the NARIs.[8] The increased scope for NARIs through collaboration with IARCs and CGIAR systems and donor funding contributed to the expansion of agricultural research activities in Kenya. As noted by Odame and Muange 2011), in the period between the early 1950s and mid-1980s, NARIs consisted of three formal categories: the public and the private sectors and the civil society. The NARIs in Africa operated in the public research sector, with the CGIAR system influencing their research agenda towards Green Revolution approaches.

In Kenya, a few NARIs and foundations such as Kenya Seed Company, Kenya Tea Research Foundation (KTRF) and Coffee Research Foundation (CRF) were semi-public (or parastatals). The expansion of the NARIs in the late 1970s was also due to their expected response to needs of small farmers, especially the resource poor and those in marginal areas. The period 1975-84 was characterised by an upsurge of smallholder adoption of improved seed, especially in high potential areas. The adoption rate of 58% for small farmers was similar to that of large farmers in the same zone. But the yields were relatively smaller for several reasons. These include many smallholders adopting improved seed and not fertilizers, unfavourable policy environment and harsh periods of severe drought in 1979-80 and 1983-84 (Hassan and Karanja 1997).[9]

The pressure on the NARIs for greater social responsibility in Kenya's rural development continued in the 1980s. However, the government made no significant attempts to improve the suitability and appropriateness of agricultural innovations to smallholders, especially poor women farmers and those in marginal areas. Apart from Katumani and Coast composite maize varieties, which were released in the 1960s and the 1970s, most modern varieties (MVs) were for high potential areas. At the organisational level, poor management, indolence and the neglect of farmer groups contributed to a high incidence of inappropriate agricultural innovations for smallholders in Kenya (Stamp 1989).

Top down approaches to sustainable agriculture development continued to dominate in the mid-1970s. As noted by Conway and Babier (1990), the idea of developing and transferring ecologically sound and cost-effective technologies to developing countries was topical. Thus, sustainable agriculture (SA) with its components: biofertilisers, agroforestry, organic farming and integrated pest management (IPM) seemed appropriate for smallholders in developing countries (ibid). Within this period, population pressure on land led to decline in agricultural output. The available land was sub-divided into smaller units which were uneconomic parcels. Over-exploitation, poor land resource management and the destruction of vegetation led to reduced productivity by these smallholders.

2.5 Structural Adjustment Programmes and Agriculture

In response to the economic downturn due to the escalating world oil prices in the 1970s, the government prepared the Sessional Paper No. 4 of 1980 on Economic Policies and Prospects, which paved the way for the introduction of Structural Adjustment Programmes (SAPs) in Kenya. SAPs became integrated into the country's economic management following the publication of Sessional Paper No. 1 of 1986 on Economic Management for Renewed Growth (Bates 1989). The public sector was subjected to across-the-board budget and employment cuts. Public expenditure on agriculture declined from 8.9 per cent of the budget in the 1970s and 1980s to 4.3 per cent for the 2008/2009 financial year (Government of Kenya 2009) In addition to curbing government expenditure, major policy reforms focused on liberalisation of trade in terms of removal of price control, import licences, and foreign exchange control.

Following the introduction of SAPs in the mid 1980s, there was a shift away from state-dominated National Agricultural Research Institutes (NARIs) to a much wider concept of National Agricultural Research Systems (NARS). NARS comprise the traditional public and private R&D sectors and a third sector involving civil society (see Table 2.2 below).

Table 2.2
NARS' constituent organisations

Category	Description	Example
Academic		
▪ Technical	Agencies that combine higher education with basic research.	Faculty of Agriculture
Public		
▪ Public-local	Applied research agencies -administered by state and semi-state agencies with no explicit profit-making objective.	NARIs and commodity research agencies
▪ Public-global	Agencies whose mandate covers more than one country	IARCs/CGIAR, and foundations
Private		
▪ Private-local	National agencies whose primary activity is the development and deployment of technology and information for profit.	Local seed, fertilizer and agro-chemical companies and agro-dealers
▪ Private-global	Similar but covering international agencies	Global seed, fertilizer and

		agro-chemical companies
Civil society		
▪ Local and Global	Agencies not directly controlled by state or private sector	For profit and not-for profit agencies (trade associations, NGOs and CBOs)
Government		
▪ Regulators	Agencies directly administered by government	Policy, legal and regulatory bodies within ministries

Source: Author's compilation

The structural change from NARIs to NARS was due to economic and policy changes and the impact of political restructuring intrinsic in SAPs. These changes resulted in the internal re-organisation of NARIs in terms of personnel, research budgets, administrative structure and project approval procedures.

The scope of this study does not allow an in-depth analysis of human resource capacity, especially with respect to management of scientific research. However, considering human resource as a visible indicator of the state of S&T, the emerging picture is not promising. In part, this is due to limited funding or recruitment and utilisation of existing human resources (see Rukuni et al. 1998).

As mentioned earlier, SAPS led to a cut in the budgetary allocations for agricultural technology development. This meant that NARS had to outsource funds in order to supplement their budgetary allocation. In KARI, for example, there was a notable increase in donor funding as opposed to the shrinking GoK budgetary allocation. The statistics in Table 2.3 confirm the high and rising agricultural research expenditure in 1992/3 due to an increase in finance from donors; much of it in infrastructure, capital, technical assistance and equipment under National Agricultural Research project (NARP I), which began in 1987. By 1992/3, donor finance accounted for two-thirds of KARI's total budgets.

Other measures to raise funds include levies, user charges and royalties, research contracts, sale of seed and other products, making effective use of existing resources through rigorous priority setting, more client-driven research system and a funding system of competitive research grants[10] (Beynon et al. 1998). Given that these measures were new, KARI faced financial constraints. This led to scaling down of research activities. Also, it was difficult for KARI to achieve a critical mass of scientists, let alone maintain the existing human resource capacity.

A prominent feature of agricultural development in sub-Saharan Africa is affiliation of the research organisations to the state. For instance, alliance between research institutes and the East African states was intended to formalise knowledge systems through policy and legislative frameworks in order to foster modern technologies to respond to needs of the region. After the East African Community collapsed in 1977, the regional agricultural research organisations were dissolved, and their operations taken over by the countries in which they were located.

From the mid 1980s, a strong move towards a synergy of the NARIs evolved as the impact of structural adjustment paradoxically attempted to transform the NARIs into NARS by prescribing the inclusion of other actors such as the universities and civil society (Eponou 1996). Today, the NARS in Africa are linked by specific regional networks including the Association of Agricultural Research in Eastern and Central Africa (ASARECA), West and Central Africa Association of Research and Development, and Southern Africa Centre for Agricultural Research (SACCAR).

2.6 Contemporary Era of Globalization

2.6.1 Strategy for Revitalising Agriculture

Following the dismal performance of the agricultural sector in the 1990s, new attempts by the government to turn the sector's performance around began in the early 2000s as stipulated in the Strategy for Revitalising Agriculture (Government of Kenya 2004). The strategy was anchored in the Economic Recovery Strategy for Wealth and Employment Creation, a broader policy framework for enhancing overall economic and social development; and the Millennium Development Goal (MDG) number 1, which aims at eradicating extreme poverty and hunger by 2015 (Odame and Muange2011).

The SRA plans to ensure food security by significantly reducing hunger, famine and starvation by 2015, in line with the United Nations MDG 1. Although there have been revitalisation efforts as the pillar to agricultural productivity, production of the main food crops has remained below consumption requirements (Government of Kenya 2004). Mose et al. (1997) attribute this post-liberalisation failure to political, structural and economic constraints that included flaws and inefficiency of technology development and dissemination due to inadequate government funding for research and extension, underdeveloped private sector, unfavourable legal framework, high cost of farm inputs, inadequate linkages among agricultural sector agencies, poor marketing, limited access to credit and infrastructure, and ethnic conflicts. To increase food production and hence improve food security and farm incomes, there have been pleas by the public sector, private sector and international research organisations for promotion and use of good quality crop varieties, mineral fertilizers and pesticides (Cartridge and Leraand 2007).

The discussion above shows improved use of modern technologies as an important policy objective in addressing the problems of low agricultural productivity. However, technology introduction and use among the poor smallholder farmers to realise the envisaged productivity growth cannot be separated from the contemporary agrarian (read land) issues in Kenya.

2.6.2 Agrarian Challenges

Although over the years, several approaches have been used to improve agricultural productivity and increase crop yields, the country is currently faced with a number of agrarian development challenges that affect the growth and development of its agricultural sector. The main challenges include: land issues, climate change, population pressure and agricultural youth, and emerging technologies (such as biotechnology and its legal and regulatory concerns).

Land issues

Mango (1999) and Foeken and Tellegen (1997) argue that the rapidly growing population in most rural areas of Kenya has put substantial pressure on arable land. This situation has led not only to increasing land fragmentation but also to rising landlessness. Continuous subdivision of land has left many families with an inadequate area to meet subsistence needs.

The Kenyan economy remains largely based on agriculture, and land is the basis on which agricultural activities are carried out. Perhaps due to this, a complex mix of political, historical, social and economic reasons have led to persistent land conflicts and inequitable distribution of land. Debates about the redistribution of agricultural land draw strong opinions.[11] As the land debate rages on, as was the case in the recently promulgated Constitution,[12] agricultural production in Kenya has been in steady decline. From being a net exporter, Kenya is now a net importer of food. Even maize, one of the staple food crops, has to be imported to satisfy national demand.

Climate Change

Trends in global warming and climate change have justified long term investments in breeding for traits such as drought tolerance with the aim of increasing agricultural productivity. In addition, several programmes have tried to address issues of experienced or anticipated effects of climate change in the context of increasingly volatile input and output markets and to the pressures of continuing land subdivision. Aside from climate change, the growing population has also put enormous pressure on the natural resources of the country and forced people to occupy fragile ecosystems such as forests and marginal lands. The marginal areas in Kenya comprise grassland and savannah rangeland. In such areas, incidences of crop failure are common. According to Foeken and Tellegen (1997), being marginal does not mean that these areas are uninhabited or are regarded as wastelands. Climate adaptation activities entail growing of orphan crops such as sorghum, millet, cassava and sweet potato and fruit trees.

Population pressure

Over the years, population in Kenya has been increasing rapidly. The 2009 census put Kenya's population at 38.6 million. The population growth rate of over 3 per cent per year has placed an increasing strain on food production and on land. A large portion of Kenya's population is concentrated in agro-ecological zones of fertile land, particularly in the high rainfall areas where most agricultural activities take place; but studies have shown that agricultural productivity in such areas has consistently declined (Wambugu and Kiome 2001). The decline in agricultural productivity coupled with a rapidly growing population poses a serious threat to soil fertility and environmental conservation. According to Mango (1999), farmers' efforts to restore soil fertility are inadequate since few can afford to use modern agricultural inputs such as inorganic chemical fertilizers.

Youth and agriculture

Farming and other activities associated with agriculture in Kenya have been regarded by many as professions for the aged and illiterates who dwell in rural areas. Youth in Kenya face several challenges in their endeavour to participate in national development.

The challenges specific to agriculture include limited access to land, ignorance of career and business opportunities within the sector, and lack of interest in agriculture given that the range of career and entrepreneurial opportunities in this sector is not fully marketed to the youth. In most households, ownership of land and control of produce usually remain in the hands of the family head even though the young family members may have portions of land for crops or livestock enterprises. This implies that they have no control over the use of land and are unable to make major decisions over its use. Most household heads prefer to grow specific crops on their pieces of land. In this case, if any land is available for the youth to practise agriculture, it would be the marginal areas or rocky parcels of land.

It has been argued that rural youth are increasingly disinterested in smallholder farming, which is viewed as 'dirty work' (Bennell 2007). The negative perception has led to the increased migration of young persons to urban and peri-urban areas in search of formal employment or 'good' jobs. The out-migration of the young and productive labour force from rural to urban centres has a negative impact on agriculture and economic development. Therefore, there is a need to stall rural–urban migration in Kenya. This can be achieved by creating opportunities for employment in the agricultural sector which attract young people.

2.6.3 Introducing Biotechnology

The persistent nature of contemporary agricultural sector challenges in Kenya as described above (viz. increasing population, land subdivision, soil infertility, low yield and the resultant food insecurity), has opened space for alternative technologies, especially those geared towards meeting the needs and priorities of smallholder farmers in Kenya. As discussed in the subsequent chapters, this has intensified debates on whether agricultural biotechnology can be harnessed for this category of farmers in the country.

2.7 Conclusion

As in other Third World plural societies with colonial history, Kenya's agricultural technology system is divided not only between traditional and modern knowledge systems but also along geographical and cultural lines. Historically, farmers of white origin were concentrated in the commercial sub-sector while indigenous farmers were in the subsistence sector. Thus, it is not surprising for the use of certain knowledge systems to be dominated by ethnic groups that are concentrated in localities producing specific agricultural commodities. The heterogeneity of geography and culture has supported and restricted the standardisation of past agricultural innovations. In particular, the government adopted a top-bottom approach in development and dissemination of agricultural technologies. These technologies were mainly favourable to the large-scale commercial farmers and only a small percentage of small-scale farmers. Smallholder farmers in low potential areas were the most neglected, with the critics of government policy complaining of marginalisation. NGOs identified this void and have taken up the challenge, but to a limited extent, to independently support smallholders and their knowledge systems.

With the implementation of SAPS, the government shifted focus from agriculture, yet it is a key sector in economic recovery. As a result of SAPs, public expenditure on agriculture in terms of price supports and subsidies of inputs were greatly reduced. In addition, trade liberalisation exposed the farmers to cheap imports of substitutes and the recurrent price fluctuations.

Despite the current efforts at re-organisation of NARS and refocusing technology development to benefit more small-scale farmers, the envisaged agricultural productivity has not been achieved. Poverty levels continued to rise in the 2000s, with smallholder farmers, pastoralists in ASAL areas, and agricultural labourers accounting for the larger percentage of the poor. Landlessness continues to prevail. This situation shows that initiatives aimed at introducing modern agricultural technologies to the poor smallholder farmers cannot be separated from the contemporary agrarian issues in Kenya. The next chapter analyses the institutional context in which biotechnology is deployed in Kenyan agriculture.

Notes

[1] Settler community comprised Europeans (0.3%), East Indians (1%), others (28%)-(Collier and Lal 1986:37)

[2] For more on the findings and recommendations of Swynnerton Plan Report, see The History of Kenya Agriculture (Winstone and Lipscomb (2007)).

[3] The objectives of KFA were to improve marketing to ensure good prices for their products and stimulate scientific breeding of maize.

[4] See, for example, Regulations of 1942: Minimum Return and "Maize Control" (Bates 1989:21).

[5] African Socialism and Its Application to Planning in Kenya (Sessional Paper 10 1965:4).

[6] See, for example, Shultz (1964).

[7] See, also, Gerhart (1975).

[8] See also www.future-agricultures.org >Accessed 8th March 2013

[9] This resulted in expensive food imports and distribution for the government.

[10] Agricultural Research Fund (ARF) was established in February 1990/91 with a grant of US$521,000 from USAID to promote a more pluralistic research system. RAF through comparative research grants aims to raise the quality, relevance and effectiveness of research within the framework of KARI's priorities for supporting agricultural development (Beynon et al. 1998).: see also http://www.opml.co.uk, accessed 17th November 2012

[11] allafrica.com/stories/200907201664.html opened on 5th July 2012

[12] The Land Chapter was one of the most contentious chapters during debates on the draft Constitution (promulgated into law on 4th September 2010).

3 Agricultural Biotechnology in Kenya

3.1 Introduction

Kenya is facing several challenges that affect the growth and development of its agriculture-based economy. Over time, several technologies and approaches have been introduced to boost agricultural productivity and food security. But as in many other African countries, farmers' experiences with agricultural technologies have been mixed, and mostly poor. It is within this context that global advances in biotechnology are considered to have important implications for agricultural productivity and food security in the country.

This chapter uses secondary and primary data to explore the contemporary status of science and technology (S&T) policy, and the institutional environment in which biotechnology is developed and deployed in Kenya. The first section reviews global trends in biotechnology and how these trends interface with the local situation. This is followed by an analysis of the technical and institutional dynamics of traditional and modern agricultural biotechnology innovation processes with respect to scientific infrastructure (viz. laboratory facilities, human resources, and funding), research organisation, policy and regulations. The next section examines capacity building to harness agricultural biotechnology for smallholder farmers in Kenya. The chapter then summarises emerging issues and provides conclusions.

3.2 Global and Local Contexts

3.2.1 Global Trends

Advances in science and technology (S&T) in the 1970s led to the advent of modern biotechnology. Since then, the new knowledge has revolutionised many spheres of life, including agriculture, industry and human health. Modern biotechnology is considered knowledge-intensive and expensive since its development is predominantly influenced by advanced human resources, scientific infrastructure (i.e. laboratories, equipment and reagents, funding) and supporting policy. Earlier technological developments in agriculture were based on conventional breeding which aimed to balance variation and selection pressure to sustain systems. There have also been advances in continuous selection and the use of molecular marker technology to speed the breeding process (Ives and Bedford 1998).

Global trends in modern biotechnology take various dimensions. These include large investments and high adoption rates of some modern agricultural biotechnology products (James 2008). Ernst & Young (2008) reported that in 2007 the biotechnology industry worldwide recorded high levels of financing and deal-making amidst a shrinking general global financial situation in 2008. This was also reported by PR Newswire in the May (2008) issue[1]. The major source of funding has since been multinational capital from leading life science companies mainly concentrated in the industrialised countries.

The US is the global leader in biotechnology R&D in investment, development and commercialization of biotechnology products. Ernst & Young (2008) reported that revenues from public biotechnology enterprises in the US grew by 11 percent from US$58.6 billion in 2006 to US$65.2 billion in 2007. In Europe, the biotech industry saw an 18 percent increase in revenue to €5.5 billion from €4.6 billion in 2006. Business to business deals reached new heights in 2007. In the US, the total potential value of deals (viz. mergers, acquisitions and strategic alliances) announced in 2007 was approximatelyUS$60 billion, thus outdoing previous years by a wide margin. In Europe, the total potential value of such deals rose steeply to about US$34billion.

According to the Ernst & Young report (2012), the global biotech industry was in 2012 showing signs of recovery since the 2009 crisis. The total revenue for the biotech companies rose by 10% to $83 billion. This was a significant recovery from the 9% decline when the economy hit bottom in 2009. At the peak of the financial crisis in 2009, about two-thirds of the biotech companies decreased R&D spending. But in 2011, about two-thirds of the companies increased R&D spending resulting in a 9% increase across the industry. The report further says, "Although the $33 billion in biotech investment approached levels not seen since the venture boom 12 years ago in 2000, there is a major difference in the nature of the current investment compared with 12 years ago. … [o]nly about half the 2011 capital investment went to companies with revenues smaller than $500 million. The rest is larger pharmaceutical companies taking advantage of low interest rates to finance acquisitions and stock buybacks."[2] An overall increase in biotechnology has been accompanied by a rapid expansion in the global area under GM crops. Since the commercialisation of the first GM crop in 1996, the global area has increased rapidly. In 2007, it was reported that about 12 million resource-poor farmers from developing countries (including India, China and South Africa) grew biotech crops. This was a significant rise from 5 million farmers in 2002. In 2008, for example, it is reported that three new countries (including Egypt and Burkina Faso in Africa) and 1.3 million different categories of famers enjoyed the profits allied with biotech crops. In addition, overall planted region rose to 10.7 million hectares (James 2008).

ISAAA (2012) reports that there were 28 countries that were planting genetically modified (or biotech) crops by the end of 2012 with the top ten growing more than 1 million hectares. The United States leads the top five countries with 69.5 million hectares of land under GM crops (including maize, soybean, cotton, canola, sugar beet, alfalfa, papaya, squash). Brazil follows with 36.6 million hectares and Argentina is third with 23.9 million hectares –with both countries growing soybean, maize and cotton. Canada (11.6 million hectares on canola, maize, soybean, sugar beet) and India (10.8 million hectares on cotton) are fourth and fifth, respectively.

Four main GM crops that have been continuously grown in the entire world since 1996 include soybeans leading the list, followed by maize, cotton and lastly canola. Private companies have played (and continue to play) a significant role in the growth and commercialisation of modern biotechnology (Millstone and Lang 2008).

The developing countries grew more biotech crops than industrial countries. They grew more (52 percent) of global biotech crops in 2012 than industrial countries at 48 percent. In Africa, South Africa expanded its biotech area by 0.6 million hectares to reach 2.9 million hectares on maize, soybean and cotton; Sudan joined South Africa, Burkina Faso and Egypt, to bring the total number of African biotech countries to four. The latter three countries grow cotton. (ISAAA 2012)[3].

Notwithstanding lack of recent and reliable data, what developing countries spend on biotechnology is relatively low. This problem was acknowledged by a recent IFPRI report (2012); which also used updated data on agricultural biotechnology R&D expenses. For instance, expenditures on biotechnology-oriented research in developing countries were 5-10% of the total amount. NARS financed the expenses. This was revealed by a study carried out on investment in biotechnology in Kenya, Mexico, Indonesia and Zimbabwe during 1985-1997 (Jansen et al. 2000). Donor funds contributed a considerable stake of the investment; about sixty per cent of the total for instance in Kenya and Zimbabwe.

Apart from private sector industries and the NARS, financial support towards biotechnology also comes from International Agricultural Research Centres (IARCs). In particular, the Consultative Group on International Agricultural Research (CGIAR) system spent approximately US$25 million annually on agricultural biotechnology. This figure represented 7.7% of total CGIAR budget. It is also claimed that such IARCs have developed some biotechnology products as a result of this expenditure (Morris and Hoisington 2000).

Given low funding levels for biotechnology in developing countries, many of these countries reacted to trends in the industrialised countries by establishing basic infrastructure and regulatory regimes for assessment and introduction of agricultural biotechnology. They first started with applications which were less science-intensive and low cost options or 'first' generation biotechnology applications. Second, in managing modern agricultural biotechnology R&D process, there has been a change from emphasis on public investments to investments by private sector and public and private partnerships (PPPs). This is explained by a shifting global trend from products that can be accessed as public tools to proprietary tools and technologies that are protected by IPRs.

This trend has created new challenges for developing countries. Access to agricultural biotechnology products and processes is becoming more difficult as biotechnology companies consolidate, merge and form strategic alliances. The inevitable commoditisation and privatization of technology often leads to products that are highly priced for poor countries. To access such goods, the developing countries require partnerships and collaborative R&D arrangements. Even biotechnology products that could address problems of resource-poor farmers are being developed and owned under complex IPR arrangements, where a given biotechnology product may be owned by a multitude of companies. For instance, the development of vitamin A-enriched rice, which has been claimed to possess up to 70 patents by 31 different companies (and some organisations) serves to illustrate this point.[4]

While appreciating that the above partnerships are fundamental in the growth and development of biotechnology, scientists and policy makers in developing countries require skills for negotiating and collaborating with private industry. This entails working out appropriate partnerships or collaborations with the private companies that have patents or exclusive rights. Having examined the global trends in modern biotechnology and the challenges posed to developing countries, we now briefly describe the local trends, especially with respect to the emerging knowledge gap in Kenyan agriculture.

3.2.2 Local Trends in Kenya

A review of global-local policy and institutional contexts by Adenle et al. (2012) reveals that the global agricultural biotechnology Research and Development agenda is largely influenced by interests of the private sector, whereas the national agenda in Kenya ought to be influenced by the public sector; especially interests of the majority smallholder farmers. In this context, most agricultural biotechnology R&D initiatives in Kenya are taking place in the public research sector. Only a few projects, including transgenic sweet potato, Bt maize and Bt cotton, are conducted through public-private partnerships (PPPs).

But partnerships in developing biotechnology products (as is the case with transgenic sweet potato project in Kenya) are not confined to private industry and the public sector. International public sector and university research organisations and foundations, including IARCs and CGIAR, are also collaborating with national public research institutions in several ways. For instance, United Nations Educational, Scientific and Cultural Organisation (UNESCO) along with other international organisations has since 1976 supported the establishment of global Microbiological Resources Centres (MIRCENS) to produce and diffuse Biological Nitrogen Fixation (See Chapter 4). In 1999, the International Maize and Wheat Improvement Centre (CIMMYT) and the Kenya Agricultural Research Institute launched the Insect Resistant Maize for Africa (IRMA) project, with funding from Syngenta Foundation for Sustainable Agriculture aimed at raising maize output and improving food security status in the country through generation and distribution of stem-borer Bt maize varieties (Odame et al. 2003). Biotechnology R&D extends to beans and cassava.

Agricultural biotechnology in Kenya is still limited mostly to public-funded traditional (non-GM) innovations such as development and deployment of bio-fertilizers and tissue culture products. Even in these traditional biotechnology applications, the funding shows declining trends. Opportunities for private funding are improving for a few biotechnology PPPs such as STRIGAWAY® Technology, transgenic sweet potato, Bt. maize and Bt. Cotton.

These research programmes have stimulated some activities in the country's S&T policy and influenced the formulation of legal and regulatory frameworks, especially with respect to IPRs and biosafety regulations. However, many research activities are yet to trickle downstream towards commercialisation of products for adoption by smallholders.

Given the global-local trends in biotechnology and the socio-economic concerns of the majority of small-scale farmers in developing countries, the main challenge facing Kenya is how to come up with suitable innovations in agricultural biotechnology. In the remaining sections, we will consider two innovation processes in agricultural biotechnology; namely traditional and modern. The two innovation processes are closely linked in the sense that biotechnology R and D activities are being integrated into the history of agriculture development in the country (Chapter 2). The process will entail continuity and change with the existing agricultural research and extension policy and programmes.

3.3 From Traditional to Modern Biotechnology

3.3.1 Agricultural Research, Policy and Programmes

The traditional (or non-GM) biotechnology research and innovation process (involving fermentation, bio fertilizers, tissue culture, and in vitro techniques) is characterised by continuity with the Green Revolution (GR) era, whereas the modern (or GM) biotechnology research and innovation process is characterised both by continuity and discontinuity with the GR period. In this context, the traditional process is characterised by unregulated and free exchange of less science-intensive materials and tools, where ownership, access and negotiation are in the public domain.

The development, distribution and use of agricultural non-GM biotechnology applications such as Biological Nitrogen Fixation and tissue culture coincided with a new agricultural research policy on broadening the desirable traits and the benefits of the original GR crops spread to other regions, crops and other types of farmers in developing countries. This was as a consequence of criticisms of the original GR or technology transfer (TOT) model[5] for its limited impact in developing countries, especially Sub-Saharan Africa (SSA) (Clark 2001, Makau and Mbote 1995: 103-123). While the original GR technologies were introduced in Asia and Latin America during the 1950s/1960s, several of the programmes were transferred and tested in Africa by the 1970s. Evidence shows that efforts to increase agricultural and food production through GR technologies failed in Africa (Conway and Babier 1990). This problem was attributed to inappropriateness of GR technologies and their supporting institutions (Sande 1994) (See Appendix 1).

According to Odame et al. (2003), the advent of traditional biotechnology applications (viz. bio-fertilization and tissue culture), and the ease with which these technologies could be integrated into conventional plant and animal breeding programmes provided prospects for addressing poverty, hunger and malnutrition because the applications hardly require advanced scientific infrastructure and personnel. As it will be explained in Chapter 4, since the late 1970s, scientists at the Soils and Botany departments of University of Nairobi have been developing and testing BNF in Kenya. In the early 1980s, the use of tissue culture began with its integration into the production of citrus and pyrethrum by the University of Nairobi and KARI respectively[6]. But these projects were simply added onto conventional agriculture research programmes in the country.

In 1990, the Government of Kenya (GoK) set up a National Advisory Committee on Biotechnology Advances and Their Applications with the following objectives: i) to set national priorities based on the country's comparative advantage and its ability to implement traditional biotechnologies in small-scale agriculture; ii) to expedite rapid access to new germplasm; iii) to reduce costs of agricultural inputs; and iv) to access affordable and more environmentally sustainable alternatives.

The Committee completed the study and reported its findings to the Government by the end of 1990. The main key findings included immediate application of tissue culture (TC) technique for disease elimination and micro-propagation, the use of Biological Nitrogen Fixation (BNF) and development of disease diagnostic kits.[11] Some areas of plant genetic transformation were prioritised by the Committee and recommendations were made to address abiotic-and biotic stresses. It further recommended that the utilisation of modern biotechnology potential in Kenya was uncertain owing to lack of regulatory and technical capacity. The NACBAA's recommendations were not implemented by the Government due to financial constraints. Another effort for evaluating and building the capacity for biotechnology in Kenya was initiated by the Dutch Ministry of International Cooperation (DGIS) in 1993. The Biotechnology Programme of the Netherlands Directorate-General for International Co-operation (DGIS) was implemented on a pilot basis in four countries: Columbia, India, Kenya and Zimbabwe. The programme aimed to contribute to poverty alleviation through agricultural biotechnology R&D programmes that integrated the needs and priorities of smallholder farmers (DGIS n.d.). It was one of the few initiatives that focused on biotechnology and poverty alleviation. Like NACBAA, the programme also proposed (as a priority) capacity building in biosafety and biotechnology. But unlike the NACBAA, Kenya Agricultural Biotechnology Platform (KABP) received US$4.2 million from DGIS for the programme. This funding facilitated the implementation of projects which had been prioritised but not implemented by the government.

The programme supported eight projects from the mid-1990s: cassava, potato, citrus, sweet potato, macadamia, marker assisted breeding in maize, banana, animal health, bio pesticides, and institutional strengthening. It also contributed the initial funding for the establishment of Biosafety Guidelines in the country.

Although the data is now outdated, Table 3.1 shows that the approximate level of funding for the research projects was US$300,000 (Odame and Mbote 2000). The MAB[7] maize programme received US$1.1 million from DGIS. The project contributed to the establishment of a molecular laboratory at KARI/Katumani and training of some KARI scientists at CIMMYT in Mexico. In doing so, it provided the foundation upon which Bt. Maize was built.

The Bt. Maize project by CIMMYT, KARI and Novartis Foundation, under the umbrella of the Insect Resistance Maize for Africa (IRMA) cost approximately US$6 million over a span of five years. (IRMA 2000)[8].

During fieldwork for this study in 2000-2001, the transgenic sweet potato project, initiated in 1990, was by then the only transgenic research by Monsanto, a multi-national corporation at US$ 2 million (see details in Chapter 5). And by 2002, US$ 4 million had been spent on the project (de Grassi 2003). Kenya also gained from research undertaken by supra-national organisations based in Nairobi. For instance, in the early 2000s, the Nairobi-based ILRI spent an estimated US$6 million per year on a 5-year biotechnology-related livestock research project. As a result, livestock research organisations and some farmers gained from ILRI's collaborative research work.

Agricultural biotechnology in Kenya depends on donor-funded research projects focusing on a wide range of biotechnology applications including: marker-assisted selection, tissue culture and genetic modification of crops (see Box 3.1). This situation has not only led to fragmentation of biotechnology activities but also raises the question of their financial sustainability. Table 3.1 provides an overview of the largely donor-funded agricultural biotechnology applications in the country.

Box 3.1
Agricultural biotechnology applications in Kenya

Plant Tissue Culture

Tissue culture (TC) is a tool for multiplying disease-free planting material into numerous tiny plantlets. Tissues or cells obtained from a desirable variety are grown under laboratory conditions. In Kenya, plant tissue culture planting materials produced include: banana, tea, coffee, cassava, potatoes, sweet potato, pyrethrum, sugar cane, citrus fruits, ornamental flowers, etc.

Marker Assisted Selection

Marker assisted selection (MAS), also known as molecular breeding, is a technique that enables recognition and assessment of plants carrying beneficial qualities in a breeding population. Application of MAS eases and shortens the selection process of quantitative traits such as crop yields, tolerance to drought, resistance to pest and diseases, in plant breeding. In Kenya, MAS is being used in several research projects: first in understanding the mechanisms of resistance against the maize streak virus disease by KARI and ICIPE; secondly in the development of Kenyan maize varieties and lines for resistance against stem borer pests and drought tolerance by KARI; and thirdly in the characterisation and conservation of plant genetic resources by KEFRI, ICRAF and the International Board for Plant Genetic Resources.

Genetic Modification

Genetic modification (GM) also referred to as genetic engineering, is a process whereby genes are transferred from one living organism to another in order to give them useful and desirable traits such as pest and disease resistance or resilience to harsh environmental conditions. Any living organism that has a gene or genes inserted into it or modified in it through the process of genetic modification is called a genetically modified organism (GMO) or transgenics. In Kenya, the technique is being used by scientists to develop crops that are resistant to the cotton bollworm, maize stem borer, cassava mosaic virus and sweet potato feathery mottle virus (SPMV). The Insect Resistant Maize for Africa (IRMA) is a collaborative project involving KARI and CIMMYT with an aim to develop and deploy insect resistant maize using *Bacillus thuringiensis* (Bt) technology. At KARI Fibre Research Centre in Mwea, field trials of Bt. cotton varieties that are resistant to the cotton bollworms have been on-going. The centre is currently testing a superior variety called Bollgard II.

Biotechnology applications that are geared toward the improvement of livestock productivity in Kenya mainly involve advanced techniques and applications. The focus is largely on the developing vaccines and diagnostic kits for the effective vaccination and accurate diagnosis of livestock diseases. Biotechnology has also been applied in the characterisation of livestock breeds and in research into the conservation of rare animal species. The key organisations involved in livestock biotechnology include KARI- National Veterinary Research Centre (NVRC) and the KARI Biotechnology Centre, the Institute of Primate Research at the National Museum, and the International Livestock Research Institute (ILRI).

Other biotech initiatives include: StrigAway technology against striga weed which is a collaborative project of AATF/CIMMYT and BSF/KARI. The Bill and Melinda Gates Foundation (BMGF) is funding the ABS, which aims to generate more nutritious and palatable sorghum varieties that have higher levels of zinc, pro-vitamin A, iron, vitamin E, and amino acids for more than 300 million people in arid and semi-arid regions of Africa where the staple food is grain. Africa Harvest Biotech Foundation International Development was the team leader of the research consortium.

Source: Author's compilation

Table 3.1
Agricultural biotechnology applications and stages in Kenya

Crops	Trait	Importance	Project Partners	Stage
Maize, *Zea mays l.*	Drought resistance (WEMA) Drought tolerance (KU)	Food and income Food and income	AATF, KARI, CIMMYT and Monsanto KU and ASARECA	Three confined trials (CFTs) completed at KARI Kiboko Green house experiments
Cotton, *Gossypium hirsutum* L.	Insect resistance (bollworms)	Fibre, feed and incomes	KARI and Monsanto	CFTs completed
Cassava, *Manihot esculenta* crantz	Virus resistance Enhanced levels of iron, zinc, protein, vitamin A and E	Food, industrial and incomes Food, health and incomes	KARI and Donald Danforth plant science centre Donald Danforth plant science centre, KARI, IITA and CIAT	CFTs 1st season
Sorghum, *sorghum bicolour* (ABS)	Biofortified with increased levels of iron, zinc, vitamin A and E	Food, health and incomes	KARI, AHBFI, DuPont Business and Pioneer Hibred	CFTs on going
Sweet potato *Ipomoea batatas* (L.) Lam	Weevil resistance	Food and incomes	International potato centre (CIP) and Kenyatta University	Contained use experiments (transformation)

Source: James (2011) in OFAB Report (Vol VI) 2012[9]

Although these initiatives had contributed to the capacity of KARI, there were concerns over the threat of weakening public goods research. Odame and Mbote (2000) argued that the application of IPRs to biotechnology R&D poses a threat to the free exchange of genetic material and knowledge. Apart from donated (or royalty-free) biotechnologies, there were few examples of PPPs research projects in Kenya. In 2003, Odame et al. (2003) also reported that the PPP initiatives focused on building capacity of researchers and regulators in organisations at the national level as opposed to those at the local level. The authors concluded that the prevailing situation showed the lack of functioning research and innovation systems in Africa.

3.3.2 Research Organisation

Synergy of research systems

A majority of countries in SSA do not have a clearly articulated policy and strategy for developing and integrating biotechnology into their national agricultural research systems, but rather operate fragmented and uncoordinated research activities which only lead to unnecessary duplication and waste (Ives and Bedford 1998:55).

In Kenya, a survey on linkages within NARS organisations conducted by Odame and Mbote (2000) revealed that the largest number of connections (or relationships) is with IARCs (Table 3.2 below). These include: ILRI, International Centre for Research on Agroforestry (ICRAF), International Centre for Insect Physiology and Ecology (ICIPE) or centres having regional offices (CIMMYT, CIP, ISAAA, etc.) in Nairobi. Approximately 158 (70%) of all the ties are linked to the three public research organisations namely, international agencies 56 (25%) ties, NARIs 52 (23%) ties and universities 50 (22%) ties. Ties to government agencies were 36 (16%) – and to other organizational categories were: private sector 14 (6%) ties, and NGOs 19 (8%) ties. These figures showed the relatively strong presence of research and education systems in S&T policy and programmes. They also demonstrated the prominence of upstream institutional linkages in the production of public goods research.

Table 3.2
Organisational synergy

Organization category	Number of ties to sector	Percentage	% Average score of tie performance[b]
University	50	22	3.20
NARIs[a]	52	23	3.04
NGOs	19	8	3.37
Private	14	6	3.37
International	56	25	3.37

Government	36	16	2.83
Total	227	100	

Notes:
a: KARI (ties =32 and score = 2.96), Other NARIs (ties =20 and score = 3.15);
b: 1= poor; 2= fair; 3= good; 4=very good; 5=excellent

Source: Odame and Mbote (2000)

Examples of public and private sector collaboration

In Kenya, public research institutes like KARI and public universities such as Egerton University and JKUAT collaborate with local private companies and the international agricultural research centres. The type of collaboration included implementing joint research projects, public universities and research contracts of individual scientists in those organisations. KARI has for example, been undertaking contract research for Kenya Breweries Ltd (KBL), British American Tobacco (BAT), and the Pyrethrum Board of Kenya (PBK) (Wambugu 1996).

Local universities also have linkages with KBL through training of its staff and field attachments for university students. Brooke Bond Ltd is another local private player in biotechnology. It established linkages with public research organisations in the tea and coffee sub-sectors including the Tea Research Foundation (TRF) and the Coffee Research Foundation. It had been funding TRF (Brenner 1999). In collaboration involving public sector and university research, the University of Nairobi MIRCEN has for over 20 years been collaborating with KARI and other international organisations to develop and diffuse BNF technology.

It is evident that aside from transgenic sweet potato and Bt maize, many public collaborative research activities in Kenya involve traditional agriculture biotechnology innovations. Consequently, public and private partnerships are few and isolated in the country. Figure 3.1 shows that several factors restrict the growth of public-private partnerships (PPPs) in Kenya, and by extension in Africa. These are first, lack of information and awareness on the potential of research collaboration; a serious problem in universities and government agencies. Barriers of effective communication across the African continent are mainly poor sharing of scientific information and research findings (Massola 1992).

In particular, lack of modern communication systems such as efficient e-mail and Internet restrict access to knowledge about application of modern biotechnology. Second, low trust was a moderate problem in universities and NARIs; often, there is suspicion between public and private sectors. The public sector perceives the private sector as an entity only interested in maximizing profits while the private sector sees the public sector as bureaucratic and indolent. These perceptions limit opportunities for collaboration in biotechnology innovations in Kenya.

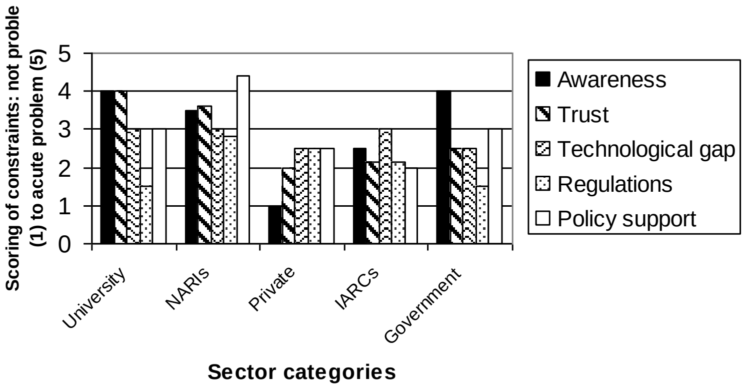


Figure 3.1
Institutional collaboration constraints

Note: 1=not a problem; 2=a least problem; 3=a moderate problem; 4=a serious problem; 5=an acute problem
Source: Field data

Third, there was technological and financial disparity between the public and private sectors. It was a serious problem in universities and a moderate problem in NARIs. This makes it difficult to find a basis for equal partnerships. Fourth, lack of effective regulations especially biosafety regulations was reported by NARIs to be a moderate problem in the introduction and management of modern biotechnology products and processes. This problem stems from lack of capacity for the government to facilitate the formulation and implementation of requisite regulations. Fifth and finally, inadequate policy support was reported as a moderate problem in all sectors – with the NARIs reporting it to be almost an acute problem. The latter was then attributed to weak institutions, policy and synergy of new agricultural biotech R&D activities in Kenya. It is hoped that the improved internet infrastructure and the recent enactment of the Biosafety Act will boost S&T in general and in particular in mutually beneficial areas.

3.3.3 Human Resource

As mentioned earlier, the NACBAA report (1991) pointed out that development of modern biotechnology would remain weak without a comprehensive strategic research focus and definite objectives. The report recommended the need for strengthening the country's scientific, legal and bureaucratic capacity. In particular, there was a need for strong scientific knowledge and linkage to technology utilisation, which was weak in traditional biotechnology.

Wafula and Falconi (1998) indicated that by 1998, approximately 56 scientists would participate in Kenyan biotechnology R&D activities; and their contribution to agricultural biotechnology research in the country would be 80%. The other 20% of the research would be carried out by researchers in transnational institutes within the country.[9]

Approximately 21 (or 38%) of the 56 scientists were based in Kenya's public universities. Scientists in these institutions spent less than 10 percent of their work-time on agricultural biotechnology research. This seemed to be the general policy of public universities which required scientists to spend more time teaching than doing research.

Building scientific capacity would remain problematic due to the deficiency of both qualified personnel in the related areas of modern biotechnology. Evidence from Odame et al (2003) supported this claim because the relevant government ministries and research organisations lacked specific training policy for building national capacity in biotechnology, IPRs and biosafety regulations. The research bodies instead merely added their training requirements into individual research programmes and projects. In so doing, capacity building in agriculture-oriented research tended to put more emphasis on physical facilities and post-graduate studies. Nevertheless, the fast growth in physical infrastructure in the 1980s meant employing a large number of non-scientific staff to maintain the expanded physical facilities. As a result, there was a low ratio of scientific to non-scientific staff in a given research institute (Beynon et al. 1998)[9].

Table 3.3 below shows the percentage of scientists in research institutions in Kenya. KARI has the highest number of FTEs at 533 (or 53 percent share) of total research staff. Universities have a total of 235.9 FTEs (or 23 percent).

Table 3.3
Percentage of scientists in research institutions

Type of Agency	Total spending			Total staffing	
	Kenyan shillings	PPP Dollars	Shares	Numbers	Share
	(million2005 prices)		(%)	(FTEs)	(%)
KARI	2,204.7	74.7	49	533.0	53
Other government (5)	1,054.6	35.7	23	200.3	20
Nonprofit (2)	234.6	8.0	5	42.2	4
Higher education (23)	1,048.3	35.5	23	235.9	23
Total (31)	4,542.2	153.9	100	1,011.4	100

NOTE: Figures in parentheses indicate the number of agencies in each category

Source: ASTI-KARI (2009)

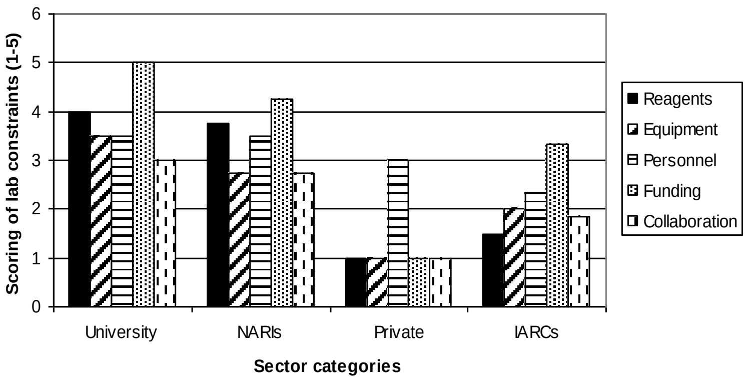
According to key informants from ILRI and some CGIAR centres in Nairobi, a large number of young Kenya researchers had basic scientific knowledge in the fields of genetic engineering and molecular biology, yet they lacked hands-on experience of working with modern biotechnology. Public universities, for instance, produced young scientists with BSc and MSc degrees in biological sciences but they lacked practical training in modern biotechnology. As well, the capacity of the scientists was not fully utilised owing to inadequate funding for scientific infrastructure, research grants and staff salaries (Odame and Mbote 2000, Odame et al. 2003).

Odame et al. (2003) noted that of the 11 laboratories surveyed, a majority used tissue culture techniques. Exceptions were international centres such as ILRI and ICRAF. Funding, reagents and relevant personnel were perceived to be facing respectively acute and serious constraints faced by laboratories in Kenya. Figure 3.2 shows that the most affected institutions were: national agricultural research institutes (NARIs), public universities and regulatory agencies. A serious problem faced by both universities and NARIs was a lack of reagents. The same respondents also reported that poor equipment, inadequate personnel and collaboration were moderate to serious problems. With the exception of the IARCs and the private sector, other actors reported that funding was an acute problem.

Traditional biotechnology involved soil science, plant breeding, etc., whereas modern biotechnology had its research focused on capacity training in molecular science, IPRs, and biosafety regulations. The public sectors' role in modern biotechnology was limited as the government budget for agricultural research was declining**.** The public research sector only gained access to technology and training through donor funding and collaboration with the private sector.[10] During this study's fieldwork, some respondents suggested that such collaboration was limited to a small number of scientists who received short training courses. One researcher respondent said that such trainings hardly contributed to the goal of achieving the critical mass of human capital for successful participation in modern biotechnology.

Kenya was facing a challenge in training and retaining scientists. Odame et al. (2003) reported that the few highly trained scientists migrated to Europe, North America and southern Africa in pursuit of better job prospects. It was further reported by one key informant that by the end of 2001, only one out of fourteen researchers with PhD qualifications in the fields of genetic engineering and molecular biology was still in the country.[11]

Figure 3.2
Laboratory capacity constraints



Notes on lab constraints: 1=not a problem; 2=a least problem; 3=a moderate problem; 4=a serious problem; 5=an acute problem
Source: Field data

The problem of brain-drain driven by under-utilisation of the available capacity is primarily due to inadequate scientific infrastructure, funding and human capital required to effectively engage in modern biotechnology. There has been an almost universal pattern of increasing intensification of science and costs in the R&D-inspired innovation process. Evidence from North America, Europe, China, etc. shows a tendency to move away from single disciplines towards increasing integration of different disciplines and fields in a bid to reduce learning costs – partly in response to increasing technological complementarities.

At a modern biotechnology laboratory in North America or Western Europe, knowledge integration between pharmaceuticals and agriculture has already been escalating. The process is sought to transfer knowledge in human genomics to the study of plants. This practice challenges the public sector researchers. For instance, scientists recalled that they are increasingly required to upgrade their scientific knowledge and skills. They feared that such a policy, while intending to expand the range of skills for scientists, has the potential to displace some traditional disciplines or fields. In a key informant interview, a former plant breeder said that, “modern biotechnology radically induced cross-crafting, which required scientists to have a wide range of skills. The scientists, (especially young ones) with strategic need to advance their careers complied while others – especially the older ones, may be left on the wayside”.

The intensification of scientific knowledge and costs in the recent past seemed to further polarize the public sector and create a possible mismatch between technology and society. In interviews with plant breeders and former KARI managers, many expressed the view that the promoters of modern biotechnology tend to treat local knowledge with contempt and also lacked respect for conventional agricultural research. According to one respondent: there was "an air of superiority from the so-called biotechnologists feeling that their knowledge and skills were more important in overcoming the obstacles of cross-species transfers, which they thought was the main constraint of traditional breeding techniques”. These pro-modern biotechnology scientists were further accused of being “technology-supply oriented and ignorant of the real needs and knowledge of local people”.

Some of the alleged bad attitude of biotechnology researchers by some NGO respondents may not represent deliberate neglect for local knowledge and disrespect of conventional plant breeding by the molecular scientists, but rather it is consistent with the new emerging knowledge management practices. Also, this attitude was not unique to modern biotechnologists. As we noted in the previous sections, scientists working on conventional agricultural technologies had also denigrated local knowledge. But as we will discuss in the next section, the international regulations that govern modern knowledge are likely to widen the gap between scientific and traditional or local knowledge systems in Kenya.

3.3.4 Policy and Regulations

Adopting IP-related laws

In Kenya, intellectual property laws are prescribed by four legislative instruments namely: Industrial Property Act Cap 509, the Trademark Act Cap 506, The Seed and Plant Variety Act Cap 326 and the Copyright Act Cap 150 of the Laws of Kenya (Olembo 2001). The power and interests of international organisations have historically played an influential role in the formulation of IPR laws in Kenya. IP law is a legacy of the country's colonial past just like all other laws. For example, the country's first IP protection was a patent registered in 1912. Thus, until 1989, Kenya had IP laws that were dependent on the colonial patent system.

Makau and Mbote (1995: 103-123) reported that in 1990 the Kenya Industrial Property Office (KIPO) was set up after the enactment of the Industrial Property Act Cap 509 of the Laws of Kenya. KIPO's mandate included: examining, granting and registering IPRs within the provisions of the Industrial Property Act and the Trademarks Act Cap. 506. This was a significant change from the previous system where the relevant authorities in Kenya merely re-registered IPRs approved in the United Kingdom (ibid).

The formation of the World Trade Organization (WTO) and enforcement of Trade-Related Intellectual Property Rights (TRIPS) agreement in 1995 was a new development in IP laws. The national patent laws were to be revised by all members of WTO to ensure they conformed to the necessities of TRIPS and WIPO guidelines. Kenya, as a member of WTO and a guarantor to TRIPS, was obligated to make changes to the Industrial Property Act. These revisions were implemented on 13th of June 2001 after the Industrial Property Bill was approved by the National Assembly.[12] As a result, the structure and functions of KIPO were re-organised.

KIPO was initially a department of the Ministry of Tourism, Trade and Industry. It was then later re-organised into a semi-autonomous patent office, the Kenya Intellectual Property Institute (KIPI). The new status provided KIPI with a broader decision-making mandate in screening and granting of industrial property rights. It was mandated to provide IP-related training courses. The organisation was further expected to raise its own funds and gradually reduce its reliance on government funding. There is no doubt that international bodies and the government will continue to meet a portion of KIPI's funding requirements.

KIPO (now KIPI) was previously supported by WIPO in areas such as IP-related staff training and computer hardware. Odame and Mbote (2000) posits that despite the fact that KIPI is regarded as one of the premier intellectual property institutions in SSA, it faces many challenges.

The challenges faced by KIPI included routine management issues in the policing and enforcement of IPR, and the drafting of suitable laws such as the *sui generis* system. Wekundah (2004) argued that R&D in Kenyan NARS was largely funded by the public for the public good. This meant that there was limited (or no) consideration given to IPRs and IPR policies. However, this situation is changing, especially following market liberations and the calls for more public-private partnership (PPP) arrangements. IPRs are receiving more attention in biotechnology R&D as a result of increased private sector partnership with public research and education organisations. At the same time, conflicts still persist between TRIPS and the CBD (Convention of Biological Diversity), especially on matters around Article 8 (j) of the CBD (Medaglia 2009[13]).

From a national development point of view, the Act is not keen on addressing a number of crucial concerns. For example, genetic resources and knowledge held by local communities is not properly protected and little effort has been made to help most Kenyan stakeholders including farmers, scientists, manufacturers and other players to understand the relevant implications of this Act and IP-related policies.

Considerations of IPRs for public research and farmers' access

Article 27 of TRIPS required the granting of patents in all areas of technology, including biotechnology. But the Industrial Property Act, 2001 only grants patents for biotechnology inventions. Section 7 of the Act states that for a biotechnology invention to be patented, it must be "new, involve an inventive step and be industrially applicable". Thus, the Act excludes plant and animal varieties from patents.

BIO-EARN (2001) revealed that under TRIPS, the protection of plant varieties can be done either by an effective *sui generis* system, patents or a combination of both. Kenya is yet to develop a *sue generis* system. This despite the fact that Kenya played a role as an important advocate "for the Global South at TRIPS –where it championed a 'no patents on life' position while also celebrating the African Model Law" (Rangnekar 2013). While posturing at the TRIPS Council, Kenya was at the same time preparing to accede to UPOV's 1978 Act. The country had a plant variety protection legislation which was dominant until the mid-1990s.

Cullet (2001) stated that the Seeds and Plant Varieties legislation (Cap 326 of the Laws of Kenya) became operational in 1975 but was limited to seed certification. The Act was revised in 1978 and 1991 in response to new developments in international trade and seed industry. The revised Act conformed to the requirements of the 1978 version of UPOV Convention. In accordance with the Convention, new plant varieties in Kenya are protected by Plant Breeders' Rights (PBRs) granted for plant varieties that are 'distinct', 'uniform' and 'stable' (or DUS). In the words of Dwijen Rangnekar (Rangnekar 2013:18), "By acceding to UPOV, Kenya miserably fails to find inspiration in the African Model Law that it championed in Geneva".

Underlying Kenya's "decoupling between rituals (Geneva rhetoric) and behaviour (domestic law)" – to use Rangnekar's fascinating words - are various domestic political economy considerations. These include the global interests of horticultural value chains (especially fruits and vegetables) and local interests of plant breeders who, through the Kenya Plant Health Inspectorate Services (KEPHIS) pushed the country to introduce PBRs and join UPOV.

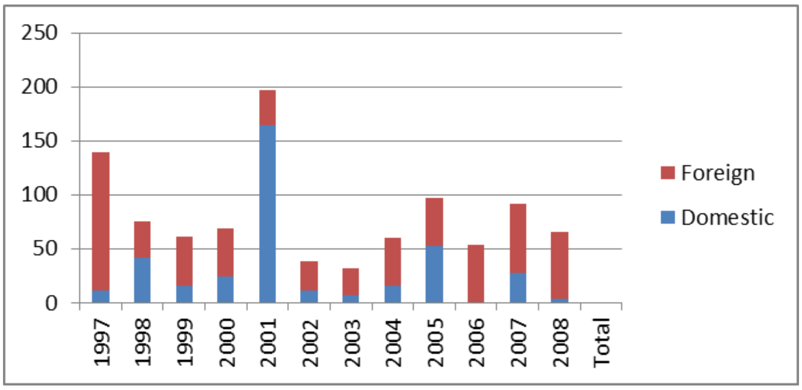
KEPHIS was established in 1996 to regulate imports and exports of plant materials and trade in biosafety governance of organisms in accordance with the International Plant Protection Convention (IPPC). It administers PBRs and is a liaison office for the UPOV convention. The PBRs office was set up under KEPHIS in 1997 to administer PBRs.

In 1991, Kenya consented to the 1978 UPOV treaty and integrated it within the Seeds and Plant Variety Act 421 of the Laws of Kenya. The main concern raised by this accession is its potential impact on farmers' privileges. KARI participated exclusively in public goods plant breeding before the introduction of PBRs (ibid). This changed with the seed industry liberalization which requires royalties paid by farmers for the purchased varieties. Plant breeding is a lengthy and costly affair given the declining government funding. KARI may be made to charge royalty fees to fund the development and maintenance of new varieties and reward plant breeders for their work. On their part, farmers will be required to start paying for varieties they have been nurturing instead of sharing benefits accruing from them.

The production of seed in developing countries is mainly done by farmer and public research systems. These systems respectively depend on the international exchange of free genetic material and on-farm practices of saving seed. The systems may even face more restrictions when protection of plant varieties is done by patent and PBR law (Van Wijk et al. 1993:16). This protection may limit the use of farm-saved seed, with consequences of household food insecurity. There were, for example, approximately 980 claims of PBRs and 376 applications from Kenyan breeders between 1997 – 2008 (see Figure 3.3).

More than 60% (604) applications came from industrialised countries. This was influenced by companies or individuals who sought to protect certain varieties of horticultural crops for the export market.

Figure 3.3
PBR applications 1997-2008



Source: Author's compilation from KEPHIS data > Accessed on 12th May 2013

Breeders in the horticulture industry influenced the enforcement of plant breeders' rights (PBRs) in international markets. This clearly shows that PBRs are made to fit the context of strengthening commercial crops in contrast to food security crops.[14] The introduction of Plant Breeders Rights (PBRs) in Kenya in a way promotes monoculture. It may also erode genetic diversity and lead to benefits of 'new' varieties accruing to commercial companies instead of poor farmers (Cullet 2001).

3.4 Biosafety Regulatory Framework

National biosafety system

There is a strong link between the existence of a biosafety system and the development of modern biotechnology. The safety of biotechnology products and processes, specifically GMOs, has been an on-going debate. Public concerns have been raised for governments to set up risk assessment and management to aid in the development of biotechnology.

One of the recommendations of NACBAA to address issues of modern biotechnology in Kenya was the need to address technical and regulatory capacity. In mid 1990s, Kenya Agricultural Biotechnology Platform (now, BTA, Biotechnology Trust of Africa) gave USD120,000 to the National Council of Science and Technology (NCST) as part of initial support for capacity building in biosafety (Wekundah 2000). However, a systematic development of National Biosafety Guidelines in Kenya was influenced by the UNEP-GEF Pilot project which targeted the development of biosafety frameworks and regulations. In 1998, guidelines for Kenya were published, which covered various aspects of risk management and risk assessment in modern biotechnology including the environmental release of GM crops (NCST 1998). There was a recommendation to establish the National Biosafety Committee (NBC) and the government designated NCST to form the Committee. In 2008, the Government of Kenya formulated the National Biosafety Act. Further amendments were made in 2011. Debates are still on-going in the national assembly for further amendments.

The NBC was established and mandated to provide technical and regulatory oversight in the introduction of GMOs into the country. Organisations that have representation on the Committee are: KIPI, NCST, ILRI, KARI, KEPHIS, KEMRI, Ministry of Education Science and Technology (MEST), Ministry of Agriculture and Rural Development (MOA&RD), University of Nairobi (UoN) Department of Resource Surveys and Remote Sensing (DRSRS), JKUAT, Kenyatta University (KU), Office of the President, Kenya Bureau of Standards (KEBS) and the National Environment Secretariat (NES).

The process of enacting biotechnology policies and biosafety laws has been sluggish due to political issues and limited knowledge on biosafety and biotechnology in general amongst legislators and policy makers. Following the Cabinet approval of the Biotechnology Policy in 2006, Biosafety Bill 2007 was published by the Ministry of Science and Technology and presented in parliament in 2007 for enactment. The Bill was debated by the legislators but failed to go through in the last stages of its enactment following the sudden dissolution of the 9th parliament by the president in preparation for the General Election. The presentation of the Bill in parliament triggered intense public debate from anti-biotech and environmental pressure groups in Kenya. The groups lobbied for withdrawal of the Biosafety Bill from parliament claiming that it was a rushed Bill aimed at legalising the large-scale introduction of GMOs in the country. The anti-biotech groups published a series of articles in the press, used the electronic media (TV and Radio), mobilized farmers to demonstrate and filed court petitions against the Bill. Eventually, the Bill was reintroduced, debated and passed in 2008 (Government of Kenya 2008). It was enacted into law in February 2009, and thus is known as the Biosafety Act 2009 (Government of Kenya 2009a). The Biosafety Act 2009 made a provision for a National Biosafety Authority (NBA) established to replace the NBC. This provision gives the proposed NBA institutional permanence and financial autonomy to efficiently discharge its mandate of ensuring safer and faster biotechnology development in the country.

The latest gazetted regulations under the Biosafety Act 2009 are as follows:

i.) Contained regulations (2011)
ii.) Environmental release regulations (2011)
iii.) Import, export and transit regulations (2011)
iv.) Regulations for labelling (2012)

The objective in all these regulations is to ensure that potential adverse effects of genetically modified organisms are addressed for human and environmental protection.[15]

Status of GMO trials

The NBC has to date authorised the following activities on GMOs in the country:

- The Bt Cotton application for field testing was approved by NBC pending approval and issuance of permit by KEPHIS.
- The IRMA Bt Maize has gone through the second planting CFT after approval by NBC.

- Transgenic cassava project was asked to present data over two seasons on insect species and mock trials requested by NBC.
- Rinderpest vaccine has been approved by KARI (Institution Biosafety Committee [IBC])

In summary, the process of biosafety law-making in Kenya, like in most developing countries, has been highly influenced by internationally-funded programmes and projects that have often determined the direction of debates and actions. For instance, the process of enacting biotechnology policies and biosafety laws in Kenya was slow and cumbersome (see Appendix 1) largely due to lack of capacity. The process was also highly contested pitting hardened positions of proponents against opponents of transgenic biotechnology. In the next section we discuss findings on available technical and regulatory capacities (or lack of them) for harnessing agricultural biotechnology for smallholder farmers in Kenya.

3.6 Conclusion

The rapid development of biotechnology in industrialised countries is explained by a combination of both investment and supporting policies. The global context of agricultural biotechnology R&D policy is influenced by interests of the private sector whereas in the local context in developing countries it is dominated by public interests especially needs of smallholder farmers. Although PPPs have become a popular institutional innovation in modern biotechnology transfer to developing countries, they are complex to administer. The question of the extent to which modern biotechnology can be harnessed for sustainable productivity and food security for smallholders in countries such as Kenya remains to be answered. Among other factors, representation and accountability to smallholder farmers in the decision about resource allocation and research prioritization is a major concern. In particular, the extent to which the research needs of different groups converge or diverge will restrict or support efforts to meet the technological and institutional requirements of less-commercially-oriented and less-organised smallholder farmers.

A review of literature shows that a significant decline in agricultural output experienced in Kenya since the early 1990s was due to several factors including: inadequate rainfall, low soil quality and input use, limited producer incentives, weak implementation of policies and lack of adequate support to the sector (Beynon et al. 1998, MOA&RD 1990 - 2000). This situation implies that harnessing modern biotechnology for smallholders will require addressing the constraints in agricultural production and productivity. Food security (rather than prosperity) is the main concern behind biotechnology initiatives in the Kenyan NARS. It contrasts with the profit motives of the private sector, yet a review of funding trends in Kenya has indicated that the contribution of the private sector in the existing private-public sector research activity accounts for almost all the programme funding on modern biotechnology research. This situation calls for a strategy for balancing private and public research interests and values. Even within the public sector, the capacity of scientists to engage in modern biotechnology is constrained by human capital. Scientists are under-utilised due to poor physical infrastructure and funding. The on-going formulation of Biosafety regulations and reforms to IP laws may stimulate investments in proprietary technologies and other types of research where benefits can be appropriated. But the need for effective regulation is emerging as an important requirement.[16]

Recent agricultural biotechnology policy and programme initiatives also encounter the difficulty of aligning scientific knowledge to production. It seems that researchers do not involve the public in awareness creation on modern biotechnology. They have also not worked closely with farmer groups in setting priorities and mechanisms for technology transfer and adaptation, seed production and distribution.

The next three chapters review these issues in greater detail through empirical analysis of two cases of less deployed biotechnology innovation, namely Rhizobium inocula (Chapter 4) and transgenic sweet potato (Chapter 5), and two cases of more deployed innovations –Tissue Culture Banana and StrigAway Maize Technology in Chapter 6.

Appendix 1
Some milestones in biotechnology development in Kenya

Year	Activity
1960s	Kenya Farmers' Association imports BNF for soya and fodder crop, East African Veterinary Research Organization produces the Rinderpest Vaccine.
1970s	University of Nairobi (UoN) starts Agbiotech projects.
1980s	KARI, UoN produce tissue culture pyrethrum and citrus. The 3rd International Plant Biotechnology Network Conference is held in Nairobi.
1991	Virus Resistant sweet potato project starts in KARI.
1993	DGIS-Netherlands programme (KABP) starts.
1995	JKUAT and KARI propagate TC Bananas. Recombinant animal vaccine is imported.
1996	ISAAA supports transfer of TC bananas to farmers.
1997	UNEP-GEF Biosafety project starts.
1998	NCST publishes Biosafety guidelines and launches NBC.
1999	KARI-CIMMYT launch the IRMA project.
2000	Kenya signs the Biosafety protocol.
2002	Kenya ratifies the Biosafety Protocol. The Seed and Plant Varieties Act of 1972 are amended to accommodate biotechnology.
2003	The Biosafety Protocol enters into force. First drafts of the Biotechnology Policy and Biosafety Bill are prepared.
2004	KARI Biotech launches Biosafety level II Green house. KARI begins field trials on Bt. cotton.
2005	President Mwai Kibaki officially opens KARI Biotechnology (Biosafety labs); Kenyatta University Commissions the second Modern Biotechnology Green house.
2006	National Biotechnology Development Policy and the Biosafety Bill are approved by Cabinet.
2007	The Biosafety Bill 2007 is published and goes through first reading in Parliament.
2008	The Biosafety Bill is re-introduced in Parliament and debate goes through all the stages.
2008	African Biotechnology Stakeholders Forum (ABSF) successfully organizes The First All Africa Congress on Biotechnology in Nairobi, Kenya.
2009	The Biosafety Bill 2008 is signed by President Kibaki into the Biosafety Act 2009 as a recognized Biosafety law in Kenya. The NCST starts developing the Biosafety regulations for operationalizing the Biosafety Act.
2011	National Biosafety Authority is established in 2010; formulation of biosafety regulations in 2011: contained use regulations, environmental release regulations, labelling regulations, import, export and transit regulations.
2012	The government through the Ministry of Public Health and Sanitation bans the importation of genetically modified foods.

Source: Author's compilation

Notes

[1] See also PR Newswire >Accessed on 6th July, 2012

[2]http://biotech.about.com/od/investinginbiotech/a/Overview-Ernst-And-Young-2012-Global-Biotech-Tech-Report.htm> Accessed 15th January 2014

[3]http://www.isaaa.org/resources/publications/briefs/44/executivesummary>Accessed 14th January 2014.

[4] See also http://umconference.um.edu.my/upload/43-1/papers/196%20NityaNanda_IndraniBarpujari_NidhiSrivastava.pdf >Accessed 2nd December, 2012

[5] The original GR technologies consisted of high yielding varieties of maize, wheat and rice; irrigation and scientists (Conway and Barbier 1990).

[6] See also www.ids.ac.uk>Accessed 6th August 2012

[7] See also www.ielrc.org >Accessed 5th August 2012

[8] See, for example, Odame and Mbote (2000).

[9] Open forum on agricultural biotechnology in Africa (OFAB) Kenya chapter, 2012

[10] See, for example, the case of transgenic sweet potato in Chapter 6.

[11] See, for example, various editions of Daily Nation Newspaper from 2000-2001.

[12] Note that KIPO was created in 1990 with the enactment of the Industrial Property Act. Cap. 509 while the Industrial Property Bill passed in 2001 amended Cap. 509 and transformed KIPO to KIPI.

[13] http://www.cbd.int/doc/programmes/abs/studies/study-regime-04-en.pdf; >Accessed January 2014

[14] Indeed, the development of PBRs under UPOV was geared towards providing incentives to commercial farming (Kameri-Mbote and Cullet 1999).

[15] See also www.point-barre.com >Accessed 5th January 2013

[16] See also www.opml.co.uk >Accessed 25th October 2012

4 University Linkages in Traditional Biotechnology System: Case of Rhizobium Inocula

4.1 Introduction

In recent times, public university research has attracted global debate on its relevance to society in terms of linking knowledge creation to diffusion and final use by society. As a traditional norm, universities have often focused on capacity building in post-graduate training as part of staff development. In doing so, the universities aim at enhancing the career opportunities of scientists and also bolstering unrestricted sharing of information through scientific journal and conference papers. This is the initial context in which the University of Nairobi Microbial Resources Centre Network (MIRCEN) project was developed.

This chapter explores the interactions among scientists, farmers and intermediaries and how they share knowledge and distribute Rhizobium Inoculant (BIOFIX) fertilizer in the University of Nairobi MIRCEN project. In doing so, it addresses the general question: does the project lead to a successful innovation in input supply to smallholders?

The Rhizobium inoculants are technological outputs of over two decades of research by the Department of Land Resources Management and Technology (LARMAT), under MIRCEN's project funding from the United Nations Educational, Scientific and Cultural Organisation (UNESCO) on six continents since 1977.[1] Building on the original project, the new Rhizobium Inoculant project started in 2008, as a PPP initiative of LARMAT and a private company, MEA Ltd, under the auspices of the African Knowledge Transfer Programme of the British Council to support increased accessibility of low cost organic fertilizers to smallholder farmers in Kenya.

The MIRCEN centres were mandated to develop and transfer Biological Nitrogen Fixation (BNF) technology to researchers, extension agencies and farmers. BNF refers to the process through which legumes take nitrogen from the atmosphere and convert it into a suitable form for use by plants (Hall and Clark 1995). Rhizobia are the most studied nitrogen fixing bacteria. Although genetic engineering experiments are underway to introduce Rhizobia into the root cells of non-leguminous plants such as maize and rice, such research is yet to result into tangible benefits for farmers (Odame 2002a). KARI has recently collaborated with the Crop Science Department of the University of Nairobi and the Egerton University to extend BNF research to bean inoculation. This research has shown that the common bean (*Phaseolus vulgaris*) has potential to fix up to 50kg of nitrogen per hectare in a year.

Picture 1: legume seed inoculant -Biofix and its effect on root nodules

Since 1981, the Nairobi MIRCEN has conventionally produced and distributed two types of Rhizobium inocula popularly known as 'Biofix' and 'Prep-pack' for use on common beans, lucerne, soybean and desmodium (a legume pasture).

The original Nairobi MIRCEN produced and distributed Rhizobium inocula in Kenya as a more relevant and cost-effective technology than inorganic fertilizers. In particular, the technology was considered cheaper and lighter to transport, less labour-intensive, more environmentally friendly and having high yield potential relative to chemical Nitrogen (N) fertilizers. However, Rhizobium Inoculum's use among Kenyan smallholders is still limited. This study tried to look at why traditional biotechnology innovations such as "Biofix", which are perceived as cost-effective, have not been taken up as rapidly or widely as might have been expected.

The rest of the chapter first provides background information on common bean production in Kenya. This is followed by a brief description of global trends in the public sector and university research collaborations for capacity building and international transfer of traditional agricultural biotechnology to developing countries such as Kenya. The next section describes the process of Rhizobium inocula research activity in Kenya. This is followed by an analysis of field data on how this research priority has converged and responded to the production constraints identified by farmers. The chapter then makes concluding remarks and points to some lessons learned.

4.2 Background of Dry Bean Production

Common or dry bean (*Phaseolus vulgaris* L.) is reported to be the most important legume consumed directly in the world. Over 18 million tonnes of dry beans, valued at US$5717 million, are produced annually in the world. About 81 per cent of this production occurs in tropical countries, where Brazil and Mexico are the first and second most important producers and consumers.

In SSA, beans are mainly grown by women as a subsistence crop although about 50% of the producers sell a portion of the harvest to urban and peri-urban consumers. The income generating potential of bean production is raising its importance because consumers increasingly rely on the crop as an affordable source of protein. The common bean is utilised in many forms namely green leaves, green pods and immature and/or mature dry seed. The dry seeds of common beans are the most important economic part of the crop because they have a long storage life, high nutritional properties and can easily be prepared for eating.

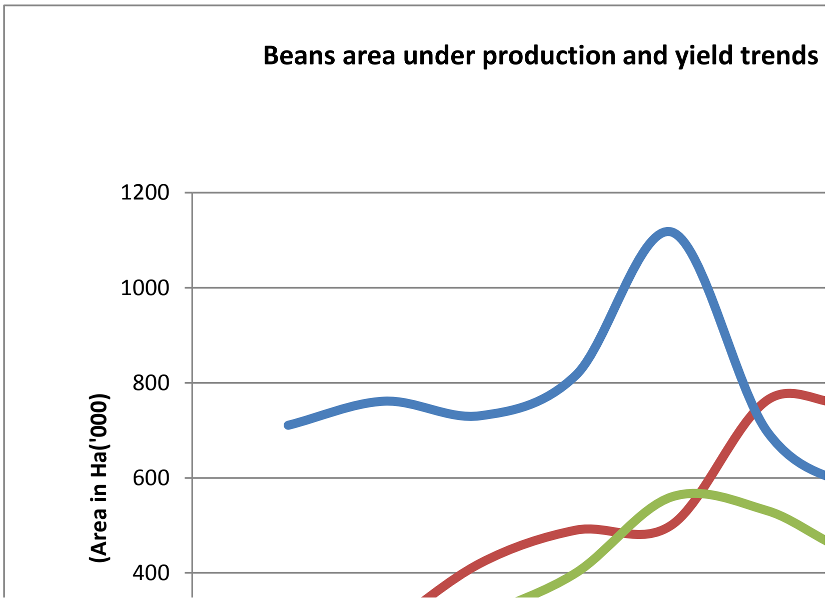
In Africa, Asia and Latin America, the bean is primarily a subsistence crop grown with limited external inputs and subjected to biotic and abiotic stresses. As a result, the average bean yields from these regions are very low when compared to those obtained in temperate regions of North America. As a food security crop, beans have a high yield potential in developing countries. The yields of beans can be improved in sub-Saharan Africa (SSA) because this region has recently experienced a modest yield increase while the area under production has decreased. Land and labour scarcity severely constrain options for increasing production by expanding the area under cultivation. Thus, farmers should achieve high bean yields per hectare from a cultivated area without using external inputs because many bean growers cannot afford them.

However, top soils of marginal and semi-arid regions of Africa are often nutrient-deficient especially in nitrogen. The scientists at the International Centre for Tropical Agriculture (CIAT) believe that the new bean cultivars will enable farmers to increase bean productivity because they are high yielding, disease resistant, drought tolerant and perform well in less fertile soils (Katungi et al. 2009)[2].

Dry bean is characterised by high levels of variation in growth habit and seed attributes (viz. size, maturity shape, adaptation, etc). This characteristic poses a challenge for scientists and farmers. The crop has 55 species and over 40,000 varieties thus making it difficult to develop appropriate varieties. Equally difficult is how to precisely assess its field performance. For instance, statistics of dry bean production are vague. Figures on production and consumption are underestimated because the crop is intercropped and/or grown in remote areas. The common bean is consumed at different stages of its growth in the form of green pods and immature and/or mature dry seed – which in turn reduces the total yields of dry seed. Also, trade between countries is opportunistic (sometimes involving illegal cross border trade) and dependent on the vagaries of climate.

Notwithstanding the imprecision in the estimation of production figures, dry bean production and yields have shown mixed performance. Figure 4.1 below shows that production was 80,000 tonnes in 1970. It increased to 160,000 tonnes in 1975 and 391,000 tonnes in 2010. The area under the crop also expanded from 150,000 ha in 1970 to 1,034,000 ha in 2005 and then declined to 689,000 ha in 2010. The yields achieved remain low, at below one tonne/hectare.

Figure 4.1
Dry bean production trends in Kenya



Source: FAOSTATS (2013)

4.4 Public Sector and University Research Collaborations

4.4.1 Global and Local Trends

Institutional collaboration involving public sector and public universities is a historical phenomenon in agricultural research. In the old days, European universities played a vital role in generating and disseminating knowledge. For instance, UK universities made a significant contribution to agricultural education and research systems by training agricultural professionals for government, research institutions, colleges and universities. Also, they were the main source of highly trained agricultural professionals for the private sector.

In the US, the federal government enhanced the role of public universities in agriculture. Under the Morril Acts of 1862 and 1890, the federal government established the Land Grant System.[3] There are three key elements of this system. First, the public laws that granted public lands to provide endowments and support to institutions of higher learning for the benefit of agriculture. Second, the passing of the Hatch Act of 1887 which sanctioned direct disbursement of federal grants to each state to set up an agricultural experiment station in connection with land-grant institution. Third, was the approval of the Smith Lever Act 1914 which instituted the Cooperative Extension Service. The common feature of these Acts is the matching of federal and local funds for agricultural experiment stations and the corresponding Cooperative Extension Service (see for example, University of Tennessee).[4]

In most of the developing countries, universities have both the mandate and the human resources for research to make significant contribution to agricultural development. But university resources are often not effectively utilised in such research. The universities are poorly funded and more concerned with academic output at the expense of effective dissemination of results to farmers. Byerlee (2002) posits that in contrast, universities in developed countries are relatively well-funded and conduct a substantial amount of research, but with only a small proportion being focused on agricultural problems of developing countries. Although universities in developing countries have less access to funds from agricultural development donors, they may benefit in other ways, especially from links to universities in industrialised countries and international assistance agencies.

The MIRCEN programme exemplifies international research collaborations involving public sector agricultural research institutes and universities. The programme was a result of UNESCO's (United Nations Scientific and Cultural Organisation) commitment to establish microbial resources centres (MIRCENS) in developing countries.[5] Drawing from the UNESCO web-page, the development of MIRCEN is characterised by three key development phases all involving collaboration with various agencies/organisations in setting-up of MIRCENS in developing countries as illustrated by three centres (Bangkok, Cairo and Nairobi), the MIRCEN is now a world-wide network that reflects a well-functioning system of research, education and development (see Box 4.1).

Box 4.1
Examples of MIRCENS in developing countries

In 1976, UNESCO/UNEP supported the establishment of Microbial Resources Centre at the Ministry of Science and Technology in Bangkok, Thailand with the aim of preserving useful microbial strains for agriculture and industry. Its principal activities include research on biodiversity and the collection, identification and preservation of micro-organisms. The Centre also provides service and training on isolation, identification, characterization and management of microbial cultures and strains.

The Cairo MIRCEN was established at Ain Sham University in 1977 to "serve different aspects of Applied and Environmental Microbiology". Its three main objectives include: conservation of micro-organisms; infrastructure support for the management, distribution and utilisation of microbial gene pool; and training and dissemination of relevant information.

In Kenya, the Nairobi MIRCEN was established in 1977 at the Department of Soil science, University of Nairobi (UoN) with the mandate to collect, preserve, test strains and produce inoculants. The Nairobi MIRCEN has contributed to the transfer of BNF knowledge to researchers, extension workers and farmers in Kenya and the rest of East African region.

Source: MIRCEN (1990)

Therefore, collaboration involving universities in industrialised countries with universities and NARIs in developing countries may contribute to long-term relations which enable direct or indirect "capacity building", especially with respect to PhD training. This may have a major advantage in providing incentives to scientists and building research skills in the long term. In this context, UN agencies (UNESCO, UNEP, UNDP, FAO) and international assistance agencies have made some contributions in strengthening the role of universities in the NARS. For instance, a FAO Expert Consultation (FAO 1991) underlined the important role of universities in NARS of developing countries and considered them as vital components of these systems. The experts called for establishing and strengthening of institutional and functional linkages and procedures for co-ordination, cooperation and collaboration between universities and NARIs, which would enable universities to become effective partners in agricultural research and thus contribute to the improved capacity of the NARS (MIRCEN 1990).

The experts further recognised the significance of having an effective NARS with the productive research potential in the universities and profitability of complementary functions of universities and the NARIs. The major limitations to university involvement in agricultural research include incoherent research policy, poor priority setting, lack of funding, heavy teaching loads, poorly trained staff, poor and inadequate research facilities, weak local and international linkages, etc. But as the example of Nairobi MIRCEN shows, there are opportunities and challenges to effective involvement of universities in the NARS of developing countries to produce new and improved technologies for sustainable food and agricultural production. The main institutional challenges hindering the original MIRCEN project are priority setting which limits the project to research and not commercialization; low funding; and poorly qualified staff. Despite the low uptake of this technology, there were concerns that privatizing this technology (to boost adoption) would deviate from the mandate of the university, which includes generation of knowledge and its provision to the public for free. Though there have been attempts to have elements of the technology privatized to enhance diffusion, progress was hampered by institutional challenges and lack of an appropriate legal framework basing on intellectual property and patent laws. Such conflict of interest has limited the uptake of many other technologies from public research institutions.

The technical challenges include the mechanical process of Biofix production, near obsolete facilities, less qualified personnel and a tedious quality control process. 'We have no capacity to produce large amounts of the inocula at once if an order is made," explained Kisamuli, the microbial technologist at UoN. He said the partnership will now see the commercial activities done by MEA Ltd. which has good networks with farmers (Kisamuli, Personal communication 24th June 2009).

4.5 Case of Rhizobium Research in Kenya

4.5.1 Overview

The *Rhizobium* research project in Kenya was initiated as part of the network of MIRCEN project, mainly supported by UNESCO. It was established at the University of Nairobi in 1977 by the Departments of Soil Science and Botany to conduct research on Biological Nitrogen Fixation (BNF). The research work was influenced by the heightened fear of a worldwide energy crisis in the 1970s and the associated high prices of petroleum-based agro-chemicals such as inorganic nitrogen fertilisers and pesticides. This led to research efforts to develop and transfer technologies that were ecologically sound and cost effective to developing countries. Therefore, *Rhizobium* inocula seemed to be an appropriate technology for small-scale farmers in Africa.

The technology had a proven record of performing well on pasture and soybean production in USA, Brazil and Australia. In Kenya, small quantities of *Rhizobium* inoculants were being imported from Australia by the Kenya Farmers Association (KFA) for white settler farmers in the 1960s and 1970s (Ssali and Keya 1986). However, most of the African farmers were not aware of this technology. This was partly due to an agricultural policy which ignored African smallholder farming systems, especially common bean produced and consumed by many Kenyans. Prof. Keya was in this period among the few scientists who attempted to address the problem. His work on *Rhizobium* research then focused on common bean (or *Phaseolus Vulgaris* L), and soy bean (*Glycine* max) as a reference legume. During an interview with Prof. Keya, he recalled:

> After enrolling for PhD at Cornell University in 1972, I returned to Makerere University in Uganda where I conducted part of my fieldwork on cowpeas. I submitted and defended my PhD dissertation at Cornell University in 1974.[6] Thereafter, I joined the Faculty of Agriculture at the University of Nairobi as a lecturer in the Department of Soil Science. In 1975, I submitted a project proposal on *Rhizobium* research to UNEP/UNESCO/ICRO Microbiology Panel. Its other related aspects included capacity building, conservation of microbial resources and generation of appropriate technologies for the poor resource farmers. The project was approved and funded by UNESCO, UNEP and FAO. Its initial financial support of US$75,000 coincided with the formation of the Microbiological Resources Centres (MIRCEN) initiated by Dr. Mustafa Tolba, then the Executive Director of the United Nations Environment Programme (UNEP) in Nairobi.

The University of Nairobi and the MIRCEN formed a partnership which became known as "University of Nairobi MIRCEN project" or simply Nairobi MIRCEN. The Nairobi MIRCEN project was launched in 1977, thus joining other worldwide MIRCEN nodes located in Cairo (Egypt), Dakar (Senegal), Porto Alegre (Brazil), Karoliska (Sweden) and Bangkok (Thailand). Today there are 31 MIRCEN in 23 countries (UNESCO 2007).

Rhizobium research in Kenya was also diffused through other scientific networks such as NIFTAL in Hawaii and IITA, Ibadan, Nigeria. NIFTAL assisted other MIRCEN centres to build capacity for the purpose of exchanging information, sharing resources (i.e. research materials) and training of staff. Subsequently, the Nairobi MIRCEN project has formed other new networks such as the African Association of Biological Nitrogen Fixation (AABNF), and more recently, the RENEASA association which is supported by Rockefeller Foundation.

These networks have, however, been characterised by knowledge creation and diffusion for the international scientific community rather than its utilisation by local farming communities. For example, in 1977, the Nairobi MIRCEN project initiated its first international training course in microbiology and fermentation. This was followed by a series of other courses on related topics such as biofertilisers, biopesticides, and photosynthesis inoculants production and use. Through the network of the MIRCEN, the Nairobi MIRCEN also provided (i) short- and long-term scientific training for scientists from several African countries, (ii) scientific and germplasm exchange, and (iii) small research grants.

At the national level, the Nairobi MIRCEN project, as a scientific research project within the university environment, focused on postgraduate training in MSc. and PhD studies as part of staff development. It also facilitated several staff, especially technicians, to receive certificate training from different training institutions worldwide. Thus, the Nairobi MIRCEN advanced the career of many of its staff. For example, Prof. Keya acknowledges that his career development was closely linked to the project as he advanced from the position of lecturer in 1974 to that of professor in 1983. The project also fostered accreditation for some of its staff through publication and presentation of scientific papers at internal conferences. Based on the university norm of fostering knowledge, Prof. Keya says, "As scientists we were obligated to write and publish scientific papers from our scientific experiments.[7]"

It seems that the University of Nairobi MIRCEN project first underscored scientific research and training and not so much on technology development[8] – which still remains a key challenge until partnership is embraced to enable achievement of technology development, diffusion and product commercialisation as in the current case of MEA Limited and UoN MIRCEN project supported by the British Council.

Box 4.2
Innovative steps in Rhizobium inocula technology

Step1: *Rhizobium* strains: searching for effective *Rhizobium* strains for pasture, grain legume and subsequently tree legumes for use in inoculants production.

Step 2: Inoculum carrier: In most countries, peat moss was used as a carrier but it was expensive and often unavailable in Kenya. Hence, efforts were focused on cheaper and more abundant filter mud, a by-product of sugar cane processing. Peat moss currently being used is mined at Ondiri, Kenya. Peat-based culture is normally preferred because of the protection it offers to the *Rhizobium* hence increasing post-inoculation survival.

Step 3: Carrier processing equipment: A hammer mill, which is used for grinding cereal grains, was purchased and modified for grinding filter mud. Modern isolation, incubation, quality control equipment had been procured and was awaiting delivery by end of the year 2009.

Step 4: Strain fermenting equipment: Fermenters were acquired and adjusted accordingly.

Step5: Quality control and packaging: Upon confirming that the laboratory results of the inoculum from filter mud compared well to that of peat moss, packaging and quality control standards of the technology were established.

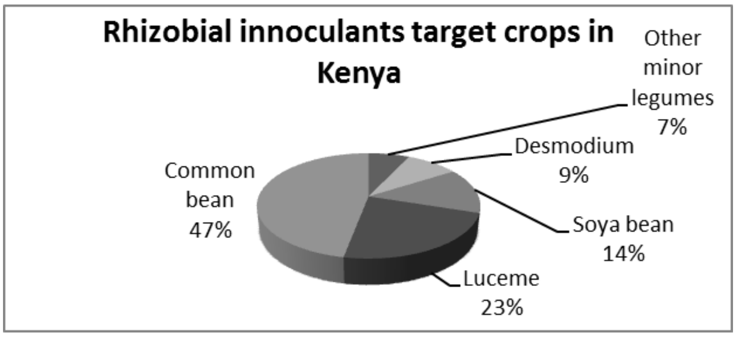
Step 6: Sticker: A locally affordable sticker, (i.e. ordinary white sugar or molasses) which would serve as an adhesive when inoculants are applied to the seed, was identified and recommended for use by farmers.

Source: Author's compilation

Gradually, the original MIRCEN project became interested to translate the accrued scientific knowledge into appropriate innovation for smallholder legume farmers in Kenya. Prof. Keya and his team were challenged by the fact that while farmers in developed countries had exploited the inoculants technology for decades, their counterparts in the developing world were not even aware of its potential benefits. According to Prof. Keya (2000: Pers. communication), "The project took a series of innovative steps to develop the Rhizobium inocula technology" (see Box 4.2).

The Nairobi MIRCEN project started producing and promoting Rhizobium inoculants or Biofix in 1981. It began with an annual production level of 60kg, which gradually increased to 700kg in the early 1990s and 850kg in the late 1990s. Figure 4.2 shows that the production targeted the following crops: common bean (47%), lucerne (23%), soybean (14%), a legume fodder, desmodium (9%) and other minor legumes (7%) (Odame 1997).

Figure 4.2
Rhizobial inoculants target crops in Kenya



Source: Field Data

The initial testing focused on soybean in four sites namely, Homa Bay, Mtwapa, Kabete and Njoro plant breeding stations. The results of these field trials showed good performance of Rhizobium inoculation with respect to soya beans. Table 4.1 shows that there was yield increase in the research sites as a result of using inoculated soybean seed.

Table 4.1
Rhizobium inoculation on legumes in Kenya

	Site	Uninoculated Yield (kg/ha)	Inoculated Yield kg/ha)	Increase (%)
Glycine max (soybean)	Homa bay	2550	3570	42
	Kabete	1021	1613	58
	Mtwapa	2333	3850	65

Source: Adapted from Woolmer et al. (1996:9)

At 65%, Mtwapa had the highest yield increase. Homa Bay reported the least but equally significant yield increase at 42%. Given that small-holder farmers in Kenya grow more common or dry bean (*Phaseolus vulgaris* L.), than soybean (Glycine max), it became important to do more testing of the Rhizobium inoculants on common bean.

4.5.2 Re-orienting the Research Project

In the early 1980s, testing of Rhizobium inoculants was extended to common bean and pasture legumes. Outcomes of the on-station trials in Kabete and Embu research stations demonstrated the yield potential of Biofix. Selected strains of Rhizobium could fix as much nitrogen as using the recommended 90kg of mineral N-fertilizer on one acre. For instance, 100g of Biofix was adequate to inoculate 15kg of dry beans required to plant one acre of land.

During extended field trials, the researchers recognized that a blanket approach of applying *Rhizobium* inoculants, especially to common bean, was ineffective due to the selectivity of Rhizobium strains to legume species, the intricacy of tropical soils, the cumulative effects of inoculation and the necessity of phosphate fertilizers to accelerate nodulation and nitrogen fixation.

Consequently, some research work was done by a Mr Mwala, a Soil Microbiologist, on mycorrhiza as a source of phosphorus. At present, three strains USDA2668, USDA2667 and CIAT 899 have been identified to have effective wide infection to legume crops, legume trees and legume pastures and are the main biofix microbial ingredient (Kisamuli, personal communication 2009). In spite of these research efforts, the use of Biofix was very limited in Kenya. Its poor performance was explained by several factors including constraints in soil structure, inoculant quality, crop production, extension service, and policy support at the national level.[9]

In particular, scientists at the Nairobi MIRCEN came to appreciate the fact that low soil pH and the lack of phosphorus in most Kenyan soils affected the performance of *Rhizobium* (i.e. rhizobia thrive well in moist soils of PH 5.8-7.4). In response to some of the above problems, the university researchers developed a new package of Rhizobium inocula known as “Prep-pack” in the mid 1990s. According to Kisamuli (ibid), Prep-pack is Biofix mixed with rock phosphate (mijingu), legume seed and urea used to inoculate leguminous plants.

Table 4.2 shows that the new package encompasses Rhizobium inoculum for fixing nitrogen from the air, phosphate powder for correcting phosphorus deficiency, lime for adjusting soil acidity and gum Arabic (as a sugar replacement) for binding inoculum onto legume seeds.

Table 4.2
Old and new packages of Rhizobium inocula compared

Main components	Old Rhizobium package (Biofix) (UoN)	Rhizobium package (Prep-pack) (Egerton University)
Size of package	100g	30g
Form of inoculum	Granules	Powder
Target area (in acres)	1 acre	0.125 acres
Labelling	Unclear	Clear
Components		
▪ Strain	Rhizobium	Rhizobium
▪ Carrier	Filter mud	-
▪ Binding substance	Molasses or sugar	Gum Arabica
▪ Phosphate source	None	Rock phosphate(Mijingu)
▪ pH adjustment	None	Lime
▪ Nitrogen source	None	Urea

Source: Field data

In addition to adjusting (adapting) the technology, the scientists were committed to work with and in turn learn from farmers through a local NGO and farmers' groups in conducting on-farm trials of the new bio-fertiliser –Pre-pack.

At the same time, there was increased demand of inocula in Kenya, Uganda and Tanzania. These new developments, and especially the existing production and diffusion of *Rhizobium* inocula in other countries, stimulated rethinking of the organisation of Nairobi MIRCEN project. For instance, in the US and Australia, BNF projects were organised as private initiatives whereas in Thailand it was set up under a special entity involving the university and Ministry of Agriculture. Following these examples, Prof. Keya and his team attempted to privatize some aspects of the project. They proposed to restructure the project to allow its scientists to focus on research and quality control activities, and leave the production and marketing aspects to a proposed private firm. However, the proposed changes in the Nairobi MIRCEN project were resisted by the university administration.

In Prof. Keya's view, the resistance was due to the 'inherent dominance of the public sector in the country's agricultural research, and the emphasis on visibility of the project to attract donor attention and funding'.[10] He also believed that the absence of intellectual property protection (especially patent laws) limited the privatization of some components of the project. Furthermore, other institutional barriers included the slow and sometimes difficult progress towards public and private collaboration in agricultural research in Kenya. Prof. Keya cites the following examples (see Box 4.3).[11]

Box 4.3
Attempts at institutional collaborations

(i) At the national level, the University of Nairobi MIRCEN project staff worked closely with the Ministry of Agriculture (MoA) to collaborate with the Kenya Seed Company but these arrangements failed to launch the commercial take-off of the enterprise as was the case in Brazil.

(ii) Limited efforts were made to collaborate with plant breeders, agronomists and soil scientists in the MOA and later on with scientists at KARI, but effective synergies and coordinations were not realised.

(iii) Some collaboration occurred between the MOA, the International Centre on Insect and Pest Ecology (ICIPE) and the Kenya Forestry Research Institute (KEFRI) which worked with the International Council for Agroforestry Research (ICRAF). Initial outcomes were achieved in testing *Rhizobium* inoculants on legume tree crops – but these linkages are yet to be effectively strengthened.

(iv) Extension service: efforts were made to disseminate information on Biofix to farmers, policy makers and other scientists through the MoA and Agricultural Society of Kenya (ASK) and NGOs. Yet, beyond these initial efforts, little systematic extension service was achieved. In particular, the MoA's field demonstrations in districts and ASK's agricultural shows were used to reach the public. These information channels enhanced the awareness of Biofix among show-goers, especially policy makers and extension workers. The project also achieved limited sales to farmers through the university pilot plant, agricultural shows and Kenya Seed Company. These efforts increased the visibility of Biofix among some agricultural professionals but not so much among smallholder farmers. This is partly attributed to unsystematic extension service.

(v) Currently, there is a partnership between MEA Limited and UoN and MIRCEN (2008) — giving MEA the exclusive right to produce on commercial scale, distribute, store and market Biofix. This is seen as an effort to overcome some institutional and organisational challenges that limit the previous inocula use.

Source: Author's compilation

As a result of some of these institutional constraints, it is claimed that limited use of knowledge about *Rhizobium* inocula exists among smallholders in Kenya.[12] According to Woolmer et al. (1996:14):

> Greater than 95% of farmers were familiar with root nodules but only 26% considered nodules to have beneficial effects. While a majority who

> considered nodules beneficial were aware of legume inoculants (16% of total), less than half had ever used legume inoculants (10% of total). [13]

This quote seems to suggest that lack of awareness among farmers is the root cause of poor use of inoculum. For instance, the report points that "it is not the presence of nodules which is unknown but rather their actual benefits”. Thus, it recommends the development of information and materials on the benefits and management of the inoculum as well as the need to conduct on-farm trials to demonstrate the yield-effects to farmers in the survey area. The project also experienced poor market penetration due to the geographical and cultural dispersion of small-scale agricultural producers in the country. But as mentioned earlier, the problem also lies in the low capacity of the Nairobi MIRCEN to produce and distribute adequate quantity and quality of inoculum to farmers. Other reasons for poor use of inoculum cited by scientists at the UoN MIRCEN project include:

- It was anticipated that farmers would either make mail orders of the inoculants from the laboratory centre or travel there to make direct purchases.
- Legume inoculants are not often supplied by agro-dealer shops because they are not listed among the products recommended for replenishing plant nutrients by the Ministry of Agriculture and allied national institutions. This situation limited use of legume inoculants by the millions of smallholder farmers where low soil nitrogen levels limit food production.
- Legume inoculants are highly perishable and sensitive to factors such as temperature and sunlight. In the rural farming areas, poor infrastructure including a lack of electricity results in poor market penetration. The low-input agriculture practised by the subsistence farmers in the tropical soils, which contain high populations of indigenous *Bradyrhizobium sp.*, lower legume responses to Rhizobia inoculants.

In view of these conflicting demand and supply explanations for the poor performance of the inoculum on farmers’ fields, this study has examined the experiences of farmers who through the assistance of their farming groups and local NGOs accessed and used the old and the new packages of inocula in Mathira and Kieni East divisions in Nyeri District and Butula division in Busia District. But we first provide an overview of the study sites which are based on the Ministry of Agricultural divisional annual reports (1997-1999).

4.6 Smallholder Agriculture in Nyeri District and Busia District

4.6.1 Description of Study Sites

Mathira division

Mathira division in Nyeri district is located in one of Kenya's high agricultural potential areas. The area receives an annual rainfall of 1400-1800 mm and is endowed with well-drained soils. Its 234 sq. km. of agricultural land supports a population of 250,000. The division has 51,000 farm families. The major staple food crops grown on these largely small-scale farms include maize, beans and potatoes. Coffee and tea are the main cash crops.

A network of farmers' co-operatives supports cash crop production by enhancing farmers' access to markets of farm products and inputs such as seed, pesticides and inorganic fertilisers. Many farmers use organic fertilisers, especially livestock manure, in the production of food and horticultural crops. For instance, Kenya Institute of Organic Farming (KIOF) has since the early 1980s sensitised and trained members of partner farming groups on organic farming. One such group is Ruthagati Self-Help Organic Farming Group in Mathira division. This group comprising over 500 members was formed in late 1989 with the facilitation of KIOF. The Kenya government officially registered the group on 6th April 1990. For several reasons, including conflicts within the group, the group membership significantly declined from 517 in 1990 to 35 active members by the year 2000.

Aside from extension activities of the Government and NGOs, farming group members also participated in 'merry-go-rounds', which provided farmers with critical informal credit for farming and petty-trading activities. Members of Ruthagati Self-Help Organic Farming Group became aware of *Rhizobium* inocula through linkages with KIOF. From 1998, according to Mr John Njoroge, the Director of KIOF, KIOF staff began promoting Biofix among its partner farming groups in Central Kenya "because the innovation was consistent with the ideals and practices of organic farming, which KIOF supported" (John Njoroge, 1998 interview).

Kieni East division

Compared to Mathira division, Kieni East division is a relatively drier area of Nyeri district. It receives bi-modal annual rainfall with an average of 970 mm. The division has an area of 72,700 ha of which only 38,662 ha (or 58 percent) are arable. This area supports a population of 61,157; mostly, smallholder farmers. These farmers grew maize, potatoes, beans and horticultural crops and raised livestock. Like in many farming regions of Kenya, maize and beans were often inter-planted by smallholder farmers in Kieni East division. Most farmers used limited amounts of inorganic fertilisers on food and horticultural crops.

In terms of extension service, besides government, NGOs and farmers' groups had become key points of entree for public and private agricultural organizations in Kieni East division. One such NGO was the Help Self Help Centre (HSHC) – which began its work by supporting integrated low-input sustainable projects within its partner farming groups. The farming activities of these producer groups later attracted private sector marketing agents. For example in 1997, twenty farming groups among them Gwitheria Women's Group and Biriri Catchment Group, entered into marketing contracts with private agents for the domestic and export markets of horticultural produce (viz. snow peas, french beans).[14] Like in Ruthagati Self-Help Organic Farming Groups in Mathira division, members of these groups were also engaged in 'merry-go-rounds', which provided them with informal credit for purchasing seed, farm inputs, medicine and school fees.

Regarding local capacity building, an international development partner, the International Fund for Agricultural Development (IFAD), became involved in Kieni East division in the 1990s. IFAD funded capacity-building of several farmer extension groups in the division through the Ministries of Agriculture and Social Services. Its training component included book-keeping, leadership and group dynamics; and project management and evaluation. To enable field extension staff to reach more farmers and more often, the new rural extension approach required every sub-location to form eight farmers' groups. An extension agent of the Ministry of Agriculture (MoA) was expected to visit at least two of the eight groups each week. It also facilitated the systematic use of *Rhizobium* inocula (or Biofix) in the division.

Prior to this period, Biofix had for several years been unsystematically promoted in Kieni East division by extension workers of the MoA through agricultural shows, field days and plot demonstrations. As such, some farmers were aware about the technology but had limited practical experience of using it. In 1996 the promotion of Biofix in the division became relatively better organised as a result of awareness campaigns conducted by extension workers of the MoA and HSHC. Consequently, members of Biriri Catchment and Gwitheria Women Group accessed and used the technology.

Butula division

Butula division in Busia district falls within the medium agricultural potential areas of Kenya. Of its 24,000 ha of agricultural land, 21,000 ha (or 88%) are arable and the rest is non-arable. The division receives an annual rainfall of 1500-2000 mm. According to the 1996 projections, the division's 236sq. km. of agricultural land supports a population of 91,000 people. The division has 13,000 farm families with an average of two ha for each farm. The main food crops cultivated include maize, sorghum, millet, beans, sweet potato and cassava. Sugarcane, sunflower and coffee are the main cash crops.

Apart from organic fertilisers such as livestock manure and compost, many farmers do not use improved seed, pesticides and inorganic fertilisers. The only exceptions are farmers who grow sugarcane on commercial basis because they receive the planting material and fertilisers from a local sugar company, Mumias Sugar Company (MSC). In terms of government extension service, the division serves as a pilot for implementing the Farmers' Field School (FFS) programme in Busia district. In part, this client-oriented extension approach has facilitated the formation of farmers' groups in the division. In turn, these groups have become the entry points for extension work of government and NGOs in the area. For instance, through farming groups, the University of Nairobi MIRCEN project in collaboration with a local NGO, Organic Matter Management Network (OMMN), conducted on-farm trials of the new package of *Rhizobium* inocula (or Prep-pack) in Kakamega, Vihiga and Butula division of Busia districts in 1997.

In Butula division, OMMN worked with five farmers' groups: Eluche Women Group, Bulala Women Group, Sponge Women Group, Benga Women Group and Eluche Self Help Group. Like those groups in Mathira and Kieni East divisions, members of these farming groups were mainly women. They were also engaged in 'merry-go-rounds' as a source of short-term informal credit to support their farming and other household needs. Therefore, the NGOs and their partner farming groups in the three study sites were the main channels through which individual farmers accessed and used *Rhizobium* inocula. Similarly, the farmers' groups became the entry points for our focused group discussions, key informant and household survey interviews.

4.6.2 Household Profile of Respondents

The number of respondents in the three divisions was 70 – with 16, 28 and 26 respondents in Mathira division, Kieni East division and Butula division respectively. Thirty-one (or 44%) of the respondents were between 19-44 years while 29 (or 41%) of the respondents were between 45-59 years. At 41 (or 59%), most of the respondents had primary education, whereas those with secondary education were 21 (or 30%). Most of the respondents were females, thus accounting for 48 (69%); males were 22 (or 31%). Thirty-nine (or 81%) and 32 (or 66%) of these respondents were married and farm managers respectively.

All the respondents belonged to at least one farming group.[15] Although most farming groups had male members, at 69% women farmers accounted for the largest proportion of group membership. Out of 70 respondents, 20 (or 29%) and 1 (or 1%) males 'owned' and 'managed' their farms respectively. This compares with 16 (23%) and 32 (or 46%) females who respectively 'owned' and 'managed' their farms. The large number of females managing farms relative to owning farms is attributed to the fact that women remained on the farms as their male spouses sought off-farm employment elsewhere. Consistent with literature on farm ownership in Kenya, the few women farmers who owned their farms were either widowed or divorced (Khasiani 1991). Overall, most respondents owned their land, with the exception of one male farmer who leased land.

4.6.3 Land and Labour Utilisation

The farm sizes ranged between 0.25-23 acres, with the mean and median being 4.7 acres and 2.50 acres respectively. In Nyeri district, the high potential Mathira division had an average farm size of 3.7 acres per farmer. In the marginal area of Kieni East division in the same district, the average farm size per farmer was 3.2 acres. Butula division of Busia district, which is located in the medium potential area of the Lake Basin, had the largest average of farm size of 6.8 acres per farmer as compared to the other two divisions.

Although this study was limited in coverage to two districts selected on the basis of prior involvement with technology as opposed to random selection, field data on farm size revealed that the 70 respondents were largely drawn from small- and medium-size farms. This is consistent with our focus on smallholder agriculture in terms of farm size. The Ministry of Agriculture statistics and other surveys confirm that on average the small-scale farms are less than 5 acres. The same statistics show that the medium and large-scale farms in Kenya are on between 5-12 acres and over 12 acres respectively.

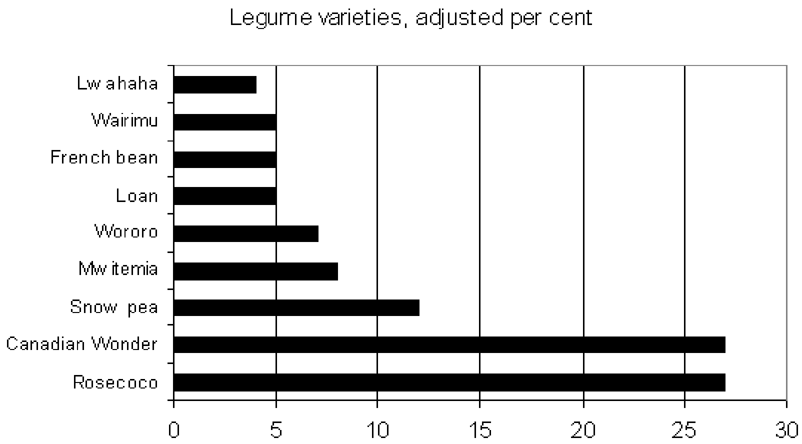
At the same time, the farm sizes are increasingly becoming smaller due to population pressure and subsequent land division. For instance, the number of full-time residents on the farm ranged between 1-9; with the average number being 4 members per farm. The number of children and adult[16] dependants living on the farm ranged between 0-16 with the average being 4 dependants per farmer. The average number of dependent children living on the farm and over 18 years was 2 and those below 18 years were 3 per farmer.[17] This shows that an increasing number of primary and secondary school graduates are staying on the farm due to lack of opportunities for further education and off-farm employment.

Fifty-two (or 74%) of the respondents reported that they hired labour, with the largest percentage being seasonal labour. About 41 (or 59%) and 11 (or 16%) farmers reported that they only hired seasonal and permanent labour respectively. The number of the hired seasonal labourers ranged between 0-10 with the average being 2 labourers per farmer. However, most of the respondents did not indicate the wages they paid for the hired labour for two reasons. First, they hired seasonal labour when farm activities required more labour than that available from family members. Second, it also depended on whether the farmer had money, with neighbours helping one another if money for wages was not available.

The proportion of farm area under common bean crop in Mathira division was 25%, with 31% and 28% for Kieni East and Butula divisions respectively. In the three divisions, most farmers used different species of common beans, which they recycled from their previous crop. Figure 4.3 shows the diversity and distribution of species of common beans that were used: rose coco, Canadian wonder, mwitemania, wororo, Wairimu and lwakhakha. Other legume species grown were as follows: snow peas, French beans, etc.

Figure 4.3
Proportion of legume species grown by farmers in the study areas

Comment [MW1]: Change Lwahaha in the figure to Lwakhakha?



Source: Field data

4.6.4 Seed and Input Use

All the farmers practised mixed farming, including tree and crop and livestock production. The area under common bean crop ranged between 0.16 and 3 acres, with a mean of 1.3 acres per farmer. The average area under common bean was 0.94 acres, 0.98 acres and 1.9 acres in Mathira division, Kieni East division and Butula division respectively.

The most important reason for producing legumes is food security. This is followed by income generation and then fixing nitrogen in the soil to help the production of other crops being also of relevance. Regarding fertiliser use, 73% of respondents used inorganic fertilizers on the farm, but far less directly on their legume crop (see Table 4.3). This means that farmers in the study sites did not directly apply N-fertilizers on legume fields. Some farmers in Butula division used the fertiliser meant for sugarcane on their legume fields. The common chemical fertilizers mentioned included Di-Ammonium Phosphates (DAP), Di-Ammonium Super Phosphate (DSP) and Calcium Ammonium Nitrate (CAN).

Table 4.3
Percentage of farmers using inorganic fertilizers, divisions and areas of study

	Percentage of farmers using inorganic N-fertilizer	
	on the farm	on legumes such as common bean
Mathira	100%	0
Kieni East	100%	0
Butula	27%	15

Source: Field data

Fifty-seven (57%) of respondents used livestock manure obtained from the farm animals they reared or from neighbouring farms. The area of land fertilised by livestock manure ranged between 0 and 6 acres, with the average area of 1.4 acres per farmer. However, most farmers did not indicate the amount of manure used because of the small quantities and its irregular use. Ruthagati Farmers Group practised organic farming. Relative to fertiliser use, 65 (or 93%) of the farmers practised intercropping; except in the production of snow peas in Kieni East division, which according to some respondents was planted as a pure stand to avoid 'cross-pollination'. The common crops that legumes were intercropped with included potatoes, maize and cassava.

In the study, we found that decisions on issues related to what to produce and sell were made by the wife only in 53% and 56% of the cases respectively – substantially more than the decisions made by either both female and male or only male (see Table 4.4). In particular, legumes are cultivated by women, thus increasing yields of this crop has potential to improve the livelihood of the household.

Table 4.4
The gender distribution of decisions on production and sale

	Production	Sale
Wife and husband	26%	23%
Only wife	53%	56%
Only husband	21%	21%

Source: Field data

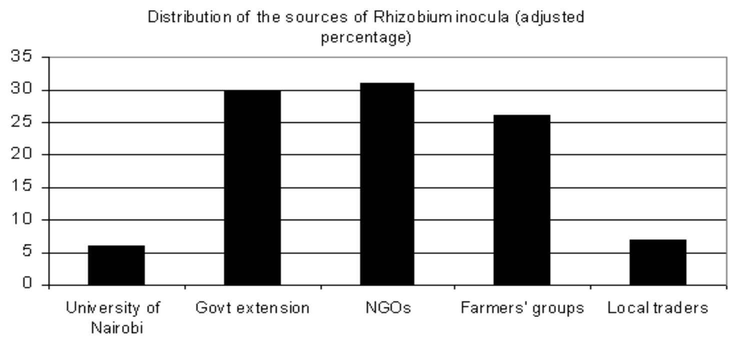
4.7 Farmer Experience with Rhizobium Inoculum

4.7.1 Sources and Prices of inocula

Until the late 1980s, the Nairobi MIRCEN staff sold the original *Rhizobium* inocula (or Biofix) either directly or by mail orders to farmers from its pilot plant in Nairobi and/or during national agricultural shows across the country. The inocula were also distributed through the Ministry of Agriculture (MoA) via its district extension offices. In the early 1990s, the NGOs, Kenya Institute of Organic Farming (KIOF), and Organic Matter Management Network (OMMN) purchased inocula directly from the Pilot Production Plant at the UoN in Nairobi for distribution to their partner farmers' groups in Central province and Western province respectively. In particular, KIOF worked with partner farmers' groups in Mathira division in Nyeri district whereas OMMN distributed a few packets of Biofix to farmers in Kakamega district.

In 1996/97 OMMN (also known as ABHL) was involved in the on-farm trials of the new package of *Rhizobium* inocula (or Prep-pack) in Kakamega and Busia districts in Western province. During the same period, the promotion of Biofix in Kieni East division in Nyeri district was as a result of collaboration of three organisations: an NGO, Help Self-help Centre (HSHC), MoA divisional extension staff and a local agro-dealer, Naro Moru Agrovet Services Ltd. HSHC purchased the inocula from the Nairobi MIRCEN and delivered it to its shop in Naro Moru for direct sale to farmers and/or through MoA local extension staff. Farmers through their groups in Mathira and Kieni East divisions used diverse sources of *Rhizobium* inocula. These include the University of Nairobi pilot plant, government extension service, NGOs, farmers' groups and local input traders. Figure 4.4 shows NGOs (31%), government extension (30%) and farmers' groups (26%) were the most common sources of inocula for the farmers. The University of Nairobi pilot plant and the local input traders were the least used sources of the inocula. The common feature of these sources is that *Rhizobium* inocula were obtained from the University of Nairobi pilot plant in Kabete (near Nairobi). This means that buyers of Biofix had to procure it from Nairobi, which involved high transaction costs in terms of travel and other indirect costs.

Figure 4.4
Sources of Rhizobium inocula

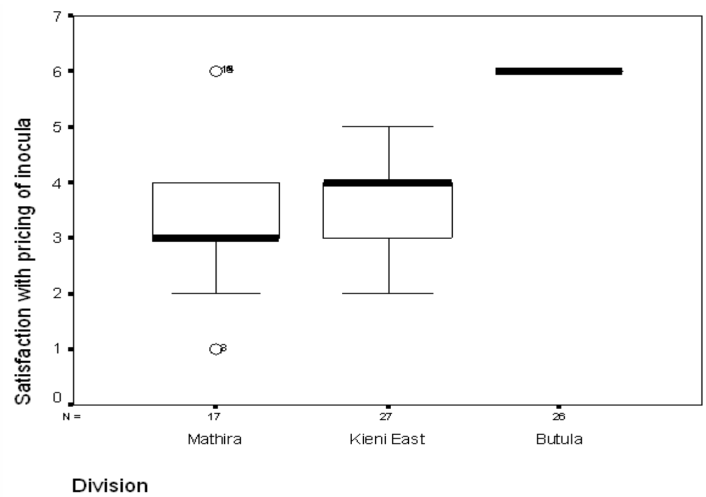


Source: Field data

Regarding the price for the *Rhizobium* inocula, the experience is different in the three divisions studied. Firstly, the costs involved in the distribution in the study areas (i.e., transport and transaction costs), were absorbed by KIOF (in Mathira division), HSHC (in Kieni East division) and the Nairobi MIRCEN project (in Butula division).

Despite the NGOs' support in accessing the inocula to farmers, the latter's level of satisfaction with the price of Biofix was mixed. Figure 4.5 shows that farmers in Kieni East, while "satisfied" with the price of Biofix, saw the additional cost of sugar, which was required for binding the inocula onto the legume seed, as quite burdensome.

Figure 4.5
Farmer satisfaction with the pricing of inocula in the three divisions



Legend (1-5 level of satisfaction indicated on vertical axis):

1=Very dissatisfied; 2=Dissatisfied; 3=Moderately satisfied; 4=Satisfied, 5=Very Satisfied

Source: Field data

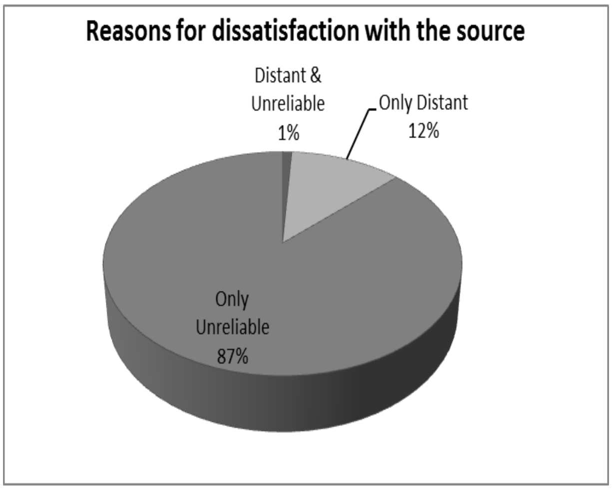
The dissatisfaction was stated by one farmer who summed up the views of members of Gwitheria Women Group in Kieni East division as follows, "…Many of us do not have sufficient money to buy sugar for our children let alone wasting it in the soil." Farmers in Mathira division were "moderately satisfied" with the price of Biofix, a situation which can be attributed to the sudden increase in its price by over 340 percent (i.e. from Kshs 17 during the period before 1992 to Kshs 75 thereafter). In Butula division, farmers received prep-pack free of charge from the Nairobi MIRCEN project for on-farm trials.

It is evident that despite the claims by scientists that *Rhizobium* inocula was more accessible to smallholder farmers because it was cheaper relative to chemical fertilisers, the relevant NGOs largely influenced its access and use in the study areas. Evidence shows that when NGOs stopped the supply of *Rhizobium* in Mathira division in mid 1990s, and Kieni East and Butula divisions in 1997, most farmers in these divisions also stopped using the technology. In Butula division, farmers only used the freely provided inocula (Prep-pack) once.

4.7.2 Delivery System

Aside from the price considerations, many farmers were dissatisfied with the delivery system of the inocula. The main reasons include long distances and unreliability of the sources to deliver the inocula in sufficient quantities and on time. Legume inoculants are highly perishable and sensitive to abiotic factors such as temperature and sunlight. As Figure 4.6 shows, unreliability was perceived as a far more significant disadvantage in using Rhizobium inocula because it was systematically promoted in the three divisions for an average of one season and thereafter it became unavailable. Specifically, farmers in Mathira stopped using the inocula in mid 1990s while those in Kieni East and Butula divisions were unable to obtain it after 1997.

Figure 4.6
Reasons for farmer dissatisfaction with the source



Source: Field data

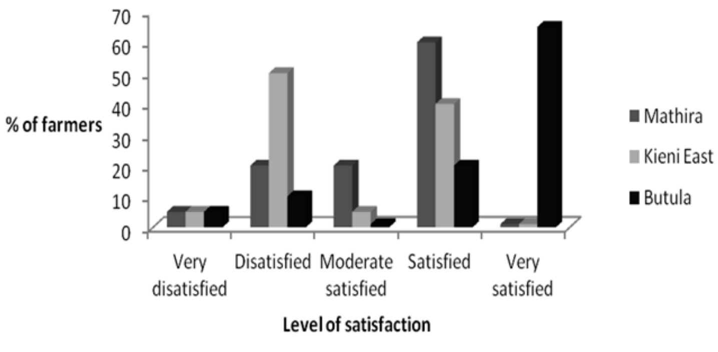
From the supply side, it seems that the unavailability of Rhizobium inocula hampered its use among farmers in the study areas. This was partly confirmed by members of Gwitheria Women Group during a farmer focus group discussion in Kieni East division. "…we collected money to buy Biofix and gave it to our local extension worker. However, he returned it to us because Biofix was unavailable at Naro Moru." Naro Moru was the secondary source of Biofix in Kieni East division from where it was distributed to farmers through MoA extension workers responsible for certain areas. Some farmers collected the inoculum directly from the Ministry of Agriculture office in Naro Moru while others purchased it from the agro-dealer, Naro Moru Agrovet Services Ltd., in the town. Farmers who had bought the inoculum from either the office of MoA or Naro Moru Agrovet Services Ltd paid Kshs.70 for a 100g packet, whereas those who bought it through friends and the local extension workers at the field level paid Ksh 80 for the same packet. This represented an extra Ksh 10 to offset the transport cost from Naro Moru. The lack of coordination among several sources and the pricing mechanisms of the inocula led to its unavailability and late or unreliable delivery to farmers.

4.7.3 Packaging and Applying inocula

The original *Rhizobium* inoculum (or Biofix) was placed in 100g plastic packets. Each packet was supposed to be used in the inoculation of 15-16kg of common bean seed, which was adequate to cover an acre of land. In this context, Biofix was promoted as light to transport, more divisible and less labour-intensive than the equivalent inorganic nitrogen fertilisers. Biofix was applied together with the legume seed in a simple and combined activity. Also, unlike inorganic fertilisers, it did not require specialised equipment to apply.

However, there were disadvantages of applying Biofix with respect to the use of available land and labour. For instance, farmers in Mathira and Kieni East divisions own relatively small land holdings. This imposed certain limitations on the amount of land allocated to the production of legumes. Farmers in Mathira and Kieni East division required an average of 25g of Biofix for relatively small portions of the land (i.e. 0.25-0.5 acres) allocated to the cultivation of legumes such as common beans. This means that the 100g packet of Biofix imposed certain limitations on the farmers' use of available land.

Figure 4.7
Percentage of farmers' satisfaction with packages of inoculants



Source: Field data

Figure 4.7 above shows that the 5 kg package of Prep-pack, which was used in Butula division, was more satisfactory than the 100 g package of Biofix which was used in both Mathira and Kieni East divisions. For instance, in Butula division, 65% farmers were satisfied with Prep-pack package. In Mathira division, 59% of farmers were satisfied with Biofix, whereas farmers in Kieni East division were split in one-half – with 44% being satisfied and the other 44.4% being dissatisfied with Biofix package. The source of dissatisfaction in Kieni East came from members of Gwitheria Women Group. In particular, members from the group became dissatisfied following the splitting of the 100g packets of Biofix among a group of farmers. During the incident, the local extension workers used teaspoons to distribute relatively small quantities of Biofix to four individuals – with each individual receiving about 25g.

Farmers found it cumbersome to transport relatively small quantities of the "unlabelled" inocula. As we will discuss later, this situation had safety and gender implications for the inocula in the study sites. Therefore, farmers in Mathira division were "satisfied" with the packaging of the inocula because unlike in Kieni East division, its distribution did not involve splitting of packets.

Regarding applying the inocula, farmers in Mathira and Kieni East divisions were dissatisfied with the method of applying Biofix, especially with respect to the requirement that the inoculated seed had to be planted within 48 hours upon inoculation. Also, the use of sugar as a binding substance in Biofix caused the inocula to 'stick on the hands' – which reduced the pace of planting. This in turn placed further demands on the women's already constrained labour. Some farmers in Kieni East division perceived it to be poisonous to children and cats. In Butula, although 65% of farmers were satisfied with Prep-pack package, they complained about its application. As one farmer summarised his colleagues' sentiments, "…the powdery form of Prep-pack made its application difficult due to constant blowing off of the substance by the wind". Prep-pack was perceived to cause 'coughing and itching'. Like farmers in Kieni East division who sought ways of safely storing Biofix, farmers in Butula division attempted to protect children and the elderly by excluding them from applying the inocula. Therefore, the exclusion of children and the elderly constrained family labour during the planting of common beans.

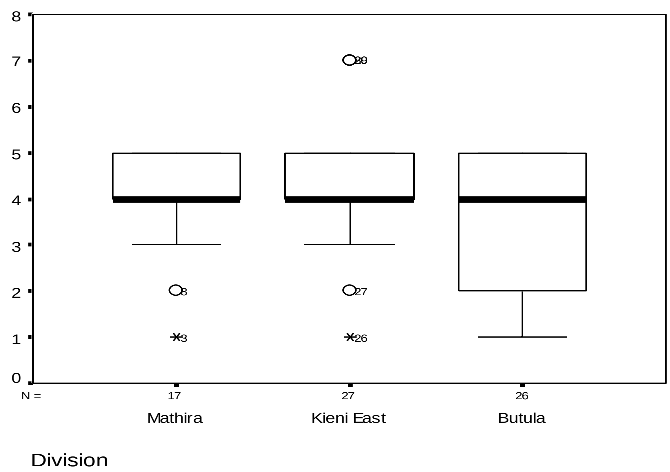
4.7.4 Training and Communication

Most farmers in the study areas received some training and information about Rhizobium inocula with respect to its inoculation procedures and potential yield effects on common bean. The training was provided through the farming groups by the extension agents from the MoA and NGOs, KIOF, HSHC, OMMN, etc. With the basic training received, most farmers in the three divisions were "satisfied" with the English language instructions used on the packets (see Figure 4.8). This is partly attributed to the high levels of literacy in the study sites. Ninety per cent of farmers in the study were literate, with 59%, 30% and 1% having primary, secondary and vocational education respectively.

Despite the general satisfaction with instructions on inoculation procedures, many farmers complained about lack of adequate information on the benefits, safety and the expiry date of the inocula. In particular, the information on the possible risks (or lack of them) of using the inocula was not effectively communicated to farmers during their training. During our farmer focus group discussions in Kieni East division, some farmers referred to Biofix as 'poison' and inquired about methods of safely storing the unused inocula and inoculated seed. Similar concerns were raised by farmers in Butula division over the powdery form of the Prep-pack, especially with respect to the fear that it could cause coughing and itching.

These findings show that without effective communication on the scientific claims regarding the ecological soundness of *Rhizobium* inocula, farmers in the study areas were inclined to give their own meaning to the safe use and storage of the technology. Also, as we shall discuss in the next section, the general training on the use of *Rhizobium* inocula was not adequate for farmers to effectively assess its yield effects on common bean. Although farmers were fully aware of the importance of intercropping beans and other crops, they were not aware of the role played by legumes (especially nodules) in fixing atmospheric nitrogen in the soil. This problem was exacerbated by the limited use of the inocula because most farmers used the technology for only one season.

Figure 4.8
Box plots on farmer satisfaction with user instructions



Legend (1-5 level of satisfaction indicated on vertical axis):

1=Very dissatisfied; 2=Dissatisfied; 3=Moderately satisfied; 4=Satisfied, 5=Very satisfied

Source: Field data

In addition to the problem of distributing, packaging and disseminating information on the inocula, farmers in the study areas reported inadequate training on the yield assessment and follow-up by researchers and extension workers. First, farmers were not trained on the procedures of assessing the effects of Rhizobium on the root nodules of common beans. Second, there was limited follow-up by researchers and extension workers to identify production problems of farmers and provide suitable advice on a continuous basis. Third, the knowledge of extension workers and other stakeholders on the performance of Rhizobium inocula was weak. During focused group discussions, one farmer pointed out, "… the extension workers are learning first-hand information about the performance of inocula from us." Therefore, even with the general training provided, there was still much information missing on the suitable conditions (i.e., soil fertility, pH and moisture) within which the potential of Rhizobium inocula could be harnessed for smallholder farmers.

In order to benefit from BNF in a nodulating legume, it is necessary to determine whether appropriate Rhizobia are present in the soil. Frequently, the bacteria are not present or, at least, the population is far too low to nodulate the legumes effectively.

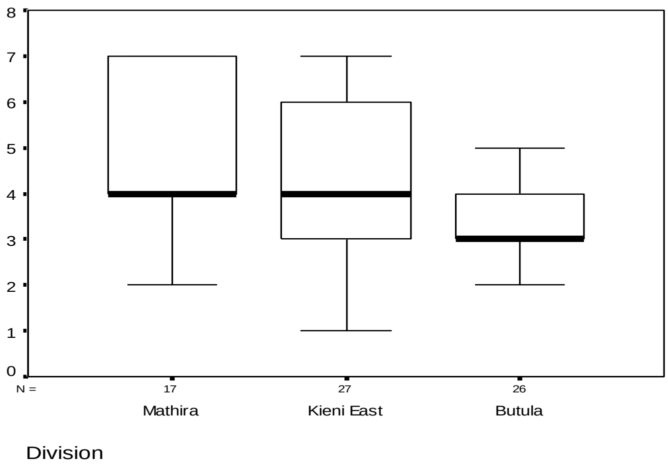
4.7.5 BNF and Yield-related Benefits

Most farmers were aware of low or declining soil fertility and attempted to use different sources of nutrient replenishment, including inter-planting and applying organic and/or inorganic fertilizers on their farms. As mentioned earlier, inter-planting is the most common feature of nutrient replenishment in the study areas. This is followed by the use of inorganic nitrogen fertilizers and then manure or compost. The use of inorganic and organic sources of fertilizers varied across the study areas. For instance, 44 (100%) farmers in Mathira and Kieni East divisions reported using inorganic nitrogen fertilizers as opposed to only 7 (27%) farmers in Butula division who used this form of fertilizers. Out of 70 farmer respondents in the study areas, only 4 farmers from Butula division reported direct use of inorganic nitrogen fertilisers on common bean fields. These farmers received the fertilizers for their sugarcane crop, which they applied to the fields intercropped by sugarcane and common beans. In terms of organic fertilizers, 40 (57%) farmers in the study reported using livestock manure or compost.

Figure 4.9 shows that farmers in the study areas were "satisfied" with the yield effects of using *Rhizobium* inocula on common beans. Specifically, farmers in Mathira and Kieni East divisions were "moderately satisfied" with the yields obtained from the use of the inocula. But there were variations in the level of satisfaction across the study areas.

For instance, 13 (18%) farmers in Mathira division stated that the inocula increased yields of common beans. In Kieni East division, 19 (70%) reported that the inocula not only increased the yields of common beans but it also improved plant health. Fourteen (54%) farmers in Butula division indicated that the inocula increased yields of common bean. The common feature across the study areas is that while farmers reported an increase of yields in common bean resulting from the use of inocula, they could not quantify such yield increases. They gave the following reasons. First, the poor memory recall for farmers in Mathira division, who had used the inocula 6-8 years before our fieldwork in 1998/2000. Second, poor weather which drastically affected the crop yields. Third, the limited experience with *Rhizobium* inocula because farmers in the study had systematically used the inocula for one season.

Figure 4.9
Box plots of farmer satisfaction with yield benefits by divisions



*Legend (*Legend (1-5 level of satisfaction indicated on vertical axis) :

1=Very dissatisfied; 2=Dissatisfied; 3=Moderately satisfied; 4=Satisfied, 5=Very satisfied

Source: Field data

Closely related to the infrequent use of the inocula is the inadequate preparation of farmers on how to conduct yield assessment as well as the uncertainty about the yield-effects of the inocula on common beans under the farmers' field conditions. Indeed, there was uncertainty about the yield-effects of *Rhizobium* inocula on the different legume species produced by farmers.

During farmer focused group discussions (FGDs), we also became aware that farmers were more reluctant to explain the reasons for their failure to assess the effects of *Rhizobium* inocula on common beans while being more enthusiastic to mention the disadvantages of the technology and its delivery system. This issue will be reviewed later in the concluding remarks on the inertia of knowledge relationships between scientists and farmers, but in order to capture some of the disadvantages of the innovation, we asked farmers to indicate their preferred attributes of the inocula and institutions supporting it.

4.7.6 Farmers' Preferred inocula Attributes

Despite the uncertainty about the yield effects of *Rhizobium* inocula on common beans, farmers expressed their willingness to use it when it is made available. At the same time, they suggested their preferred technical changes in the inocula. First, there was the need to adjust the Rhizobium technology to make it respond to the existing practices and constraints of producing diverse legume species on relatively very small farms. As mentioned before, a wide range of legume species are grown by farmers in the study areas. Most farmers grow an average of three legume species irrespective of the small landholdings allocated to legume production.

Farmers in Mathira and Kieni East divisions preferred different sizes of Biofix of less than 100g (i.e. mini-packs) to reflect the diverse needs of farmers with respect to the available land and labour. They also preferred the *Rhizobium* inocula to be packed into small plastic bottles with lids to keep the inocula dry. Table 4.5 summarises the above preferred technical attributes in Rhizobium inocula.

Table 4.5
Scoring of reasons for changes to the Rhizobium technology

	Percent of the total adjusted
Appropriateness	35
Stickiness	4
Shelf-life and safety	32
Tangible yield effects	29

Source: Field data

At 35%, appropriateness was the most preferred technical attribute. This was followed by shelf-life and safety at 32%. At 4%, stickiness was the least concern among the preferred technical attributes.

Second, related to the issue of adjusting the technology packaging was the need to increase the shelf-life (legume inoculants are highly perishable) and/or viability of the inocula upon opening the Biofix package or mixing it with legume seeds. For instance, many farmers suggested that the user instructions should be written in English and Kiswahili to facilitate easier application. Farmers in Kieni East division strongly discouraged the use of sugar as a binding substance because of the added cost of inocula. As well, it made the inoculated seeds sticky which slowed down the pace of planting. Many farmers expressed the need to conduct on-farm trials to demonstrate the yield effects of *Rhizobium* inocula on common bean. One farmer effectively pointed out, "… most of us believe in the little we see with our eyes than the much that is said." In particular, the information that compared the yields of the "inoculated" and "un-inoculated" common beans on the farmers' fields was lacking. Also lacking was the information about the potential negative effects of using the technology. As discussed in the next section, some farmers wondered whether the inoculum had long-term effects in the soil as is the case with chemical fertilizers. Aside from technical attributes, there were other preferred changes to motivate the accessibility of farmers to *Rhizobium* inoculum. Farmers emphasised the need for availability of affordable inoculum relative to other alternatives and the effectiveness of supporting institutions. NGOs and their farming groups enhanced the relative diffusion of *Rhizobium* inocula in the study areas.

Table 4.6
Scoring of reasons for institutional change

	Percent of the total adjusted
Improved delivery	26.0
Improved extension	20.0
Improved credit access	4.0
Improved access to markets	8.0
Improved self-help capacity	42.0

Source: Field data

Table 4.6 above shows many farmers suggested that in resuming the diffusion of the inocula, efforts should be directed at bringing its supply sources as close to the farmers as possible. Although these institutional attributes are not mutually exclusive, 42% farmers preferred improved capacity building of self-help groups to manage the technology in a sustainable manner. This was followed by improved delivery system at 26%. At 4%, improved credit access was the least concern among the preferred attributes of institutions supporting the inocula. This could also be achieved through the participation of local stockists or traders to allow farmers purchase the inocula when and if need arises.

4.8 Capacity to Innovate

4.8.1 Research and Education

The motivation for the *Rhizobium* project was the general desire by university scientists to address the challenges of low crop yields and food insecurity faced by the poor. This was made possible by availability of biofertilisation technology through the support of institutions in the public domain. As noted earlier, the *Rhizobium* project came onto the global scene after the energy crisis of the early 1970s and the formation of United Nations Environmental Programme (UNEP) to address environmental issues. There was a push for appropriate technology to substitute for fossil-based energy sources. The driving force of the technology was alternative energy source modulated by the techno-populism of the day. This explains why the technology was promoted as a relatively cheap, easy to use and environmentally-friendly innovation for smallholder farmers.

The innovative aspects in the research and education domain included re-orientation of *Rhizobium* research from soybean to common bean, and an attempt to establish a pilot commercial venture in a public university. The University of Nairobi (UoN) scientists also made an initial effort in the late 1980s to diffuse the old package of *Rhizobium* inocula (or Biofix) from their university laboratory to farmers through some local NGOs and farmers' groups. In the mid 1990s, the UoN scientists developed a new package (or Prep-pack), with some adjustments to take into consideration technical and socio-economic concerns of farmers. However, the availability of resources could not solve the uncertainty about the ability of *Rhizobium* inoculum to increase yields of common beans. This was due to a number of factors that included: the complexity soil structure in the tropics, specificity of *Rhizobium* strains in infecting particular legume species, residual effects of inoculation, and the requirement of p-element to stimulate nodulation and nitrogen fixation (Ssali and Keya 1983).

The specificity of *Rhizobium* inocula to legumes, especially common bean, limits its use among smallholder farmers. At the same time, while diversity may require developing specific inocula for specific soils as well as moisture and common bean varieties, such a research approach is costly and time-consuming. Given that farmers in the study sites rarely use the inocula (not even the organic fertilisers) on their legumes: are they willing to pay for the cost of adjusting and distributing the technology? There was also an attempt by the scientists to work with an NGO and farmers' groups in some areas of western Kenya to carry out on-farm trials and diffuse the technology.

4.8.2 Bridging Institutions

The original Biofix was developed and deployed in university research and education conditions with minimum participation of farmers. Its production, distribution and marketing were centralized. The NGOs were later involved in the distribution of Biofix to farmers in Western province and Central province respectively.[18] The NGOs acted as guarantors of the quality of *Rhizobium* inocula, and communicated available information. In addition, they stimulated a further multiplier effect for their farmer groups in terms of income generation and credit access to resource-poor group members.

NGOs accounted for much of the *Rhizobium* inocula used by farmers in Nyeri District. However, the role of NGOs in Biofix distribution and extension was constrained in several ways. The *ad hoc* nature of the alliance with civil society reduced an opportunity for sustained user interest and reciprocity. There was also limited effort by scientists to provide information to NGOs promoting *Rhizobium* inocula. Thus, NGOs assumed the risk of technology success or farmer failures.

4.8.3 Business and Enterprise

The Nairobi MIRCEN project promoted *Rhizobium* inocula as cheap, less labour intensive and more environmentally friendly than chemical fertilizers. However, there were mixed farmer experiences with the use of the original package (Biofix) and the new package (Prep-pack) of *Rhizobium* inocula in Nyeri District and Busia District respectively. Women farmers in the two districts criticized the fact that extension officers had not put into consideration the manner in which Biofix was disseminated. This criticism does not only show the need for improved ways of packing and labelling Biofix but also the importance of understanding gender and social dimensions that underline technology dissemination. There was also lack of clear information for farmers on the life span and the possible risks (or lack of them) on the Biofix packages. Further, farmers expressed fears of the potential health risks for their little children and small animals upon exposure to Biofix.

The Pre-pack was believed to cause coughing and irritation, which led to exclusion of children and the elderly from its application. Children are an important part of the family labour during planting, which means that their exclusion from applying the inoculum constrains family labour.

Rhizobium inoculum seemed to be relatively simple, less labour-intensive and more environmentally-friendly in the research but it was less so during use by farmers. Many farmers in the study sites were satisfied with the training they received from the relevant NGOs and the local extension workers before using the inocula. However, some farmers especially those in Kieni East division were rather dissatisfied with the sources and pricing of the inocula. In particular, they were dissatisfied with the inadequate and untimely supply of the inocula. Also, farmers in Kieni East expressed dissatisfaction with the requirements of mixing the inocula and common bean seed before planting. For instance, sugar was initially required as a substance for binding the inocula and beans during the inoculation process. For many farmers in Kieni East division, the idea of using sugar as a binding substance was unacceptable for two reasons. First, it was an expensive undertaking for poor farmers and secondly, the stickiness in the hands caused by sugar slowed the pace of line-planting the inoculated seed. Many farmers were also dissatisfied with the package size of the original *Rhizobium* inocula (or Biofix). Also, closely related to the use of the Biofix package was the pressure on family labour, especially women agricultural producers. This problem was exacerbated by the exclusion of young children and the elderly in the planting of the inoculated seed –for the fear of poisoning them. In the words of Mama Njoki:

> …my children help me during planting period because they move much faster than I do when it comes to placing seeds in the holes and covering them up with soil. Hence, their exclusion from this activity places great demand on my labour for planting and other household chores.

In terms of effectiveness of Rhizobium inoculum, farmers in the study sites were uncertain about the technical efficacy of this technology. They specifically wanted to know more about its demonstrable yield effects on the different types of common bean species and also other crops. Apart from the common bean which is the target of Rhizobium inoculum, farmers wanted to know the impact of this technology on other non-legume crops. For instance, Mama Wambui wondered "…why can't the researchers develop *Rhizobium* inoculum for maize and potatoes as they are important crops to us yet we are experiencing low yields due to lack of the required chemical fertilizers as we cannot afford them".

4.8.4 Policy and Institutions

The original *Rhizobium* inoculum project received funding from donors for over twenty years without showing significant yield increase for legume farmers who used the technology. Ostensibly, scientists on the project turned to external agencies for funding, which resulted in scientific research proposals being accepted at the global level before the local needs of the smallholders are assessed and prioritised. The project also experienced inadequate personnel to facilitate transfer of the technology from the university laboratory to farmers' fields. There were no systematic on-farm trials in the country's diverse agro-ecological conditions. Consequently, the old package (Biofix) performed poorly in terms of increasing yields of common beans. The scientists blamed farmers' ignorance and poor extension service for its poor performance. However, the evidence from Kenya and other countries showed that the technology was constrained by technical problems. In particular, the limitations of the technology, soils on farmers' fields and the farmers' socio-economics remained major constraints of generating and retaining acceptable Biofix innovation for farmers (Giller et al. 1998).

The project, through its research networks, facilitated training and publications for the scientists on the project. It enhanced the career advancement of some scientists. The project also resulted in the formation of networks or linkages with international organisations. It seemed that the University of Nairobi MIRCEN project lacked a strategy of supporting the NGO and its local partners in adaptive research. Therefore, the main policy lessons learned included the technical and institutional challenges of successfully deploying an appropriate and profitable technology for smallholder farmers.

4.8.5 Coordination of Linkages

In 2008, a new *Rhizobium* Inoculant (Biofix) fertilizer project was started to support improved accessibility of low-cost organic fertilizers to smallholder farmers in Kenya. The agri-business PPP project involved licensing of a private fertiliser company, MEA Ltd, to do mass production and marketing of Biofix —a technological output from a public institution, University of Nairobi (UoN). The partnership was facilitated by the British Council, which also provided grants to both UoN and MEA. The project exemplified a model for deploying technologies from public universities that could spur agribusiness and create employment (Odame and Kangai 2013).

4.9 Conclusion

Although it is not considered a modern agricultural biotechnology, the *Rhizobium* inocula research project exemplified a public university initiative to move technology from the laboratory to farmers' fields through free generation and diffusion of knowledge and materials. This traditional innovation process presents useful lessons for other biotechnology innovations like transgenic sweet potatoes, Bt. Maize and Bt. Cotton, which are yet to reach farmers in Kenya. For instance, when the University of Nairobi tried to privatize some aspects (including production and marketing) while the university researchers concentrated on quality control activities, it encountered institutional barriers since such a move would challenge the traditional role of public universities within the Kenyan NARS.

In general, poor performance in the use of the original Biofix despite substantial research efforts can be associated with its physical/technical obstacles; product quality; low rates of production; weak extension service; lack of national policy and institutional support; low soil ph and lack of phosphorous in Kenyan soils. Biofix was promoted by researchers at the Nairobi MIRCEN project as a cost-effective technology relative to chemical fertilisers. Biofix is certainly affordable in terms of price. However, evidence shows that smallholders do not often apply chemical fertilisers in their fields of common beans. Second, its relatively cheaper sale price at the pilot plant in Nairobi does not mean that many smallholders in the country could gain its access because Kenyan smallholders' geographical dispersion implies high transport costs and time for distributing technology and related information.

This shows the weakness in the prevailing thinking among public agricultural researchers, that once they have generated a 'cost-effective' technology, their job is done. Yet, the usefulness of any technology lies in its wider access among farmers and their supporting institutions. Despite the NGOs' support in accessing the inoculum, farmers' level of satisfaction with the price was mixed. This is because it is not just the direct price of technology that matters but also the associated costs of the other requirements in the technology package. Agricultural prices in Kenya are quite unstable and also subject to movements in world prices. The rapid change in the price of a technology should be matched with demonstrable benefits. The potential of *Rhizobium* inocula to increase yields of common bean is still indeterminate (Ogendo and Joshua 2001, Ssali 1988).

Field findings, to some extent, countered the researchers' claims that Biofix was less labour-intensive compared to chemical fertilisers because it was lighter to transport and did not require special application tools or equipment. In fact, the size requirements of Biofix packages had a negative impact on available household land and labour. This means that researchers may have the best interests of farmers in mind in designing technologies, but this alone is insufficient to capture the practical problems faced by farmers (Odame 2002a).

Some NGOs, through their closer interactions with farmers, reduced distribution costs, enhanced trust relations, promoted Biofix and ensured its use by farmers despite its technical uncertainty. Such relationships and continued support may, however, promote the use of technologies with unknown use values characteristics.

Problems such as packaging and labelling of Biofix could have been corrected by improved interactions between farmers and university scientists. However, responding to farmers' needs and wants creates pressure to change research and extension systems. Such change requires resources and trained personnel that are already major constraints for the project, government agencies and NGOs.

This case study points to the pressing need to carry out adequate socio-economic studies and systematic on-farm trials in different agro-ecological zones prior to commercialising any agricultural technology. The researchers at the Nairobi MIRCEN project recognised Biofix's technical constraints and developed a new package or Prep-pack, using the latter approach. Therefore, this case study shows that the generation of a relatively cheaper technology does not ensure its access and use among smallholders. As such, reshaping the institutions and policy towards strengthening appropriateness or profitability of agricultural innovations is an old challenge confronting the development, delivery and use of modern agricultural biotechnology.

Notes

[1] See also http://www.bdt.fat.org.br/bin21/ws92/mircen.html, accessed 5th October, 2012 The Nairobi MIRCEN project supported research efforts to develop and transfer technologies that were ecologically sound, cost effective and appropriate to smallholder farmers in developing countries. The then high prices of petroleum-based agro-chemicals such as inorganic nitrogen fertilisers and pesticides led to research on Biological Nitrogen Fixation (BNF) and thus Rhizobium inoculants.

[2] http://www.icrisat.org/what-we-do/mip/projects/tl2-publications/research-reports/rr-common-bean-esa.pdf, accessed 10th April 2013.

[3]A land grant system is a federal, state and local government partnership dedicated to education, research and extension in agriculture and related areas.

[4] At http://www.mycorrhiza.org/gauge/casnr/landgrant.html, accessed 27th December 2012

[5] At http://www.bdt.fat.org.br/bin21/ws92/mircen.html, accessed 3rd December 2013

[6] His PhD dissertation was entitled "Effect of Parasitic *Bdellovibrio* and Predatory Protozoa on Survival of Cowpea Rhizobium in Culture and Laboratory Soil" (Keya 2000: Personal communication).

[7] Prof Keya has either singly or co-authored several publications, technical reports, booklets and conference papers.

[8] One of the aims of starting inoculant production was to create awareness on the use of legume inoculants and benefits likely to accrue from its use (2009: per communication with Prof Gachene).

[9] See, for example, Odame (1997), Odame (2002a)

[10] This included UNESCO, FAO, UNEP, USAID, IDRC, US, National Academy of Science etc)

[11] This information was corroborated by other key informants.

[12] It is hoped that by acceptance and signing of an MoU between MEA Ltd. and UoN MIRCEN, the technology will be effectively diffused to end users.

[13]The results are from the survey of 60 households in the Central Highlands of Kenya, an area where inoculants have been promoted through District Agricultural shows and by local NGOs for several years.

[14]According to ILEIA at http://www.ileia.org/2/19-1/05_06.PDF, accessed 7th May, 2012 "Farmer Field Schools consist of groups of people with a common interest, who get together on a regular basis to study the 'how and why' of a particular topic. The topics covered vary considerably –from IPM, organic agriculture, crop husbandry and animal husbandry to income-generating activities such as handcraft. [Therefore], FFFs are particularly adapted to field study, where specific hands-on management and conceptual understanding is required".

[15] Some respondents claimed to have been members of several farming groups but had dropped out due to various reasons including financial constraints and group conflicts.

[16] Adults are considered to be above 18 years.

[17] These statistics might have changed with the introduction of free primary education in 2003.

[18] Compared to OMMN, KIOF's involvement in the promotion of Biofix was more systematic and widespread.

5 Partnerships in Modern Biotechnology System: Case of Transgenic Sweet Potato

5.1 Introduction

Collaborative research is increasingly becoming a prominent feature of modern biotechnology. It transcends the traditional boundaries of public and private research sectors. This approach is also sought to establish frameworks for capacity building and international transfer of modern technologies to developing countries. But much of these developments are driven by current economic and social changes in global, national and commodity spheres.

This chapter investigates deployment of a modern agricultural biotechnology research project, which is characterised by public and private partnership, more science-intensive, regulated and limited to upstream research system.[1] It specifically explores the challenges of linking science and production under uncertainty of science and policy. The project was initiated by KARI and Monsanto under the framework of the Agricultural Biotechnology for Sustainable Productivity (ABSP). Its mandate is technology access, generation and deployment to developing countries. The transgenic sweet potato project involved use of modern biotechnology, especially genetic engineering, to develop a new variety of sweet potato that is resistant to Sweet Potato Feathery Mottle virus (SPFMV). Conventional approaches to breeding virus-resistant sweet potato varieties have been less effective because the degree of resistance is inadequate and it takes a long time to introgress the resistant gene(s) into the genome of the sweet potato. It was thus recognised that conventional approaches could be complemented by use of modern biotechnology tools to develop transgenic sweet potato for African farmers. This was done through collaboration between public and private research sectors (or third sector). Therefore, the project exemplified research collaboration that involves a public good (an orphan commodity).[2]

This chapter follows the same structure as the case study of *Rhizobium* in the previous chapter. It begins with background information on practices and constraints of sweet potato production in Kenya. This is followed by a review of global trends in capacity building and international transfer of agricultural biotechnology to developing countries. The next section describes the transgenic sweet potato research activities in both the USA and Kenya that generated a CTP560 variety with the potential to tolerate viral disease(s) and raise yields of sweet potato in Kenya. This is followed by an *ex ante* analysis of how this research priority converges with and is likely to respond to the production practices and constraints identified by smallholder farmers in Busia district. Finally the chapter provides lessons learned and conclusions.

5.2 Background to Sweet Potato Production in Kenya

Sweet potato was introduced by the colonial administration in Kenya at the end of the 19th century. Sweet potato (*Ipomoea batatas* LAM.) is ranked as the fifth most important food crop on a fresh-weight basis in developing countries after rice, wheat, maize, and cassava. The crop is one of the most extensively cultivated root crops in SSA, occupying approximately 3.2 million ha with an estimated output of 13.4 million tonnes of roots in 2005. According to the FAO statistics, annual sweet potato production in Africa recorded a moderate increase from 11.6 million tonnes in 2002 to 12.9 million tonnes in 2006. In year 2006, the FAO estimated annual production of 7.2, 4.2, 1.2, and 0.5 million tonnes respectively for East, West, Central and Southern Africa (Andrade et al. 2009).

Farmers in western Kenya grow a large number of sweet potato varieties. A collection exercise in parts of south Nyanza and western provinces yielded around 240 varieties. On the basis of farmers' identified varieties, Kenya, along with several other countries in eastern and central Africa, is a secondary centre of genetic diversity of the crop.[3] In this region, farmers generate new varieties frequently through the selection of chance seedlings. Introduced varieties also contribute to its diversity.

While some excellent varieties are grown, many are late maturing and/or low yielding, and there is relatively constant turnover of varieties as farmers abandon or lose old varieties and adopt new ones (Bashaasha et al. 1995, Kapinga et al. 1995). Farmers obtained materials as vine cuttings from a variety of informal sources, including their own previously existing fields, from neighbours, or more rarely from local markets. As such, there were no certified sources of plant materials.

The availability of planting materials (in sufficient quantities and on time) is the main limitation for sweet potato production in drier regions (Ngunjiri et al. 1993). In these areas, there is a market for sweet potato vines during planting season. Also, planting materials for these areas are often obtained from relatively distant and high potential agricultural areas that have adequate supply of planting materials due to high rainfall and fertile soils. This indiscriminate introduction of planting materials contributes to the large mix of varieties being grown by farmers, but does not necessarily lead to sustained production of preferred varieties.

In the past years, several KARI research centres and CIP have made - concerted efforts to conduct sweet potato variety testing and trials, which have led to identification of several promising varieties for specific regions of Kenya. However, sweet potato farmers still experience low crop yields due to pest and disease incidences and inadequate supply of clean planting materials (ibid).

The sweet potato virus disease (SPVD) is caused by a complex of at least two of four major sweet potato viruses resulting in sweet potato virus disease. Resistance to Sweet Potato Feathery Mottle Virus (SPFMV) was expected to significantly lower the incidence of SPVD. Of those four viruses, the SPFMV is the most widespread. It is prevalent in sweet potato growing regions including Africa. It is the most common sweet potato virus in Kenya. Aside from indirect yield losses, the direct loss may result from external cracking of and internal corking of the roots, which make the tuberous roots unsuitable for consumption and marketing. The virus also significantly reduces the sweet potato foliage thus compromising its potential in soil conservation as a cover crop and as an animal feed. The use of virus resistant sweet potato cultivars developed through traditional breeding has been the most reliable form of disease control, although the strategy has had limited success so far.

Production of sweet potato varied from year to year and remained low due to the effects of pests and diseases. A KARI report (KARI 2000) stated that viruses cause up to 80 percent loss in yields. Kenya's sweet potato average yields are between 6-8 t/ha (see Figure 5.1). However, researchers often use an average yield of 6t/ha), which is less than one-half the world's average of 14 t/ha (Mungai 2000).[4]

On the basis of laboratory results, transgenic sweet potato was expected to reduce incidence of disease and raise crop yields by 18-40% (Wambugu 2001). Transgenic sweet potato was expected to be relatively cheap because farmers could freely exchange plantings and the ease of use of the technology due to its compatibility with existing production practices of traditional and improved sweet potato varieties. However, major challenges still remain as the analysis in the subsequent sections will reveal. The transgenic sweet potato programme was also motivated by the poor public image of agricultural biotechnology industry in developed countries, as documented by Odame and Mote (2000). In response, there were several public and private collaborations aimed at building scientific and regulatory capacity of developing countries. In Kenya, the programme coincided with some interests in KARI to link the global developments in agricultural biotechnology with local food needs in the country (Odame et al. 2003) .

5.3 Public and Private Research Collaborations

5.3.1 Global and Local Trends

Partnerships between the public sector and private industry in the area of biotechnology have existed for a long time. The development of biotechnology in countries such as the USA, the UK, Germany and Japan[5] has been closely associated with public-private partnerships (PPPs). The USA stands out as one country where such partnerships are more pronounced than anywhere else in the world. The genesis for such arrangements has been in the pursuit of alliances between existing institutions and achieving common goals. In the USA, the federal government has fostered closer university-industry relations over the years.

The university was perceived as a source of new scientific knowledge that could stimulate the country's long-term economic recovery. Further, the private industry perceived universities as a source of highly trained professionals and experienced technicians, while the industry was seen as a source of finance for biotechnology R&D through venture capital arrangements.[6]

In the UK, the government played a more influential role in stimulating public-private partnerships (PPPs). In 1981, the UK Government established the Biotechnology Directorate (BD) to exploit innovations coming from studies that had been publicly financed. There were two main motives behind BD. First, was the concern about the limited exploitation of inventions and discoveries coming from the UK research system, so that subsequently commercial profits were going to other countries. The pitfall of this biotech model was exemplified by its inability to establish the discovery of monoclonal immunoglobulins by the UK Medical Research Council (MRC) as a copyright.[7] It was thus feared that this pattern would continue unless the UK Government intervened. Second was the influence of the Rothschild Report published in 1971. One of the latter's controversial recommendations was a "customer-contractual system" of financing for public R&D initiatives that led to the establishment of coalitions of departments in the government, research entities and private sector to facilitate the development of new technologies such as polymer engineering, biotechnology and marine technology.

In the specific area of biotechnology, the UK Government had set up the Spinks Commission to recommend options for commercialisation. In 1980, the Commission's report recommended the use of public funds to set up a research-based company that would have direct access to information emerging from research in the UK MRC facilities.[8] The initial response of the Government to the report was unenthusiastic. However, another organization, the Science and Engineering Research Council (SERC), formed the Biotechnology Directorate (BD) in 1981 "to foster and promote the British scientific-based application in biotechnology, specifically for university researchers to build links between the scientific community and industry".[9]

In developing countries, public-private sector collaborations have taken a different form, with the international private sector donating proprietary technology to public research organisations of developing countries. Under such circumstances, the private and public sectors possess different comparative advantages in resources and expertise that offer them prospects for coalitions and complementarities. Germplasm and facilities for seed development and distribution are among the resources possessed by the public sector. The private industry has assets in the form of biotechnology tools and genes, and access to international capital markets (Byerlee and Fischer 2000)[10].

In 1993, Monsanto contributed proprietary virus coat protein (*cp*) technology, through a Mexican project, that was proven to confer resistance to PVY and PVS viruses in potato. The project received funding from the Rockefeller Foundation and was brokered by International Service for the Acquisition of Agri-biotech Applications (ISAAA). The Research Centre for Advanced Studies (CINVESTAV) implemented the project in Mexico (Brenner 1999). ISAAA facilitated the transfer of Monsanto's patented technology for Bt.-induced resistance to *lepidopteran* pests in cotton in Zimbabwe. Under this transfer agreement, the Cotton Research Institute (CRI) of Zimbabwe was to test imported Bt. protein against local pests.

Another project implemented under the Agricultural Biotechnology for Sustainable Productivity framework is the transgenic sweet potato project, in which Monsanto donated a proprietary technology to KARI. As discussed later in this chapter, this project steered the development of a sweet potato variety that is resistant to viruses. It also contributed to technical and legal capacity building in Kenya. Therefore, PPPs in biotechnology transfer to Africa have, so far, involved donated technologies under royalty-free transfer arrangements.

5.4 Case of Transgenic Sweet Potato in Kenya

5.4.1 Overview

The transgenic sweet potato research project in Kenya was established within the context of the ABSP, which was supported by the United States Agency for International Development (USAID). The research comprised a partnership between the public and private research sectors in the US and public research sectors in developing countries such as Costa Rica, Indonesia, Egypt and Kenya. Its aim was to develop GM sweet potato that is resistant to viruses. The project was led by scientists from KARI and Monsanto, with support of the researchers from Central Research Institute for Food Crops (CRIFC) in Indonesia. The ABSP structure and function entailed the generation of technology, access to technology and its transfer to developing countries.

According to Hinchee (1998:91), "scientists at Monsanto felt that the virus-resistance technology developed at Monsanto for commercial crops such as potato and tomato had the potential to reduce world hunger by increasing yields of subsistence crops such as the sweet potato".

Sweet potato is primarily cultivated by farmers living below the poverty line and in various agro-ecological regions of the country (Qaim 1999). Sweet potato is a suitable crop in Kenya's agriculture due to its ability to adapt to a wide range of growth conditions: in both fertile and marginal areas (Gibbons 2000). A major problem faced by sweet potato farmers is low yields due to diseases, pests and inadequate clean planting material. Of these factors, the virus disease and the weevils are among the main threats of sweet potato. SPFMV is considered one of the greatest limitations to the crop quality and production.

It was in this context that the transgenic sweet potato project was conceived as a collaborative initiative between scientists at KARI and Monsanto in 1991. At the time of conducting our fieldwork on this study in 2000/2001, research trials were being conducted in five areas of the country. The current status of this project is presented in the subsequent sections. .

5.4.2 Partners and Their Roles

Although the project was in the ninth year of implementation, a majority of Kenyans were not aware of this technology. Even agricultural professionals were not aware. It seems the initiative was largely influenced by KARI scientists including Dr Cyrus Ndiritu, the former Director, Dr John Wafula, Biotechnology Programme Director and Dr Florence Wambugu a research scientist in charge of the sweet potato in the Roots and Tuber programme. In particular, Dr Ndiritu and Dr Wafula influenced the programme by supporting Dr Wambugu's research work at the Monsanto Laboratory at St Louis, USA. The programme also benefited from the human capital of KARI scientists and the germplasm brought in from KARI by Dr Wambugu (Hinchee 1998)[16]. The specific roles played by the initiative and its main actors are summarized in Table 5.2.

Given that public sector financing is declining, this public-private collaborative research project became a source of private sector financing.

It also prioritised a minor crop grown by subsistence farmers for household food security.

Table 5.2
Actors and their roles in transgenic sweet potato

Activity	Actor-roles	Remarks
Initial project funding	Monsanto, USAID/ABSP	Raises the question of sustainability.
Technology generation	Monsanto & KARI,CRIFC, ABSP	Production of disease-free planting materials, on-station trials.
Capacity building among scientists, policy makers and administrators	KARI, Monsanto, ISAAA & MSU	Training on application of biosafety procedures and IPR issues, technical and legal capacity building.
National Biosafety guidelines	KARI, Monsanto, ISAAA & MSU	Setting up of NBC/NCST, perceived as point of entry for Bt crops in Kenya.
Technology deployment & on-farm trials	CIP, KARI, MOA&RD, CBOs ARDAP & MOA	Use of (non-GM) improved sweet potato variety for the analysis of an anticipated farmer adoption of transgenic sweet potato.

Source: Author's compilation

According to Gibbons (2000) "...Kenya is characterised by diverse agro-ecological conditions, which in turn influence farmers' preferences for particular sweet potato varieties or clones. In this context, the project was reported to be undertaking crop transformation of popular Kenyan varieties for disease resistance to develop a variety or clones that can satisfy the diverse varietal preferences of sweet potato producers and consumers." Apart from ABSP, KARI and Monsanto, other actors that supported the project include Michigan State University (MSU) and ISAAA. In terms of initial funding, Monsanto contributed US $2 million to the transgenic sweet potato project. The actual development of virus resistant sweet potato transformation began in 1991. This was after Monsanto and some other scientists donated a gene for a virus coat protein (*cp*) against the Feathery Mottle virus in the African Sweet Potato. Consequently, the programme supported a post-doctoral research at Monsanto and short-term training visits of several Kenyan scientists to Monsanto.

Gibbons (2000) further mentioned that a number of researchers from KARI who travelled to USA for short-term capacity building courses were sponsored by ISAAA. Other support included establishment of institutional biosafety structures, preparation and submission of biosafety permit applications, and laboratory and field biosafety evaluation of transgenic crops. The programme contributed to the technical and legal capacity building for modern biotechnology at the national level. It was expected that the technical training would allow scientists to apply the knowledge to other crops. The programme also enhanced the career of some scientists through post-graduate training programmes, publications and overseas trips to attend international conferences. It also contributed to scientific infrastructure for field evaluation and further development of transgenic sweet potato in the country. Further, the programme contributed to the updating of laboratory facilities. As an international requirement, the ABSP project and Monsanto insisted that KARI put in place the minimum requirements of a containment laboratory, prior to the importation of transgenic sweet potato material for field evaluation in Kenya (Odhiambo 2000).

Through collaboration with the private sector, the programme allowed some KARI scientists to contribute to this technical change. According to Hinchee (1998) and other key informants at KARI, the order of technical change in the upstream research involved the following key steps (see Box 5.1). Therefore, the transgenic sweet potato project was a model where researchers from the private and public sectors worked in collaboration to develop modern biotechnology solutions for small-scale farmers in Kenya and Africa.

Box 5.1
Contribution of KARI scientists in upstream research

1) Monsanto and other scientists donated a gene for a virus coat protein against the Feathery Mottle virus in the African sweet potato.

2) Dr Wambugu's work at Monsanto during 1992-1994 focused on developing the basis for a sweet potato transformation system. She was assisted by a KARI scientist, Ms Charity Macharia, to ship eight virus-free samples of African sweet potato genotypes to Monsanto. Mr. Daniel Maingi was seconded to the project to accelerate the research process.

3) Following the departure of Dr. Wambugu to become the Director of the AfriCentre office of ISAAA in Nairobi, Mr Maingi was joined by Dr Jeffrey Lowe to improve the efficiency of the transformation system, especially CPT560.

4) The transformation protocol which Mr. Maingi developed during 1994-1996 produced 200 plants containing the SPFMV cp gene. At this point, the sweet potato transformation and regeneration system procedure was confirmed to be reliable and reproducible.

5) Ms Charity Macharia of KARI joined the project on a 6-month capacity training in sweet potato transformation and to assist Mr. Maingi in the production of transgenic sweet potato. She returned to Kenya in mid 1996 to establish the sweet potato regeneration and transformation system at KARI prior to the transfer of the technology.

6) With the respective advice and assistance of Dr W. Kaniewska and Ms Maria Kaniewska of Monsanto, KARI scientists, Dr Anne Wangai, Dr Duncan Kirubi and Ms Charity Macharia successfully developed a reliable screen for SPFMV resistance.

7) The transfer of the recombinant sweet potato technology from Monsanto to KARI for actual field-testing took place in April 2000. The first round of field trials in 2000/2001 was at four centres of KARI. The second round of field evaluation in 2002 involved four transgenic lines noted to have shown superior performance during the first round of evaluation. The optimization of the transformation protocol of CPT560 continued based on a revised version of the Monsanto protocol proposed by Daniel Maingi.

8) Transformation of CPT 560 and KSP 36 at KARI Biotechnology Centre began. CPT560 and KSP 36 were successfully transformed. The Monsanto protocol for sweet potato transformation and regeneration were also successfully modified at the Biotechnology Centre Lab. The transgenic lines developed have undergone field trials and green house trials.

9) Sweet potato virus challenge experiments came underway; the main objective of this experiment was to evaluate the susceptibility/resistance of 8 lines of transgenic sweet potato varieties to SPFMV.

10) Work is still being carried out on the survey for distribution of SPFMV strains to identify various strains of SPFMV in different regions of Kenya and thereafter identify the most virulent strains. Optimization of the transformation protocols at the KARI Biotechnology centre is reported to be at an advanced stage and may result in higher production of transformed sweet potato lines from the lab. The current progress on this research work is unknown.

Source: Author's compilation

5.4.3 Legal and Regulatory Issues

Monsanto's free donation of transgenic sweet potato for public goods research raised the question of post-release IPR implications for researchers and farmers. The Monsanto-KARI agreement required that KARI researchers share the technology with other African countries.

KARI could also protect the resulting varieties through plant breeders rights (PBRs). Although KARI has applied for PBRs over transgenic sweet potato, it does not have plans to charge royalties. Therefore, farmers may produce sweet potato without worrying about IPRs. But will this situation remain the same in future?

The National Council of Science and Technology (NCST)/National Biosafety Committee (NBC) began implementing the National Biosafety Guidelines in Kenya in 1999. The Biosafety Act was passed into law in 2009 to establish the legal framework and laws governing importation and evaluation of genetically modified organisms. Laboratory research, station, and on-farm trials/evaluations have to follow strictly the laws governing their operations (See Biosafety Act 2009).

Transgenic sweet potato was the first crop to receive a permit in the country for field testing.[11] On this basis, some respondents suggested that transgenic sweet potato project was used to spur the formulation of biosafety regulations in Kenya. For instance, after approval of transgenic sweet potato in 1999, Bt maize followed. Other subsequent approvals were Bt. Cotton, Bt. Potato and Bt. Carnation.[12] It was also suggested that transgenic sweet potato was being used as a market opener for other GMOs from developed countries to be introduced into African countries such as Kenya. This conclusion was reached because Kenyan researchers had not developed a biotechnology product of their own. Besides, the local capacity for monitoring risks had not been put in place.

The enactment of the Biosafety Act 2009 set the regulatory framework in which generation, development, introduction, and marketing have a universal basis for evaluation, participation and acceptance of transgenic products. This is seen by proponents of GMOs as a step forward in allaying fears that Africa is not bypassed by biotechnology as was the case in the original Green Revolution of 1960s. For opponents of GMOs, there are old problems of diffusing existing technologies in Kenya's smallholder agriculture, let alone new challenges of safely deploying and utilising GMOs (Odame and Muange 2011).

5.4.4 Envisaged Technology Diffusion Pathway

The envisaged diffusion for transgenic sweet potato technology was a pathway initiated and tested by a collaborative project involving CIP, KARI, MOA&RD and CBOs and farming groups in western Kenya.

The project was motivated by the need to improve farmers' knowledge of conserving planting stock and product utilisation. In Busia district, the CIP and KARI scientists worked closely with a local NGO, ARDAP, and the extension staff of the Ministry of Agriculture in Bukhalalire community of Butula division.

This study entailed working with farming groups comprising women members at the community level. According to the project documents, every farmer group from each of the groups was identified by ARDAP and the extension staff to have participated in the sweet potato on-farm trials. These groups received new planting material and some training on on-farm conservation of planting material as well as utilisation of sweet potato. At the same time, some planting material was given to some untrained farmers in the community. This approach was, however, resisted by farmers on the following basis: First, at the national level, the markets for sweet potato are poorly organised; sweet potato is characterised by subsistence production and limited local sales. Second, in terms of research priorities, sweet potato received very low ranking by KARI researchers (KARI 2000). Third, previous initiatives by CIP and KARI researchers to diffuse improved sweet varieties and clones to farmers were limited partly due to poor extension services.[13] Fourth, while initial results of the Competitive Grant project showed enthusiasm on the side of farmers to learn about improved management of on-farm trials and utilisation of sweet potato, the farmers did not significantly change their existing production practices. Fifth and finally, the existing production practices influence farmers' low crop yields and use of external inputs such as fertilisers or pesticides. It is against this background that this case study set out to analyse the anticipated deployment and use of transgenic sweet potato to smallholder farmers in Butula division in Busia district.

5.5 Smallholder Agriculture in Busia District

5.5.1 Farming Activities

Butula division is one of the four administrative units of the former Busia district in Western province. Other divisions are Nambale, Funyula and Budalang'í. Butula division is located in the medium agricultural potential areas of the Lake Basin and Sugar Belt zones. Its annual rainfall of 1500-2000 mm is divided between two periods: long rains (March-April) and short rains (September-November). The division has an area of

24,000 ha of which 21,000 ha (or 88%) are arable. This area supports a population of 91,000 people on 13,000 largely smallholder farms. The farmers grow a range of crops including maize, sorghum, beans, sweet potato, finger millet, bananas and groundnuts. Sugarcane and sunflower are the main cash crops in the division.

Table 5.3 shows that with averages of 0.78 acres and 0.28 acres, maize and sweet potato respectively occupy the largest and the smallest farm area. At 0.62 acres, common beans occupy the second largest farm area after maize. However, it is difficult to estimate with certainty the area under common beans because of the local practice of inter-planting common beans with maize and/or sorghum. Like in most farming areas of Kenya, maize is the main food crop in the division. Most food crops (especially maize) in the area are produced for food security and are largely utilised at the household level.

Although sweet potato occupies the smallest area on the farm, it is ranked the second most important food crop with respect to household food security. These findings show that smallholders in the area are mainly subsistence producers, with very little farm produce sold on the market.

Table 5.3
Statistics of selected cropping area (in acres)

Crop	Number of farmers (count)	Mean	Standard Deviation	% obs Sample
Farm Size	160	2.34	1.23	100
Maize	157	0.79	0.73	98
Sorghum	117	0.47	0.36	73
Beans	108	0.62	0.69	68
Sweet Potato	160	0.28	0.18	100
Finger Millet	61	0.51	0.14	38
Groundnut	40	0.58	0.79	25

Source: Field data

As it will be noted in the next section, many farmers do not use modern seeds, inorganic pesticides and fertilizers. The same situation applies to farmers' limited access to extension services. Although this will be reviewed later, it is important to note that farmers reported that the recent activities on sweet potato in the area had increased farm visits by extension workers. This followed a decline in activities of Farmer Field Schools (FFS) and hence the reduced number of visits by the extension personnel from MoA. The increase in sweet potato extension activities in the division was a result of the Competitive Grant project on participatory approaches for identification of sweet potato varieties in western Kenya. This was a collaborative project of CIP, KARI and three CBOs in Siaya, Teso and Busia districts in western Kenya.

The household survey involved 160 (N=160) farmers comprising three categories: (i) farmers who had been trained and had received new planting material (n=60); (ii) farmers not trained but who had received new planting material (n=60); and (iii) farmers neither trained nor received new planting material (n=40). During the study, the farmers from Bukhalalire community formed the core of the first two farmer categories. These two groups of farmers shared the planting material and knowledge with their neighbours, which means that by the time of conducting this study, the spread of this innovation was restricted to a small geographical area. The third category comprised farmers from other communities who had received neither the new planting material nor training.

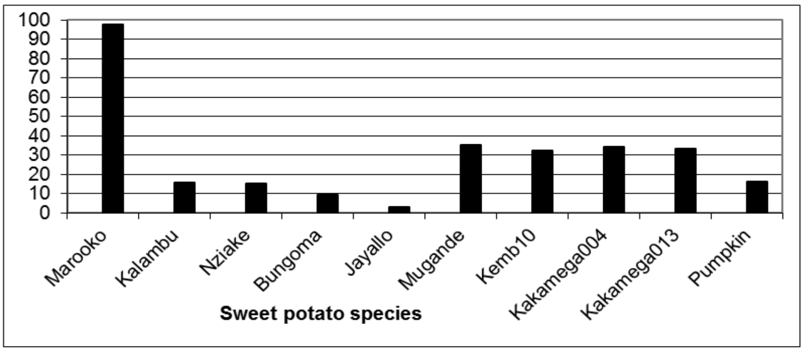
The largest number of respondents (136, or 85%) were women. Of these female respondents 116 (or 85%) were married and 43 (or 32%) owned farms. This implies that 93 (or 68%) female respondents managed their farms but did not own land. Most of the respondents belonged to at least one farming group. Women formed the largest number of group members in the study area. This finding concurs with the results from the Rhizobium case study in Chapter 4 and other studies carried out in Kenya.

5.5.2 Land and Labour Use

Out of 160 respondents, 138 (86%) had less than 5.24 acres, 20 (13%) had between 5.25 and 12 acres and only 2 farmers owned over 12 acres. The sample selection in this case study was not based on farm size, but on whether or not farmers had prior access to training and new planting material of sweet potato. A majority of respondents were smallholders owning less than 5.25 acres.

In the study site, the number of full-time residents on the farm ranged between one and 20, with an average of four residents per farm. As in the case of Rhizobium study in Chapter 4, the largest number of dependents living on a given farm was 16 while the average was four. The farms with the largest number of dependants had 14 children who were under 18 years and 7 adults over 18 years. The corresponding average number of children dependants under 18 years and adult dependants over 18 years was 4 and 1 respectively. Of 160 respondents, 79 (or 49%) indicated they hired labour. However, only 15 (or 9%) and 64 (or 40%) hired permanent and seasonal labour respectively. The minimum and maximum amount of money paid for an individual or group of seasonal labourers was Ksh 30 and Ksh 2,000 respectively, with an average amount of Ksh 245 per month.

Figure 5.2
Sweet potato species grown (percentages)



Source: Field data

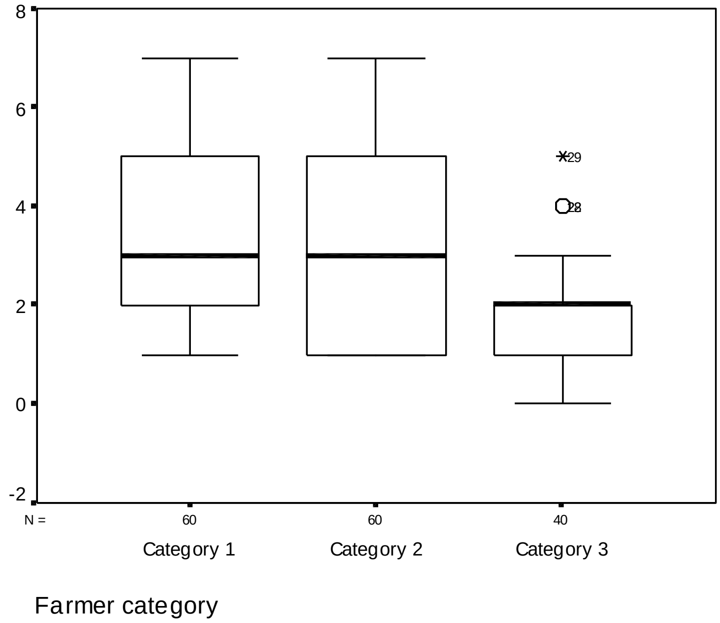
5.5.3 Seed and Input Use

Farmers in the study area grew a wide range of sweet potato varieties. For instance, through focused group discussions and household surveys, we identified at least 16 varieties grown in the study area. Figure 5.2 above shows the diversity and proportion of sweet potato varieties grown in the study area, both traditional varieties such as Marooko, Kalambu Nyerere, Nziake, and Jayalo; and modern (non-GM) varieties: Mugande, Kemb 10, Kakamega 004, Kakamega 013 and Pumpkin. According to some sources on the project (who did not want to quoted), the traditional varieties are considered low yielding and late maturing. In contrast, the modern varieties were selected on the basis of high-yield, low fibre content and early maturity. For instance, pumpkin represents an orange-fleshed and early maturing modern sweet potato variety.

For reasons which will be discussed later, it is important to note that a relatively large population of farmers in the study area planted Marooko despite its inherent low root yields and late maturity. The number of sweet potato varieties produced per farmer ranged between 1 and 6, with the average of 2 varieties per farmer. Figure 5.3 below shows that an average farmer in categories 1 and 2 planted three varieties per farm while those in the third category planted two varieties per farmer. This may be attributed to the fact that farmers in the first two categories received and planted five new varieties of sweet potato as opposed to those in category three, who only used traditional or existing varieties.

Most farmers (88 % of the respondents) do not use fertilizers on their sweet potato fields. The remaining 12 % of the respondents use the following forms of fertilizers: inorganic fertilizers (6%), livestock manure (5%) and compost (1%). The data also shows that farmers using organic fertilizers and livestock manure applied them more to traditional varieties than modern varieties. The exception was compost, where more farmers used it more on modern varieties than on traditional varieties. This variation may be attributed to the fact that most respondents reported (i.e. 98 %) growing Marooko, a traditional variety (see Figure 5.3). Also, the use of compost manure on modern varieties may be a coincidence because ARDAP simultaneously promoted the above two activities in the community.

Figure 5.3
Estimated number of sweet potato species grown by farmer categories



Note: (1-8 are number of sweet potato species indicated on the vertical axis)

Category 1: Farmers trained and received planting material; Category 2: Farmers not trained and received planting material; Category 3: Farmers not trained and not received planting material.

Source: Field data

The low use of external inputs by farmers in the study area makes them *de facto* organic farmers. This does not mean that these farmers were not faced with some constraints in the production of food crops. Table 5.4 shows the scoring of general constraints faced by farmers in the production in the study area. At 49%, soil fertility was ranked first and markets at 4% last in terms of the seriousness of the constraints to sweet potato production in general. More than half the respondents (53%) considered pests and diseases either a moderate or a serious problem.

Table 5.4
Percentage subjective scoring of production constraints

	Not a problem	Not a serious problem	A moderate problem	A serious problem	An acute problem
Land size	11.3	21.3	33.8	23.8	8.8
Soil fertility	3.8	5.6	33.1	48.8	8.1
Pests and diseases	8.8	34.4	33.8	20.0	1.9
Planting material	48.1	19.4	23.1	8.8	0.0
Labour	6.9	26.3	40.0	21.3	5.0
Extension service	20.6	16.9	19.4	29.4	13.1
Markets	55.6	31.3	6.9	3.8	0.0
Moles	20.0	.6	3.1	6.9	.6

Source: *Field data*

As noted earlier, the low product marketing may be attributed to the fact that most farmers produce sweet potato for household food security instead of markets. Like legumes in Chapter 4, women mainly produce sweet potato for food at the household level. The next section analyses the common practices and specific constraints these farmers face in the process of producing and marketing sweet potatoes in the study area.

5.6 Sweet Potato Production

5.6.1 Sources of Planting Materials

Farmers in the study area used a range of sources to obtain sweet potato planting material. These include farmer's own previous crop, borrowing from neighbours, community multiplication sites and farmers' training centres. One common feature of these sources is that they involve free exchange of planting materials. Even the community multiplication sites and Farmers' Training Centres (FTCs) provided the planting materials free of charge. But while the process involved non-market transactions, there were varied indirect (or transaction) costs which may explain why farmers preferred some sources to others.

However, there were differences between traditional and modern varieties of sweet potato. Table 5.5 shows that the informal system of seed recycling through own previous crop and borrowing formed the main source of the traditional species. At 52%, neighbours, friends and relatives were the most common sources of planting material for the existing or traditional species. Similarly, at 53%, the community multiplication sites were the most common source of planting material for the modern species.

Table 5.5
Sources of planting materials by species (adjusted %)

Source/Species	Own previous crop	Borrowed from neighbours	Community bulking centre	Farmers' Training Centre
Traditional species	46.4	51.6	2	0
Modern species	0	36.4	53.2	10.4

Source: Field data

The table also shows that the formal system of community multiplication sites and the FTC were the common sources of modern species of sweet potato. Recycling of sweet potato planting material is a cultural practice in western Kenya and it involves sharing of existing varieties. Unlike the formal sources that involve long distances and waiting time, the traditional methods are within reach and owned by farmers.

Farmers often collect seed in the form of new vines from as many farmers as possible and plant small portions of their land after the long rains. This practice explains why farmers use different varieties or clones of sweet potato at any given time. As we shall note in the next section, it also explains why many farmers plant relatively smaller fields in mid period (May/June) as opposed to the start of the long rains in March/April. In the focus group discussions, we were informed that a farmer learns about a new variety/clone of interest by acquiring and planting it, then giving it a local name on the basis of its source or special characteristics. This renaming of the variety may be done immediately or after a few planting seasons. A farmer, (personal communication Mama Anyango on 26 November 2009), observed:

> I grow three varieties of sweet potato including Marooko, Nziake and Mwezi Moja. I obtained these varieties from my neighbours in May. I also received some planting material from a community multiplication site.

Mama Anyango, like many farmers in categories 1 and 2, used informal (i.e. seed recycling) and formal sources for the existing (or traditional) and new (or modern) species of sweet potato respectively.

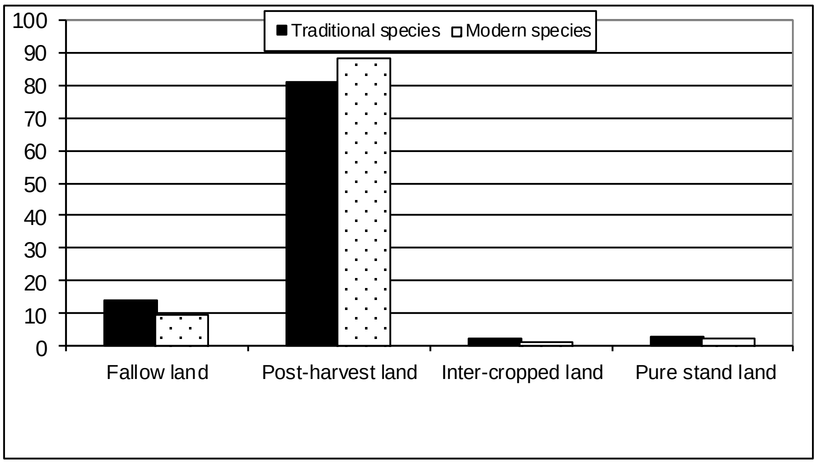
However, over time, the formal sources may give way to the persistent informal practice of recycling seed as farmers learn to domesticate the new varieties. As the next sections will show, this implies that farmers try or experiment with many different varieties/clones of sweet potato and retain those with desirable characteristics. These include: yields in terms of quantity and size of tubers, maturity in terms of early and/or late maturing, cooking qualities such as white-fleshed or yellow-fleshed colour, duration of cooking, water content, taste and palatability. The time it takes the crop variety to mature becomes important because sweet potato, like cassava, is stored in the soil and conserved for a long time. As it emerged from the farmer focus group discussions, there are several methods of maintaining the crop genetic resource throughout the year. For instance, the crop may be left in the ground, in moist areas of the farm, especially banana fields or in pots. The most successful methods of conserving planting material involved farmers who planted the crop in moist parts of their farms, including swamps.

5.6.2 Planting, Weeding and Harvesting

As we noted earlier, at 0.28 acres, sweet potato occupies the smallest area of the farm (with total farm size averaging 2.5 acres in the study area). This raises the issue of the type of land on which sweet potato is planted. Is it for instance, planted on land left fallow or land immediately left after harvesting, or land in which it is inter-cropped, or simply planted on virgin land? Figure 5.4 below shows that more than 80% of traditional and modern species of sweet potatoes were planted on post-harvest land, while only around 10% of the crop was planted on land left fallow. Sweet potato is seldom inter-cropped or planted on virgin land in the study area. This shows that planting of sweet potato fits into the local cropping system that is sensitive to availability of moisture and family labour (especially women's labour) amid farmers' production priorities. For instance, maize and beans are considered important food crops but also critical in terms of their moisture requirements and the narrow range of days during the planting period.

Farmer focus group discussions also revealed that the existing land-use patterns placed sweet potato after maize, sorghum, beans and cassava because these other crops are sensitive to available moisture and labour. Consequently, the available land and labour will first be allocated to planting maize and beans and then sorghum before attention was diverted to other crops such as cassava and sweet potato. Maize, beans and sorghum are often planted immediately before the onset of the long rains in February/March. Farmers plant sweet potato at least over three periods: (i) early planting (April-May); (ii) mid planting (May-June) and; (iii) late planting (September-October).

Figure 5.4
Distribution of planting methods by species (adjusted %)



Source: Field data

About 51% and 54% of the traditional and modern species of sweet potato respectively are planted in mid period (May-June). Early planting (April-May) and late planting (September-October) account for around 36% and 10-15% respectively.

During farmer focused group discussions, we learned that apart from being less critical to moisture stress, cassava and sweet potato were considered food security crops with expected low external input use and low yields. There was also the issue of timing by ensuring availability of food sources from cassava and sweet potato from December to February. Another reason relates to the practice of recycling the planting material. This results in two months of waiting for the effect of long rains in March-April to spur adequate vegetative growth on the previous crop. In other words, sprouting of sweet potato vines coincides with the planting and first weeding of maize, beans and sorghum.

In May/June, sweet potatoes will have produced sufficient vines for planting. Depending on whether the variety/clone is early or late maturing, the crop planted in May/June will be ready for harvesting in September/October/November. The crop planted during the short rains of September/October, with the May/June crop as the source of planting material, will be harvested in January/February of the following year. This period is considered very dry; which means most of the sweet potato (above ground) foliage will be damaged. But with the onset of the long rains (March-April), the roots will sprout and develop into full vegetative cover by May/June for another mid-period crop. This pattern of planting is logical since it meets the labour and moisture constraints faced by farmers in the region. It also meets the household food security objectives of farmers over a relatively long period.

Closely related to the period of planting is the method of planting. Farmers in the study use two methods of planting sweet potato, namely on flat ground and mounds. There were several advantages and disadvantages cited by farmers for each planting method. For instance, some farmers reported that "planting on flat ground resulted in good and sustainable yields of roots and foliage. The method is also less susceptible to soil erosion compared to planting on mounds". For some farmers, planting on mounds had many advantages. These include "the ease of identifying roots, weeding and harvesting especially during dry weather. The method also increases air and water circulation which results in many and large sized tubers." However, it exposes the mounds to soil erosion and this reduces the root yields. The method also requires more labour, which is a serious constraint for the largely female sweet potato producers. Weeding of sweet potato is done in two stages. The first stage, which takes one month after planting, is done using a *jembe* (hoe). At this stage, precaution is taken to avoid disturbing the delicate vines. The second weeding is done by use of an iron rod to avoid damaging the root tubers. Key informant Mama Philystia explained, "This period is marked by vigorous vegetative growth, thus an iron rod is preferred to a *jembe* because pricking or 'trial-harvesting', which is done during this period, requires minimum disturbance to the roots" (interviewed on 20 November 2009).

The iron rod was the most common tool for weeding all species of sweet potato. The remaining methods are less used, with the traditional hoe more often employed for traditional than for modern species; the opposite being the case for the *jembe*. The iron rod is also used for piecemeal harvesting because it enables household food security over a long period while a *jembe* is often used for bulk harvesting.

We also found that 159 (or 99%) of the farmers in the study use piecemeal harvesting practice. There are at least three reasons given by farmers for the overwhelming use of piecemeal harvesting as opposed to bulk harvesting. The corresponding percentages of these reasons are as follows: food availability over a long period (78%), underground storage (30%), and on-farm conservation of planting material (11%). Indeed, piecemeal harvesting allows storage of the crop under the ground and ensures that farmers use the crop continuously for a long period. Apart from gender, age also plays an important role in piecemeal harvesting.

Key informant Mama Atieno said, "Although piecemeal harvesting is done by females, many young girls do not know how to harvest sweet potato by piecemeal method. As such they should not be allowed to do so" (22 November, 2009). Many farmers during focus group discussions and key informant interviews shared this view. The main reason given by farmers is that "because of attending school today, girls lack farming experience and are also impatient." Thus, they often damage or expose the tubers to sun and rodents – which reduce the yield and quality of tubers. The complex process of planting, weeding and harvesting in Bukhalalire community is best captured by the narrative of one key informant, Mama Phylistia (Box 5.2 below).

Box 5.2
Narrative of Mama Philystia

Mama Philystia lives in Bukhalalire sub-location of Butula division. Like most farmers in the study area, she grows sweet potato on any available land in mid period (May-June). Some farmers plant sweet potato in the late period on either post-harvest land, borrowed land or on land leased from other farmers. Many farmers in her area plant in different periods mainly to ensure food security and on-farm conservation of planting material. Mama Philystia points out that "planting of sweet potato in the area is considered a woman's task because men perceive it as a minor crop. This in turn affects family labour available for sweet potato production." She only remembers a few occasions where men helped women to make mounds for planting.

Mama Philystia plants in mid period (May-June) because during this period there is abundant labour. She further states that this time is preferred as sweet potatoes do not require too much rainfall, which affects the development of roots. Mama Philystia does not use inorganic fertilizers. She observes that fertiliser application in sweet potato is not a common practice here, due to lack of awareness "on our part because we just follow our traditional practices".

Like many farmers in the study, Mama Philystia uses the flat ground planting method because she considers it "more durable despite the fact that harvesting is often difficult in the absence of rainfall". She points out that "although harvesting is much easier on mounds, the mounds are easily eroded and this reduces root yields". Mama Philystia also weeds the sweet potato crop twice. She uses a *jembe* and an iron rod in the first and second weeding respectively but carefully considers the depth and direction of the tender vines to avoid damaging them. She prefers piecemeal harvesting as opposed to bulk harvesting because of its advantage in enhancing continuous supply of food.

Source: Author's compilation (2000)

5.6.3 Utilisation and Marketing

Farmer focus group discussions and key informant interviews reveal that current utilisation of sweet potato reflects the changing habits of people of western Kenya. Previously, sweet potato was eaten besides other foods, including a mixture with vegetable or served with groundnut sauce, simsim (sesame) paste, or fried white ants. It was indeed served in a diversified way.

Over time, other complementary foods such as indigenous vegetables, mushrooms, groundnut and simsim (sesame) have gradually been disappearing. Respondents stated: "Today, sweet potato is served without other foods and on a continuous basis. It is also increasingly being served as a 'snack' and not as the 'main meal'. This has led some farmers (especially men) to refer to sweet potato as children's food."

Sweet potato is considered a low priority food crop despite the fact that it is an important famine/hunger crop in western Kenya (Odame et al. 2003). The recent introduction of the new sweet potato varieties in western Kenya was supported by farmer training on on-farm conservation of planting material and alternative ways of utilising sweet potato. During focused group discussions, farmers identified a range of traditional and alternative ways of utilising sweet potato. The traditional methods were boiling/roasting, *'mushenye'* or food mixture, and drying; whereas alternative methods included serving sweet potato with a vegetable source, chips/crisps and baking.[14]

For the traditional species of potatoes, the traditional methods of utilisation (i.e. boiling/roasting and food mixture), are the most common (see Table 5.6). For the modern species, the alternative methods such as baking (38 %) or chips are as important as the traditional ones, especially boiling/roasting at 45%. This can be explained by the fact that there is heightened awareness in the farmer categories 1 and 2 of these alternative methods of utilising sweet potatoes.

Table 5.6
Processing and utilisation methods (by species, adjusted %)

Source/Species	Traditional species	Modern species
Boiling/roasting	89.4	45.4
Food mixture	6.4	3.6
Vegetable	0.2	5.6
Chips	1.4	7.2
Baking	2.6	38.2

Source: Field data

Apparently, many farmers in the first category who had received training on alternative ways of utilising sweet potato restricted this practice to baking *chapati* and *mandazi* for their families as opposed to commercializing it. There are at least two reasons given for this situation. Many farmers in the study lacked baking ingredients such as flour, baking powder, oil, etc. Second, the baked products faced low market prices owing to lack of awareness by the public as well as low priority attached to these products. Indeed, these products do not form a major diet of the older population. With their rapidly changing food habits, the likely target for such products is youth, especially school children. But this part of the population lacks income to purchase baked products. According to Mama Philystia, the crop has the least priority when it comes to marketing by farmers because it serves mainly as a food security crop. Table 5.7 shows that any marketing of sweet potato largely involved the raw state for both traditional and modern species of sweet potato. In contrast, marketing of cooked (boiled) sweet potato was higher in the traditional species as was baking in modern species.

Table 5.7
Proportion of marketing form by species (adjusted %)

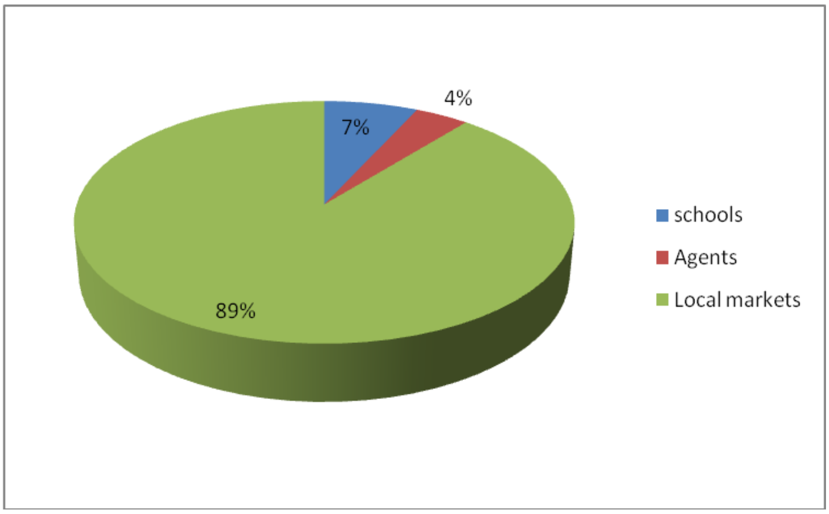
Source/Species	Traditional species	Modern species
Raw	77.8	68.8
Cooked	16.6	9
Chips/flour	0.2	0
Baked	5.4	22.2

Source: Field data

Regarding the methods of final distribution, the household survey summarised in Figure 5.5 shows that most marketed sweet potato crop was sold in the local markets (89%), agents or "middlemen" (7%) and schools (4%). Similar findings emerge from the survey of 27 local traders in six local markets in Butula division in June 2000. Of the 27 local traders interviewed, 22 (or 82%) were women and 5 (or 18%) were men. The 20 (or 91%) women traders marketed their own produced crop. Apart from only 2 women agents, the 5 male traders worked as agents at the local markets, thus buying the crop from farmers and selling it at the local markets.

In terms of market destinations, 24 (or 89%) respondents reported selling sweet potato in the raw form. Only 3 (or 11%) of the respondents sold sweet potato in the boiled form at the local schools.

Figure 5.5
Marketing destinations: Percentage share of marketing destinations



Source: Field data

5.6.4 Farmers' Preferred Sweet Potato Attributes

In view of the existing practices and constraints of producing and marketing sweet potato, we sought to find out from farmers their preferred characteristics for adjusting the sweet potato technology and its bridging institutions. The positive attitude of farmers in the study towards improved sweet potato innovation was impressive. Table 5.8 shows that 149 respondents (or 93%) were willing to accept improved (transgenic?) sweet potato varieties. Only 10 (or 6%) respondents reported their unwillingness to accept the new technology. This willingness is confirmed by the farmers' reactions towards others who had received and planted the improved (non-GM) planting materials of sweet potato. In particular, farmers in Bukhalalire community sought planting material from farmers in category 1 and some in category 2. Also, farmers in category 3 who had neither received new planting material nor received training were eager to learn more about the new technology.

Table 5.8
Acceptance of biotechnology-related sweet potato

	Percent
Willing to accept/buy	93.1
Not willing to accept/buy	6.3
Do not know	0.6

Source: Field data

In terms of preferences, farmers identified a range of technical characteristics regarding agronomic and consumer factors. The agronomic factors include root and foliage yields, virus and weevil resistance, and maturity in terms of early and late maturity. The consumer preference factors included colour in terms of white-fleshed or yellow-fleshed, taste, fibre, water content and duration of cooking. Field data shows that the yield of roots was the most preferred agronomic factor (for 87% of respondents) for accepting the new technology.

On institutional characteristics for supporting a new technology, Figure 5.5 shows that nearness or proximity to source of planting material is the most preferred characteristic at 66%. The percentages for the other characteristics are complementary services (18%) and previous relations (16%). These relational characteristics correspond to different organisations and cultures. Personal friendliness was characteristic of the neighbours as complementary services were characteristic of the farmers' training centre. Also, farmers identified previous relations as characteristic of community multiplication sites.

These farmers' views were, however, based on their recent experience with the introduction of improved (non GM) sweet potato varieties by CIP and KARI scientists in collaboration with the NGO, ARDAP and the local extension worker in the area. For instance, farmers in category 1 and 2 who had received planting material and/or training pointed out that they preferred ARDAP and then the Ministry of Agriculture extension workers in the provision of seed, farm inputs and extension service. One farmer suggested: "The most important and missing link for accepting new technologies is extension service to strengthen close relationships with farmers."

5.7 Capacity to Innovate

5.7.1 Research and Innovation

The motivation for this project was the potential to generate virus-resistant varieties to increase yields obtained by smallholder farmers. The innovation in sweet potato was driven by the availability of a technology and the scientific networks to back it. Thus, the research interests of scientists of Monsanto and KARI and the funding priorities of ABSP influenced the agenda of the project.

The innovative aspects of transgenic sweet potato technology in research and education domain include PPPs, high costs of research, and legal and regulations frameworks. However, in the extension and utilization/marketing domains, the technology would be characterised by challenges of adapting it to diverse agro-ecological conditions, which in turn influence the farmers' preference and use for particular sweet potato clones (Odame 2002b).

The downstream research and extension activities require money and time amidst declining public funding. There are also problems of determining whether the desired local germplasm will work bearing in mind that virus disease in sweet potatoes is a combination of at least three common viruses. Among them is the Sweet Potato Feathery Mottle Virus (SPFMV). This raises the issue of whether a single gene CPT560 can control the complex SPVD in the long run. Also, aphids and weevils transmit viruses and so far there are no biological ways of controlling weevils.

According to sources at CIP in Nairobi, "… for this innovation to be successful, there is need to introduce CPT560 in to a minimum of two preferred sweet potato varieties in every ecological zone." The basis for the introduction would be preferred agronomic and consumer characteristics. Upon generating an appropriate technology, it would still have to be diffused to farmers.

5.7.2 Bridging Institutions

The test-case project under the Agricultural Research Competitive Grant attempted to link with NGOs and farmer groups in western Kenya. But this process faced several constraints. First, the farmers' reluctance to own on-farm research trials. Farmers used different treatments on their own plots against the initial research instructions of managing on-farm trials of improved (no-GM) 'test' sweet potato varieties. Second, some farmers harvested and 'ate' the experimental crop, largely due to the late arrival of the research team to visit and take measurements. Third, following four seasons of testing different clones of sweet potato, farmers said that they wanted to move on. Fourth, most farmers persisted in their traditional practice of conserving and re-using planting materials. These findings show that change is a slow process that requires effective communication and closer interaction to build trust. Also, sustainable use of improved planting materials will increase when farmers see tangible benefits.

5.7.3 Business and Enterprise

Until recently, sweet potato was considered a low priority household crop in western Kenya in terms of the use of available land, women's labour and external farm inputs. Other constraints cited by farmers include moles, processing equipment and product markets. However, the destruction of cassava by the African Cassava Mosaic Virus (ACMV) and the droughts in the area motivated farmers' to increase the area under sweet potato. This raises the issue of whether the current importance of sweet potato will continue as the full production of cassava resumes following the availability of mosaic virus-free cassava planting material in the area. Also, apart from traditional methods of boiling and making food mixtures (or *mushenye*), most farmers in the area were not aware of improved methods of utilizing sweet potato.

KARI scientists promoted the technology as a solution to the problem of food security and poverty in Kenya. Besides its potential for high yields, the cost of transgenic sweet potato planting material would become insignificant. This would make the technology more accessible to poor farmers. Furthermore, sweet potato is transplanted by vines; they are easy to transport and to use. Thus, the technology was considered compatible with existing production practice.

During the implementation of the Agricultural Research Competitive Grant project as a test case for transgenic sweet potato, CIP and KARI scientists tried to establish relations with NGOs and farmers' groups in the delivery of improved sweet potato varieties. But there were weak (or no) linkages to the private sector especially the local traders. The small-scale traders of raw or cooked or baked sweet potato provide an important link between local production and marketing. The availability of marketing opportunities for sweet potato is likely to stimulate production through increased adoption of high yielding and virus-resistant varieties such as CPT560. This would stimulate farmers who produce improved planting materials to expand the area or production for sale. It may also allow other producers to enter into commercial production of planting materials. To maximize yields, farmers would have to change the timing of production practices. With increased yields, the harvesting would shift from piecemeal to bulk harvesting. Thus, an early recognition of these issues by KARI scientists may have led to some convergence of the priorities of scientists, farmers and intermediaries.

5.7.4 Policy and Institutions

The transgenic sweet potato project sought to establish policy and regulatory frameworks for capacity building and international transfer of modern technologies to Kenya. There are several areas of capacity building in agricultural biotechnology in which the transgenic sweet potato project has made initial contribution. For instance, through ABSP, the project carried out capacity training of PhDs, post-docs and many short course participants on the transformation systems and biosafety procedures for KARI scientists. It supported the upgrading of scientific infrastructure, especially laboratory facilities, for technology testing. At the same time, the project indicated that inadequate human capacity, specifically molecular scientists, delayed the National Biosafety Committee (NBC) to approve importation of transgenic sweet potato material into the country. Furthermore, the IPR issues resulted in the need for organizational change from predominantly public sector research to private sector or public-private partnerships (PPPs). On legal and regulatory capacity building, the project contributed to the formulation of Biosafety regulations and stimulated debates on IPR issues in Kenya. In particular, ABSP and Monsanto insisted that KARI establishes a minimum containment laboratory as an international requirement before importing transgenic sweet potato plantlets for testing. This meant that KARI researchers could extend the gained knowledge, skills and experience to other agricultural biotechnology applications.

At the individual level, the project enhanced the career opportunities of many KARI scientists through overseas trips to attend conferences and getting international jobs and recognition. The training was limited to a few scientists which raised the issue of how the project would contribute to Kenya's long-term plan to produce adequate human resource capacity to successfully carry out modern biotechnology R&D. With respect to IPRs, transgenic sweet potato is not patented. It was also provided royalty-free as a public good (Odhiambo 2000). The implications of IPRs for the donated technologies will be via Plant Breeders Rights (PBRs) granted to KARI.

As noted in Chapter 3, PBRs in Kenya fall under UPOV Convention. The convention does not include farmers; it rather encourages commercialization and privatization of plant breeding. There are views that this trend has potential to lead to uniformity and genetic erosion of sweet potato. The introduction of transgenic sweet potato to small-scale farmers may also increase the time they spend to access planting material. However, farmers would access and eventually domesticate the new transgenic sweep poatato (tsp) varieties. Thus, it is evident that without significant change in how the tsp is perceived and received by farmers, the existing cultural practices of selecting planting stock, producing and utilizing of the sweet potato will persist.

5.7.5 Coordination and Linkages

Through ABSP's coordination, the transgenic sweet potato project was one of the few examples of private-public partnerships (PPPs) in modern biotechnology transfer to sub-Saharan Africa. Public goods research and weak linkages with local entrepreneurs were characteristic of KARI, whereas Monsanto was characterized by private research underpinned by IPRs and other interests. The partnership between the two organizations enabled them begin learning how to balance public and private research interests. But the partnership was largely limited to upstream research and is yet to be extended to the downstream extension and farmer networks. On research priorities, one question often asked is why Monsanto chose to go with sweet potato, given that it is a minor crop. Was Monsanto using the crop as a market opener for their other commercial transgenic crops in Kenya and elsewhere in Africa? Irrespective of Monsanto's motivation, the project opened the debate on coordinating public and private interests in agricultural biotechnology to meet needs of smallholder farmers.

5.8 Conclusion

This chapter has attempted to show that transgenic sweet potato offers potential benefits to smallholders, especially poor women farmers in Kenya. Unlike traditional and conventional plant breeding methods, it increases crop productivity by generating sweet potato varieties that are resistant to feathery mottle virus. But the project faced several challenges that it has to respond to in order to transform it into appropriate and profitable transgenic sweet potato varieties for farmers and consumers.

Firstly, the project has increased the capacity of KARI scientists in the technical aspect of the technology as well as in biosafety evaluation and IPRs. Secondly, it is one of the few examples of private-public partnerships in modern biotechnology transfer to sub-Saharan Africa. However, the partnership has been limited to upstream research networks, and not yet extended to the downstream actor networks. This implies that the project will rely on the traditional ways of distributing planting materials, translating knowledge and marketing of the product. The distribution of planting stock is organised on the basis of free exchange. The introduction of transgenic sweet potato may initially alter the existing delivery system of planting stock. This may imply increased transaction costs in terms of travel and waiting time for farmers to collect the initial planting stock. In addition, once some farmers have acquired the initial planting stock, others are likely to access it cheaply or even freely through the existing cultural practice of free exchange of vines.

Thirdly, the project has contributed to the contemporary state of Kenya's agricultural biotechnology, especially IPRs and biosafety regulations. For instance, the project enabled KARI to sign a non-exclusive royalty-free licensing agreement with Monsanto. The agreement allows KARI both to use the technology by and to share it with other African countries in the future. The KARI researchers may need to undertake further transformation of popular Kenyan varieties for resistance to

FMV and other related viruses, and/or develop several clones to meet the diverse tastes and preferences of sweet potato producers and consumers. Under such circumstances, KARI is also allowed to protect the transgenic varieties under the plant breeders' rights. This raises the question of future implications for access to transgenic sweet potato and other donated biotechnologies for both researchers and farmers (Cullet 2001).

In addition, the project contributed to the formulation of Biosafety Guidelines. The initial guidelines were used to review and approve the application for the introduction of transgenic sweet potato, Bt maize, Bt cotton, etc. for research in Kenya. This process led to the enactment of the Biosafety Act 2009. In the view of some critics, KARI was used by the industry, especially Monsanto, to promote GM into Kenya and other markets in Africa. At the same time, NCST and NBC lack the capacity to implement Biosafety regulations. For instance, the approval by NBC of importation of transgenic sweet potato for KARI to carry out trials in the country took more than two years. This problem was caused by delays in the formulation of Biosafety Guidelines and shortage of qualified molecular scientists. As it is discussed in the synthesis and concluding chapter, this situation raises the issue of institutional capacity to manage potential risks at the farm level, as efforts are made to facilitate the transfer of biotechnology products from research locations to farmers' fields following the gazetting of Biosafety Regulations (Ikiara 2004).

However, there are important lessons learned from this case study. Transgenic, virus-resistant sweet potato variety was developed in the early 2000s for deployment in Africa, but it was never released. The reasons for this are known to the project staff but not available to researchers outside the project, and the public. This study made several written and verbal requests to KARI Biotechnology Centre, which is responsible for the project, but there was initial reluctance to provide results on the basis that they were not yet known in 2000/2001.

In the intervening years (2005-2010), unconfirmed reports have emerged that the new strain performed badly in field trials because it is difficult to sustainably address a virus-resistance trait with genetic strategies given that plant viruses mutate quickly and resistance may be short-lived. Based on an interview in this study conducted in April 2010 with a project staff (who preferred to remain anonymous because he is not authorised to speak for the project), transgenic lines performed poorer than the non-transgenic (control) lines in terms of root and vine yield when taken to the field for virus challenge. He attributed this situation to various factors including:

- Having done most of the work at the Monsanto laboratory in the US, the scientists never used Kenyan constructs (viruses) and instead worked with the US constructs which are totally different from the Kenyan type. This shows the importance of local context.
- The virus undergoes rapid mutation so that during the time taken for the construct to be brought and utilised in Kenya, mutation could have already taken place thus conferring susceptibility.
- The new virus could have worked in synergy with the local viruses bringing about susceptibility.
- The main lesson learnt is that the scientists working on the transgenic sweet potato project would have been better off doing the work in Kenya and using Kenyan constructs for manipulation in the laboratory and released the transformed lines in the Kenyan fields for virus challenge trials.
- The future prospect of the technology is to produce tangible results that will benefit the small-scale farmer. Work is being done on RNA silencing and it is hoped that this work will bring about tangible results.

In conclusion, there were technical obstacles to develop transgenic sweet potato varieties that are resistant to viruses. This problem was exacerbated by differences in the needs, capacities and priorities of smallholder farmers and those of researchers in the transgenic sweet potato project. The scientists focused on producing virus/disease resistant sweet potato varieties aimed at increasing yields obtained by farmers, while farmers needed interventions in product utilisation and marketing. This means that despite the technical obstacles of the technology, the approach may result in inappropriate or unprofitable innovations for smallholders unless significant changes in policy and institutions are made to effectively engage farmers in the on-farm trials and technology delivery, and product processing and marketing.

Notes

[1] In Kenya, many of the modern biotechnology products, including transgenic sweet potato, Bt. maize, Bt cotton and genetically-engineered livestock vaccines, are yet to be used by farmers (See, for example, Chapter 4).

[2] According to Qaim (1999: V) "…Orphan commodities refer to technologies developed by the industry to address problems of resource-poor farmers."

[3] The primary centre of genetic diversity is Central America

[4] China has realized a yield of 18 tha^{-1} (Hinchee 1998). >Accessed on on 28th October 2013 from http://www.ids.ac.uk

[5] See also www.nepadast .org opened on 26th January 2013

[6] http://www.ielrc.org/content/a0107.pdf, accessed on 15th July 2012

[7] This is one of 5 bodies that carry out publicly funded R&D in the UK.

[8] This is one of 5 bodies that carry out publicly funded R&D in the UK.

[9] See, for example, Senker (1998)

[10] See also Byerlee (2002)

[11] See also Kingiri and Hall van Vliet (2012)

[12] See, for example, BIOEARN (2001)

[13] The specific objectives of the virus resistant sweet potato programme were: (i) to develop transformed Kenyan sweet potato varieties with resistance to Sweet Potato Feathery Mottle Virus (SPFMV) at Monsanto and to transfer these to Kenya, (ii) to train KARI scientists and technical staff in all aspects of technology, including biosafety evaluation and Intellectual Property Rights (IPRs) and (iii) to evaluate and improve production of transgenic sweet potato in Kenya (KARI 2000).

[14] This includes: chapati, mandazi or doughnuts, and cakes.

6 Examples of Biotechnology Innovations at Farm level: Tissue Culture Banana and StrigAway Maize

6.1 Introduction

Examples of biotechnology applications that have successfully reached farm level are few in Kenya. For any agricultural innovation to be successful, a holistic approach to technology development and deployment is required (Clark 1995). Through this approach, the farmers' needs are addressed through interactions and linkages with various institutions instead of top-down system. Equally important is the coordination of linkages within the system to ensure all key actors work towards achieving a common goal, appreciate the learning process and respond to the feedback from other stakeholders.

This chapter uses secondary literature and key informant interviews to review the introduction of Tissue Culture (TC) Banana and StrigAway Maize biotechnologies to smallholder farmers in Kenya. The review shows that the two projects were not just about developing biotechnology, but about interactive learning processes of bringing together scientific and local knowledge on production of bananas and maize. Also, unlike the case studies in the previous two chapters (i.e. original *Rhizobium* inocula in Chapter 4 and transgenic sweet potato in Chapter 5), the TC Banana and StrigAway Maize initiatives in this chapter are rare examples of using biotechnology to address low production of smallholder farmers in Kenya. Examining how the two case studies evolved in terms of successes and challenges provides insights into pro-poor biotechnology innovation processes.

First, the chapter highlights the initial problems and the subsequent challenges addressed by the two projects and the actors and their roles in technology development and deployment. Second, it analyses the technology package requirement versus resources available to the farmer. The analysis employs the innovation systems (IS) approach by discussing learning between farmers and other stakeholders. Third, in conclusion, the chapter highlights key lessons learned from the two case studies.

6.2 Tissue Culture Banana

6.2.1 Problem addressed

Banana production systems can be classified into three sub-systems: backyard garden system, subsistence, and commercial/plantation system. The backyard system is practised in peri-urban areas and has close proximity to the family house. Production here is mainly limited by small land size. It is characterised by low input use and minimal crop management. Consequently, there are high incidences of pest and disease infestation. The main motivation for this banana production system is to supplement food sources. Apart from being an important source of food for the rural and urban people, banana is a key income source for smallholder farmers.

The subsistence system accounts for more than 87% of global banana production. It is mainly practised by rural dwellers and production is done on small pieces of land (0.25-5ha). In Kenya, holdings of less than 0.5 hectares contribute 83.5% of banana production (Acharya and Mackey 2008). Like the backyard system, it is characterised by low input use and high incidences of pests and diseases. This problem is exacerbated by land degradation caused by population pressure on land. Production takes place mainly for food security. There is variability in variety and quantity produced between households due to different soils, management skills, pest and disease control and utilisations of the banana.

Picture 3: TC banana plants and mature bunch

In the plantation system, there is intensive management throughout the value chain, which results in high yields (40-60 t/ha). Unlike other production systems, there is only one cultivar grown per farm and uniformity in management. However, the plantation system is uncommon in East Africa (INIBAP 2005).

In the early 1990s, banana production in Kenya declined significantly. The decline in output was partly associated with panama disease, black and yellow Sigatoka disease, infestation by pests especially weevils and nematodes (Acharya and Mackey 2008), and environmental degradation such as declining soil fertility. AATF (2008) also associates disease spread to: vectors (insects, birds, bats, grazing); infected tools (paring, pruning, de-trashing, leaf and bunch harvest); and infected planting materials and tools of the trade (latent, wrapping). Declining yields have also been blamed on farmers' poor agronomic practices such as minimum mulching, minimum pruning, wrong spacing, sourcing planting materials from older stools and failure to renew stools for improved yields (INIBAP 2005).

The traditional practice of propagating bananas entails the use of banana suckers as planting material. This practice aggravates the spread of pests and diseases. This resulted in a significant reduction of banana yields estimated at about 90%. From 1992 to 1994, the yields of bananas in Kenya dropped from an average of 12.8 tonnes to 9.9 tonnes per hectare (Acharya and Mackey 2008). Around the same period and until the mid-1990s, banana acreage and production experienced a major setback, mainly due to high incidence of diseases and non-availability of disease-free planting material.

In addition to declining yields, incomes realised from banana sales are significantly below the potential due to poor quality of post-harvest products (poor handling and processing) and socio-economic problems such as market access and management costs. The problem of low yields is perpetuated by cultural farmer practices such as procuring suckers from other farms where plants are already diseased or attacked by pests. This practice is common among farmers either due to poor access to clean planting materials or because such suckers are affordable and in other cases given for free.

Suggestions to address the problem of low banana yields include use of resistant varieties, disinfection of tools, uprooting/cutting and burying/burning diseased plant/materials, timely and proper use of healthy suckers, good crop husbandry (e.g. chemical control), irrigation, pruning and scouting for disease or pest infestation. Unfortunately, attempts to manage disease and pest infestation faced the following challenges: commercial resistant varieties were not readily available to banana producers, tools disinfection was poorly applied, there was continued planting of diseased and/or pest-infested suckers, and poor crop husbandry continued to reign. Consequently, the low yields led to increases in banana prices making it expensive for poor consumers and traders who derive their food and income from bananas. Through provision of improved TC banana planting material, both acreage and production of banana increased.

6.2.2 Evolving Partnerships

In its efforts to deploy the TC banana technology to farmers' fields, ISAAA encountered challenges which could only be addressed through partnerships with both public and private sectors (see Table 6.1). For instance, during the first phase of technology deployment, ISAAA realised that farmers faced financial constraints to acquire the TC banana plantlets. To overcome this challenge, ISAAA partnered with a local micro-finance scheme (K-rep) for credit services to farmers.

Technoserve, a US-based NGO with offices in Kenya, observed that banana had a long supply chain. At the lower level, most farmers are small scale and have limited market information and demand-driven value addition. Price negotiations are based on the size and type, and due to perishability of bananas, producers are forced to sell their output at low prices. Also due to poor infrastructure, 80% of all banana transported to markets is wasted. This is partly attributed to poor roads, lack of equipment like storage and ripening facilities and poor means of marketing the banana crop (Technoserve 2007). This constraint raised the need for organised marketing channels. ISAAA collaborated with Kenya Agricultural Commodity Exchange (KACE) to facilitate linkages between farmer and output markets. With time, KACE faced capacity problems which led to increased transaction costs, forcing ISAAA and KACE to rethink other ways of reducing transaction costs.

Table 6.1
Actors and their roles in TC banana

Objective	Key actors	Roles	Remarks
Coordination	ISAAA, MTF	Seeking funding and coordinating linkages by ISAAA.	ISAAA had limited capacity to manage complex networks.
TC Production	Genetic Technology International Labs (GTL), JKUAT	TC banana production, extension training in nursery management.	Source of some poor or diseased planting material.
Strategic/ adaptive research	KARI, ISAAA, Farmer groups (FGs)	On-station and on-farm trials and feedback.	Infrastructure & incentives required.
Distribution	KARI, ISAAA, FGs	Channels: individuals and farmer groups.	Challenges of group dynamics.
Micro-credit	K-rep	Provide micro-credit for purchase of TC banana planting material.	The credit recovery failed due to mismatch with the banana production calendar.
Linkages with farmers	KARI, ISAAA, Commodity Interest Group (CIGs)	Needs assessment, technology-needs matching, procurement and distribution, demos & micro-credit.	Required participation, access to affordable credit for seed purchase, and product market.
Marketing/selling of products	KARI, ISAAA, KACE, farmer groups (FGs)	Market research, provision of ripening equipment and training on value addition.	Weak market linkages, packaging & standards, KACE lacked capacity.
Expansion of options (indirect benefits)	Micro-entrepreneurs, NGO's, K-rep	Manure business, micro-irrigation, dairy raising, etc.	Incentives required for private investment. Spanning boundaries.
Technical backstopping[1]	KARI, MoA/ extension service – coordinated by ISAAA.	Appropriate field management packages, commercialization strategy, disease diagnostics & training.	Public-private collaboration, networking & experience-sharing required.

Source: Author's compilation

The Kenyan TC banana project is considered an exemplary innovation partly because it has adopted an all-inclusive approach (involving farmers, research institutes, and private sector) in technology development, dissemination and evaluation. The project has evolved and now integrates all players in the banana value chain: from the provision of seeds (plantlets) to the production in farmers' fields and all the way to the final marketing when consumers purchase a finished product (Acharya and Mackay 2008). The 'whole value chain' strategy developed and perfected by Africa Harvest has acted as a model for introduction of new technologies for resource-poor small-scale farmers. This approach may ensure a wider adoption of biotechnology.

6.2.3 Technology Requirements versus Farmer Resources and Practices

Plant tissue culture technique involves culturing of plant tissues to eliminate diseases and pests which results in disease-free planting material available to farmers for the propagation of new crops. The sterile operational nature of the TC procedure excludes fungi, bacteria and pests from the production system hence diseases and pests cannot be transmitted through the TC micro-propagation system. However, most farmers are resource-poor and the cost of the TC plants of US $ 0.8-1.2 per plantlet is way above that of the traditional varieties (at US $ 0.3) per plantlet. Literature informs us that most farmers are not able to purchase sufficient quantity to break even. On average, a farmer buys 8-10 plants but to break even, she requires 0.25 Ha of land planted with 80 stems (Qaim 1999, Wambugu and Kiome 2001). Consequently, the potential impact of TC banana on poverty alleviation is yet to be realised.

TC banana technology package is inclusive of additional inputs (fertilizer, manure, water and labour) and informed management. However, many farmers buy the TC plantlets and do not necessarily practise the recommended crop husbandry resulting in lower yields. The inability of farmers to adopt the entire technology package was associated with poor access to rural credit and lack of technical information on production of TC banana. In other regions of the world, low adoption of TC banana technology has been associated with the high number of tender plantlets requiring intensive labour, of which may not be at an individual farmer's disposal.[2] This calls for institutionalisation of community satellite nurseries for hardening of the young and tender plantlets which can then be sold to farmers to transfer into their fields.

6.2.4 TC Banana Successes

The project is considered successful for the following reasons:

- Since its inception in 1998, the TC banana project has had a high farmer adoption rate, with 15% adoption rate in the first year. Over 500,000 smallholders in Kenya derive their livelihoods from production and marketing of TC banana.
- Availability of disease and pest-free planting materials.
- Observed higher annual yield (40-60 tonnes/Ha).
- TC bananas mature in a uniform manner and within a period of nine months. Uniformity and simultaneous 'plantation' development promises easier marketing and coordination of the whole production process.
- Ease of introducing and disseminating superior germplasm through institutional partners.
- New job opportunities for people engaging in banana production. TC banana increased small-scale farmer incomes.

Research trials indicate significant yield benefits of TC banana technology over the traditional use of suckers. However, a rigorous evaluation of impact TC banana on farmers' fields is yet to be conducted (Nassul 2011[3].

The evolving benefits derived through ISAAA brokerage are:

- Fostering of interactive learning among farmers, where knowledge on banana production and farming in general is shared.
- Facilitation of linkages of banana farmers to produce markets while supporting farmer associations.
- The organisation also builds capacity of farmers on post-harvest management. The organisation trains farmers' groups who in turn train their members to enhance adoption of TC technology.

6.2.5 Challenges in Technology Development and Deployment

Since the enactment of post-SAPs recommendations[4] in the mid-1980s, resource mobilisation for agricultural technology development and deployment has been a great impediment to the success of the technology system. Government funding reduced significantly while donor-funded projects have been increasing gradually over the years (Beynon et al. 1998). In addition, the Kenyan government has paid much attention to export cash crops such as coffee and tea at the expense of food crops like the banana, yet such food crops could feed the rural communities and generate sustainable income from domestic and export markets.

The TC banana project has not fully achieved its goal of reverting declining banana yield due to a number of reasons. First, baseline studies have revealed that farmers' socio-economic conditions affect technology adoption. They include financial constraints, land constraints, farmer habits and practices, marketing constraints and little value addition activities. Some farmers have not adopted the technology holistically. This means that they buy the TC plantlets but maintain their poor management practices on banana fields (including, minimal mulching, irrigation, pruning and manuring), leading to yields below the potential.

The supply of TC plantlets has also been found inadequate. Along with insufficient supply is the high price of a plantlet relative to farmers' own suckers which are freely sourced from their own farm or borrowed. Moreover, the plantlets require very good care while on transit and while transplanting to the main farm. Farmers have resorted to their old ways of sourcing planting materials from older stools and from neighbours – which increases disease spread.

The markets for planting materials are poorly developed, which explains the poor distribution of TC plantlets. This is partly due to lack of a commercialisation strategy by public institutions involved in development of technology and also because of poor linkages with agents in the supply chain (Smale and de Groote 2003).

TC banana stools should be renewed at an interval of 5 years to maintain crop yields. But farmers rarely renew stools; a practice common even among TC banana adopters. This practice could be attributed to both ignorance, limited technical information and weak support from technology suppliers. Further, TC bananas mature evenly and the early adopters are faced with marketing problems. In particular, the yield increase from wider adoption of TC banana technology led to oversupply, and some farmers suffered substantial post-harvest losses. Consequently, there was a significant reduction in prices, poor marketing and utilisation strategies and exploitation by middlemen.

6.2.6 Innovation Capacity in the TC Banana Project

Smale and Groote (2003) suggest that pro-poor biotechnologies should tackle economically important constraints to production, such as input costs, which have not been properly addressed. Such innovations should also minimize risks in terms of international market access and promote the welfare of the small-scale farmers. The emerging issues in technology development and deployment will therefore be based on the impact it will have on production, marketing and institutional linkages.

A study by African Agricultural Technology Foundation (AATF) revealed that some farmers neglect TC banana technology because the plantlets supplied initially performed poorly. This calls for better service delivery and raises the need for greater interaction between public institutions and technology developers for validation and certification of varieties to ensure distribution of quality plantlets to farmers.

To enhance effective TC technology dissemination and adoption; extension, training and marketing should be coordinated. The coordinating body(ies) could adopt an approach where the need is first identified then farmer capacity built to facilitate their linkages to market. Building the capacity of farmers may include raising their levels of awareness to gain access and adopt technology through closer collaboration with technology developers, distributing agents and government regulating bodies such as Kenya Plant Health Inspectorate Service (KEPHIS). Equally important innovation is the establishment of community "satellite" nurseries and demonstration plots by involving farmers and/or farmer groups. The above objectives will be realised through increased knowledge learning and sharing and when farmers feel that they own the technology.

Stakeholders in TC banana must also engage the government to set policies to support banana as an industry in Kenya. It was recommended by the stakeholder forum that banana associations should be set up to govern banana as an industry just like other cash crops in Kenya. It was argued that this will also enable banana farmers to start receiving support from the government. To meet the ever-increasing demand for TC banana among small-scale farmers, the stakeholders also suggested the need for the technology brokers to enter into an agreement with technology developers and set conditions (viz. quantities and the recommended retail price) under which TC plantlets will be received.[5]

On banana value addition, Africa Harvest, among other actors, provided an ambitious training programme that focused on enhancing banana farmers' marketing and value-addition skills. This aimed to reduce post harvest losses and increase farmer incomes through the highly priced value-added banana products. To jumpstart banana crop as an industry, the government must look at all bottlenecks and adopt a holistic approach to build a credible banana innovation system. In particular, it must be willing to subsidize the technology by offering TC banana plantlets at reduced costs to spur high adoption rates. However, the above recommendations will be effective only when all stakeholders perceive the banana as a potential commodity (that can be commercialized).

6.3 StrigAway Maize Initiative

6.3.1 The Striga Problem

Striga is a parasitic weed that destroys cereal crops like maize, millet, sorghum, upland rice, and sugarcane with greatest losses occurring in the maize crop. Depletion of soil fertility due to continuous cropping as a result of increasing population density is one of the major causes of the spread of the weed (Gitau et al. 2006). Striga affects growth and development by attaching itself to a plant and feeds on sugars, minerals, nutrients and moistures of its hosts. Striga also releases phytotoxic elements that makes leaves change colour from yellow to bronze. This leads to loss of all crops under worse environments. One striga plant produces many small seeds that are integrated into the soil in the process of ploughing but may however stay latent for a long period of time (years). It has diverse and long lasting effects, causing food insecurity in thousands of households.

Maize is one of the most affected crops in Africa. It is the most important staple food that accounts for almost 40% of all cereal production. However, its average yields are less than 1.5 tonnes per hectare, compared with more than 8 tonnes per hectare in industrialised countries.

According to Manyong et al. (2008)[6], the constraints against increasing maize output include the striga weed, the maize stalk borer, storage insects, little and unpredictable rainfall, low productivity levels from the soil and scanty use of input. The striga weed has been classified as the major constraint to maize production in terms of its impact on yields and management of its spread (also see Woolmer and Omare 2005)[7]

Picture 4: The field shows striga-infested maize, StrigAway maize seed and clean field

In Kenya, Striga infestation is more pronounced in the Western part of the country where it is present on an estimated 210,000 hectares of maize farmland (AATF, 2006). Production loss due to destruction by Striga varies from twenty to eighty per cent per field subsequently leading to overall losses of approximately 300,000 tonnes of maize (and estimated Kshs800 million) per year (Manyong et al. 2008) (see Table 6.4). But low yields have also been associated with existing farmer agronomic practices which include inefficiencies in resource use.[8]

Table 6.2
Impact of Striga infestation on maize yields

Level of striga infestation	Nyanza Yield (Kgs/Ha)	Western Kenya Yield (Kgs/Ha)
Low Striga	1,482	1,788
Moderate Striga	750	891
High Striga	317	425

Source: Compiled by author from Manyong et al. (2008)

In an effort to overcome the adverse effects of Striga infestation, the Striga eradication initiative came into effect in 2006, bringing together stakeholders in developing 'best-bet' Striga control practices. The StrigAway PPP initiative was established out of the need to overcome risks in production, input supply, food insecurity and diminishing rural incomes. The PPP was motivated by three main drivers: first, the need to devise an effective technology of controlling Striga given that other conventional methods of Striga control seemed less effective; second, the need to develop a technological package that would not only suppress Striga but also lead to yield increases, and thirdly the need to involve private sector participation due to the envisaged potential for profitable investments in seed supply.

The benefits to accrue to beneficiaries were estimated in terms of: total acreage under Imazapyr-Resistant (IR) maize, level of Striga suppression, yield and productivity increases, increased awareness of effective methods of Striga management, and returns on investments by seed companies and farm input suppliers (AATF 2006). Of the tested Striga management practices, the IR maize demonstrated the highest maize yields and largest Striga suppression.[9] The IR maize technology involves herbicide coated maize seed which provide chemical protection against Striga infestation. The IR maize technology is marketed as StrigAway® (Manyong et al. 2008).

6.3.2 Partnerships and Cascading Innovation

The International Maize and Wheat Improvement Centre (CIMMYT) and the Weizmann Institute of Science in Israel in collaboration with Kenya Agricultural Research Institute (KARI) carried out intensive research on Striga and came up with the StrigAway Technology (see Table 6.3). The Rockefeller Foundation funded the research carried out by CIMMYT, Weizmann Institute and KARI. BASF, a multinational producer and supplier of chemicals, provided the initial germplasm for research. The African Agricultural Technology Foundation (AATF) funded extensive on-farm demonstrations and courses that played a role in increasing awareness of about thirteen thousand farmers in western Kenya. It also monitored the utilisation and performance of StrigAway maize among farmers. Under the coordination of AATF, Western Regional Alliance for Technology Evaluation (We RATE), KARI, the Tropical Soil Biology and Fertility Institute of CIAT (TBSF-CIAT), Maseno University and Moi University carried out field demonstrations with farmers.

Table 6.3
Partnership and cascading innovation

Objective	Institution(s)	Indicators	Output
StrigAway Technology Development	CIMMTY, KARI & Weizmann Institute of Science in Israel, BASF	Research in striga & StrigAway Technology.	StrigAway Technology.
Creation of Awareness & Demonstrations	AATF, We RATE, TBSF-CIAT, KARI, Maseno University and Moi University	Field & on-farm demonstrations, monitoring of utilization & performance.	Established over 13000 on-farm demonstrations, 505 tonnes of maize.
StrigAway maize production & distribution	Western Seed, Kenya Seed Company & Lagrotech	Certified StrigAway maize seed. Distribution of the StrigAway maize seed to stockists and farmers.	>60,000kg of StrigAway maize seed produced & distributed.
Monitoring & Evaluation	AATF	Assessment of compliance among farmers & stockists	Training workshops, feedback

Source: Author's compilation

Farmers established over 13,000 on-farm demonstrations plots and produced about 505 tonnes of maize. Western Seed, which is based in Kitale, produced about 60,000kg of certified StrigAway maize. NGOs such as WeRATE, SACRED AFRICA, SCOPD, TSBF and home-grown seed companies, through their distribution networks of agro-dealers and stockists, collaborated in disseminating the IR-Maize technology, facilitating farmer adoption of this technology and its incorporation into smallholder production practice.[10] AATF assessed compliance among farmers and stockists to product user instructions. It also facilitated training workshops for farmers and stockists and obtained feedback using the new technology.

The Forum for Organic Resource Management and Agricultural Technology (FORMAT) engaged eight other NGOs and farmer organisations (FOs) in combating Striga through agricultural information and communication. In addition, FORMAT produces and distributes Striga-suppressive legume seeds which are not readily available in the market (AATF 2006). Thus, the StrigAway initiative has embodied the entire value chain of maize. This has been achieved by incorporating relevant bodies and institutions at every level along the chain.

6.3.3 Technology Requirements versus Farmer Resources and Practices

Seeds of Striga are very small and easily dispersed via human shoes, digging tools and animals. These means of spreading Striga and the changing farming practices from shifting cultivation to more permanent cropping, attendant loss in soil fertility, and repeated growing of susceptible crops are the main causes of increased Striga infestation (Gitau et al. 2006).

There are three traditional methods of controlling Striga in Western Kenya: applying manure, uprooting of Striga plants, and burning dry Striga plants. Pulling out Striga plants is the most common practice (done by more than 80% of farmers) followed by application of manure while burning of Striga plants is uncommon. Striga affects growth of a plant in the soils before its germination. Thus, pulling out Striga after seed germination (say maize seed) would not prevent reduction of its (maize) yields. If uprooting of Striga plants is done consistently and before flowering, it will contribute to reduction of the Striga seed reserve in the soil. Unfortunately, uprooting of Striga plants is cumbersome and not consistently done by many farmers. Thus, it is not an efficient method of controlling Striga. Application of manure improves soil nutrients and spurs crop growth and health. A healthy and vigorously growing crop is more resistant to biotic and abiotic stresses. But application of manure in the soil does not reduce the Striga seed bank; hence it is not an efficient method of controlling Striga. Like uprooting, burning of dry Striga is equally an inefficient control method. Therefore, the traditional methods of controlling Striga are inefficient and unsustainable (IITA 2008). For this reason, several modern technologies are now available for Striga control. The most common technologies available to farmers in western Kenya include: the push-pull (or maize–Desmodium strip cropping), intercropping of the cereal with legumes followed by intercropped cassava with Desmodium, the Striga-resistant maize intercropped with legumes, and Striga-resistant maize, etc.

Farmers also intercrop the StrigAway maize with legumes like soya beans, lablab or groundnuts. The roots of these leguminous plants stimulate suicidal germination of the striga seed reserves in the soil and are uprooted before putting on seeds. This is the "push- pull" technology. Apart from uprooting and burning crop residues in the affected fields to destroy seeds that may have escaped, farmers also erect soil conservation structures which limit the flow of run-off from infested fields. They also restrict the movement of animals between infested areas and non-infested areas as collective measures of striga management. StrigAway maize is also dressed with fungicides (Thiram) and insecticide (Lindane) like all other formal maize seeds to protect them from fungal infection and insect infestation. Along with acquisition of StrigAway maize seed, other agronomic practices in farmer fields are also pertinent to the success of the technology.

6.3.4 The Success of StrigAway Technology

When compared with other technologies available for Striga control, adoption of StrigAway technology in Kenya has had a positive impact on maize yields. IR maize restores production of maize under Striga-infested conditions to normal standard levels while reducing the quantity of Striga seed in the soil. A study carried out by AATF in 2005/2006 on 108 farms for three seasons established yield improvement of 44% with a 70% Striga suppression[11] (AATF 2006). Other positive outcomes of this project include: rise in yields that have resulted in increased incomes and a reduction in cost of production. Woolmer and Savala (2007) estimated that yields have gone up from an average of one-half bag (40kgs) per acre in the uncontrolled Striga fields to 4-6 bags (480kgs) per acre in Striga controlled fields using IR maize. This implies that if the technology is adopted widely in all Striga affected areas, food security and social welfare will be improved while the cost of production will be reduced.

StrigAway technology is an example of technologies which incorporate farmers' practices. Thus, it is likely to succeed because of its compatibility with farmers' practices such as intercropping and crop rotation (AATF 2007). The IR-maize seed can be planted along with the already known Striga suppressive legumes, such as soybean and groundnuts, which together reduce the impact of Striga to very low levels. Some studies have not shown any herbicide damage to intercropped maize-legume crops where appropriate spacing is done. Kanampiu et al. (2001, 2002) demonstrated that sensitive leguminous plants can be safely intercropped with imazapyr-treated maize seeds, an indication that the Striga control technology could be adopted without necessarily adjusting traditional cropping practices.

The same study suggests that despite the accumulation of the herbicides in soil and leaching below the root zone, there are no carryover effects of herbicide on plants grown in rotation after planting imazapyr-dressed maize seeds. Thus, this technology allows rotation of IR maize with herbicide-susceptible crops. The IP-related benefit is that the Material Transfer Agreement (MTA) for StrigAway technology deployment allows IR maize to be cultivated even in non-Striga infested regions just like any other maize. This has reduced the chances of Striga affecting maize production in those areas. According to farmers, IR-maize is relatively drought tolerant when compared to other maize varieties. Moreover, it is early maturing and has remarkably higher yields in fields infested with Striga.

The success of StrigAway can also be associated with institutional linkages in technology development and deployment. The significance of public-private partnerships can be underscored from Section 6.3.2 – where the ARCs and National NARS are involved in technology development, private companies are engaged in seed production and distribution while AATF undertakes monitoring and evaluation.

Community level initiatives in technology deployment can further be applauded for the success of StrigAway technology especially in Striga-affected regions of the country. These include support to farmer organisations, who through their collective action in acquisition of farm inputs and marketing of their output take advantage of economies of scale. Farmer-to-farmer exchanges were instrumental in StrigAway adoption. This was achieved through exchange of information between farmers and actual visits to farms applying StrigAway technology. The technology's success is also associated with increased extension services in the Striga affected regions. AATF (2008) however notes that extension services are more intense in Nyanza province than Western Kenya. The initiative has also received attention in institutions of higher learning. For example, in Maseno University's Department of Botany and Agriculture, some scientists and graduate students engage in investigative studies of Striga management. Finally, NGOs and seed companies through their distribution networks of dealers and stockists have disseminated the IR-Maize technology and facilitated farmer adoption of this technology.

6.3.5 Challenges in Technology Development and Deployment

Striga can develop resistance to Imazapyr. Hence, StrigAway technology is a short-term strategy which requires farmers to combine it with other existing methods for effective Striga eradication. This sentiment is supported by Kanampiu et al. (2001) who caution that introducing technologies to African cropping systems should put into consideration the needs of smallholder farmers and the agricultural ecosystems.

Low levels of technology uptake in the past have been associated with low levels of awareness and poor extension services. For instance, studies conducted by AATF and IITA found out that for sources of seed, farmer-to-farmer channel represented 0.2%, 0.5% for government extension and 0.7% for national research organisations (specifically KARI) in Nyanza. For Western province, CIMMYT and KARI were main sources of seed (Manyong et al. 2008).

One of the other major challenges of deploying StrigAway technology is that StrigAway production system is too expensive to be widely affordable. This makes the seed companies and multi-national corporations more powerful, as farmers become entirely dependent on them (Grain 2006). Also, the technology does not fit within the financial means of the subsistence farmers. From farmer interviews,[12] it was established that low technology uptake was associated with the highly priced Striga-tolerant seed relative to other maize seeds, as well as resistance to change as some farmers were still gathering more information about the technology. Other farmers feel that the limited quantity of seed available in the market and also issued through farmer organisations limits the potential impact of the technology. The problem of inadequate seed supply has persisted since the technology was launched as noted by Manyong et al. (2008 who established that some early adopters were quitting the technology altogether due to its limited access. The problem of seed supply was occasioned by unmet resources to facilitate the production of the IR maize in response to demand on the market.

StrigAway technology faces cultural challenges which characterise farmer practices, such as use of farmer varieties as opposed to buying seed for every cropping season, exchange of seed between farmers, planting several varieties in one plot in a season and even saving hybrid seeds for the next planting season. For instance, the technology promoters have specified the optimal quantity of seed per hectare as 27 kgs. However, farmers have continuously either under or over-applied the seed leading to low production under both instances (Manyong et al. 2008). From farmer interviews,[13] the IR maize supplied per farm was not adequate and coupled with low input supply it led to some farmers quitting technology use altogether. Thus, despite the StrigAway technology success, there is still a possibility of not being widely adopted especially in other areas, as it may not be considered 'appropriate' for the famers' needs and capacities especially in providing them sufficient food for their families on small, intensively cultivated farms.

6.3.6 Innovation Capacity in StrigAway Maize Project

Studies have shown that maize yields in Kenya fall short of the potential yields despite increased use of new maize varieties. The decline in yields is attributed to many factors but Striga weed is considered the greatest constraint in maize production. The impact of Striga weed is greatest in the lake region of Kenya where Striga also affects other crops such as sorghum and millet, increasing vulnerability of the farmers to food insecurity and poverty (Woolmer and Omare 2005).

Despite the fact that the StrigAway initiative exemplifies a successful venture, collaboration with multinational companies for supply of Imazapyr (the herbicide used to coat IR maize) ties farmers to dependency relationships with multinational firms (Grain 2006). Several suggestions have been made to address the challenges facing StrigAway technology development and deployment. At the development stage, the technology needs to incorporate farmer knowledge, habits and practices. Farmers have over the years developed a habit of selecting and saving seed for the next season. This is not possible with IR maize seeds which have to be purchased for each season. Farmers need to be informed of the compatibility of StrigAway technology with their usual farm practices such as intercropping maize with legumes, push-pull and uprooting immature Striga. This information should also be communicated to extension officers for greater diffusion. Stakeholders involved in technology diffusion should make an effort to translate the user guidelines in local languages in order to reach out to illiterate farmers and hence enhance learning and knowledge sharing.

Many researchers argue that during technology development, it is important to consider farmers' cultural practices with regard to production. For example, Ransom et al. (2002 and Kanampiu et al. (2002) suggest that for any new technology to address the exceptionally high infestation levels of Striga in African soils, and to be widely accepted and adopted by the farmers, it must meet the following four important criteria: control Striga in its initial growing stage in order to reduce yield crop loss; reduce Striga seed bank in the soil; be cost-effective; and match farmers' existing cropping systems and technologies.

This argument is also echoed by Warren (1992), who demonstrates that rural communities have always devised different strategies to cope with environmental challenges at the local level. He also notes that in the past, developers of technologies ignored the innovative capacity of the rural people.[14] However, in recent times, adaptive research has been key in many African governments and public research agenda. This is done by engaging rural people through participatory approaches to contribute their views which are incorporated in technology development. Such a technology will be desirable to farmers and also it will address their immediate concerns. It is therefore clear that a technology that integrates elements of farmer practices has a greater chance of adoption than one that introduces all new techniques.

From its inception, the StrigAway initiative involved only four formal institutions in technology development. However, beyond technology development, the initial stakeholders found the need to collaborate with other organisations which would deploy their product to the target groups. There were many challenges in the technology deployment and it required well networked stakeholders for effectiveness. This involved collaborating with seed suppliers, distributors, stockists, extension officers, CBOs, NGOs, farmer organisations, micro-credit firms and farmers themselves. Over time and through a learning process, the project has expanded and is likely to meet its objectives.

For the StrigAway initiative to be effective, farmers need to adhere to correct field management practices. These include sowing the recommended seed quantities per hectare, using inorganic and organic fertilizers, and maintaining general cleanliness in maize fields. The StrigAway production system (Herbicide-Tolerant Maize seeds and herbicides) is too costly and thus smallholder farmers can barely afford it. AATF (2007) called upon farmers to join farmer organisations to explore economies of scale in acquisition of inputs which include IR maize seed, fertilizers and herbicides. Moreover, farmers can benefit much from organized farmer-farmer exchanges and involvement in exhibitions, trade fares, seminars, field days and workshops aimed at Striga management.

The NARS was challenged to improve capacity for Striga characterisation, IR maize seed supply, monitoring and evaluation of technology delivery systems. There is also a need to regularly train extension agents on new Striga management techniques for greater levels of technology awareness and higher adoption rates at the grassroots. Policy makers and development partners need to place Striga eradication top on the agenda for rural development, especially in the lake region where the negative impact of Striga infestation is overwhelming.

Manyong et al. (2008) found out that some farmers had not yet adopted StrigAway technology due to inadequate information on the technology. This calls for improved extension services both by the government agricultural extension department and private institutions' extension officers. Awareness campaigns should be conducted in Striga infested regions with greater involvement of stakeholders in the initiative, including farmers.

To make Striga history on farmer fields, all stakeholders (existing and potential) need to work together at all levels of technology development, diffusion and use. This requires creation of an enabling policy environment which attracts more stakeholders, such as technology developers, farmers and the seed distributors in Striga eradication initiatives.

6.4 Conclusion

The TC banana and StrigAway initiatives discussed in this chapter were selected to exemplify biotechnologies which had reached farmers in a systematic manner. The case study in chapter four, in contrast, involved a biotechnology currently being manufactured by large farms to the point of export, but inaccessible by smallholder farmers.

Both the TC banana and StrigAway initiative embraced PPPs in technology development through to utilisation. However, the TC banana has, so far, adequately addressed some aspects of food security but is still struggling with establishment of an elaborate marketing system for the output. This has greatly discouraged potential adopters whose main motive is commercial production. In the case of the StrigAway initiative, empirical reports confirm the motive of the project 'Striga eradication'. However, the technology's full potential has not yet been realized. Subsequent field studies revealed inadequate seed supply and low levels of awareness among farmers. Even among farmers who were aware of the technology, issues of compatibility with farmers' socio-economic conditions and cultural practices of seed saving were of great concern.

TC banana initiative serves as a good example of a technology which has captured learning as key to the success of a technological innovation. This is observed in the evolutionary nature of the technology where in the initial stages, there were few actors involved. However, through needs assessment, there was a need to incorporate bridging institutions to ensure technology delivery and uptake by farmers. This led to collaboration with institutions of higher learning for enhanced research and training, farmer groups for demonstrations and awareness, financial institutions to provide credit for acquisition of seed and other technology requirements and sensitizing micro-entrepreneurs to provide the technological requirements.[15]

In contrast, the StrigAway initiative is yet to effectively respond to the increasing demand for IR maize seed. In as much as the technology is still undergoing trials, only a few local seed companies have taken up seed production and distribution activities. Why are investors shying away, and yet IR-maize seed production and distribution is viewed as a profitable venture due to excess demand for seed? This situation requires a closer examination of the policy environment under which the technology is developed and deployed so that policies which deter or facilitate participation can be identified and addressed.

In terms of system linkages, the TC banana and StrigAway initiatives employ both formal and informal institutions involved in knowledge creation and use. These include institutions of higher learning, NARS, IARCs, private companies, NGOs, CBOs, small and medium enterprises and farmer groups. This is an indication of a holistic approach to technological innovation where the needs of the farmers are addressed through interactions and linkages with various institutions, rather than the top-down approaches characteristic of the Rhizobium and Transgenic sweet potato projects.

In conclusion, it should be noted that for any agricultural technological innovation to be successful, all the main actors in the process of innovation need to play an active role and be aware of their mandate in the process. Equally important is the coordination of linkages within the system whereby all actors work in harmony towards a common goal, appreciate the learning process and respond to the feedback received from other stakeholders in the system (Clark 1995).

Notes

[1] See also Wambugu (1996)

[2] IITA annual report 2008

[3]http://www.econstor.eu/bitstream/10419/48314/1/43_kabunga.pdf, accessed September 15 2013

[4] See Chapter two on evolution of technology systems

[5] Stakeholders forum in Thika – during fieldwork in 2007.

[6] Baseline Study of *Striga* Control using Imazapyr-Resistant (IR) Maize in Western Kenya, 2008

[7] The maize yield losses due to Striga range between US $ 10-38 M per annum (Woolmer and Omare 2005; Kanampiu et al. 2002)

[8] In Western Kenya, the recommended maize seed input use is 34 kg/Ha. However, farmers plant double the recommendation. Similarly, inorganic & organic fertilizer use is below the recommendation.

[9] For more information on other Striga management practices, see AATF (2006).

[10] See also www.future-agricultures.org, accessed 25th July, 2013

[11] In empowering African farmers to eradicate Striga from maize croplands. The African Agricultural Technology Foundation, Nairobi, Kenya.

[12] Baseline study of Striga control using IR Maize in Western Kenya (AATF and IITA 2008).

[13] Farmer perceptions on the use of IR maize technology in Striga control in the lake region of Kenya, (Manyong et al. 2008).

[14] In evolution of technology systems (Kenyan context), indigenous knowledge of the rural people was ignored hence failure of technologies developed using top-down approach.

[15] See, for example, table 6.1

7 Synthesis and Conclusion

7.1 Introduction

This study set out to examine the capacity of NARS in Kenya to innovate in harnessing agricultural biotechnology for smallholder farmers given the technical, policy and institutional challenges posed by modern biotechnology. The study also sought to know whether the agricultural innovation systems (AIS) approach can be employed in harnessing biotechnology for sustainable productivity and food security of smallholder farmers. The general theoretical literature on this subject and specifically in the context of biotechnology and African smallholder farming is lacking on several vital questions within innovation capacity discourse. Thus, the study sought to answer two of these questions:

1. Does the National Agricultural Research System (NARS) in Kenya have the capacity to innovate in harnessing agricultural biotechnology for smallholder farmers given the challenges posed by modern biotechnology?

2. Does the innovation capacity of NARS influence the dynamics of success and failure of agricultural biotechnology policy and programs in response to needs of smallholder farmers?

The rest of this chapter is organised into six brief sections. The second section provides a synthesis of the findings of the study with respect to the above research questions. The third section highlights the contribution and/or implications of these findings on the current theories underpinning the AIS framework. The policy implications of the study findings are discussed in section four. The key elements arising from domains of the AIS conceptual framework in Chapter 1 are: (i) Research and education; (ii) Business and enterprise; (iii) Bridging institutions; (iv) Policy and institutions; and v) Coordination and linkages. This section is followed by an outline of plans for further research on this topic in section five. Section six highlights limitations of the study. Section seven concludes this dissertation.

7.2 Harnessing Biotechnology for Smallholders

Research Question 1: Do the National Agricultural Research System (NARS) in Kenya have capacity to innovate in harnessing agricultural biotechnology for smallholder farmers given the challenges posed by modern biotechnology?

Although biotechnology has the potential of increasing yields of crops and improving food and nutrition security of the majority smallholder farmers, its ability to provide a formidable solution depends on establishing mechanisms for NARS to engage farmers on its research action.

a) Response to changing landscape of agribusiness and knowledge management

The analysis of case material shows that biotechnology is being introduced into largely failed systems to meet needs of smallholder farmers irrespective of the technology types or characteristics. Thus, the sustainable deployment of biotechnology will require a critical reflection on NARS' past performance in generating appropriate agricultural innovations for smallholders.[1] Increasingly, the NARS are more challenged to respond to the changing landscape of agribusiness and knowledge management (World Bank 2006, Chataway et al. 2005).

b) Linkages with industry and markets

The weak linkages with industry and markets constrain technology adoption in Kenya. This is largely due to lack of information, high transportation costs, constraining policies and weak enterprise value chains. Improving value chain competitiveness for biotechnology adoption may require the following strategies: end-market positioning in technology design, upgrading to innovation platforms that strengthen technology and information flow to NARS, users of technology (including intermediaries) and policymakers who determine resource flows for public investments.

c) Influence of international and national actors in agricultural biotechnology policy and programmes

Agricultural biotechnology policy and programme activities are influenced by particular international and national actors whose priorities may not be guided by local realities. At the same time, global trends show that scientists in modern biotechnology research are increasingly using science-intensive knowledge which constrains communication between people in the laboratory and the non-scientific community. This is also a serious challenge for many researchers in developing countries such as Kenya given that much of this knowledge requires high-tech labs, specially trained personnel and adequate funding (Odame and Muange 2011, Hall and Dijkman 2006).

d) Influence of international legal and regulatory regimes on modern agricultural biotechnology

Modern agricultural biotechnology is influenced by international legal and regulatory regimes, including intellectual property rights (IPRs) and biosafety regulations. IPRs mediate market exchange in modern biotechnology and knowledge. This contrasts with conventional agricultural technology innovation processes, where knowledge management is characterised by free exchange of information, materials and tools. Even where biotechnology transfer to developing countries involves donated technologies, there are still post-release IPR concerns with respect to generating appropriate innovations and accessing them to smallholders. Besides access to modern biotechnology, there are concerns over biosafety regulations. International regimes require the establishment of national regulations for assessing and managing risks in the governance of modern biotechnology. However, many developing countries, including Kenya, still lack the technical and legal capacity as well as adaptive capacity to implement and enforce biosafety regulations (Odame et al. 2003, Ikiara 2004).

e) Policy and coordination of agricultural biotechnology R&D initiatives

Most agricultural biotechnology R&D initiatives in Kenya are taking place in the poorly-financed public research sector with a few initiatives conducted through donor-funded public-private partnerships (PPPs). These arrangements have contributed to some technical and legal regulatory capacity building in Kenya. However, this capacity does not stimulate creativity and is confined to upstream research networks and not extended downwards to extension and producer networks. Weak coordination of these linkages also leads to fragmented biotechnology programmes with indeterminate impact in the country (see Hall and Dijkman 2006).

Research Question 2: Does the innovation capacity of NARS influence the dynamics of success and failure of agricultural biotechnology policy and programs in response to the needs of smallholder farmers?

a) National capacity

As in other developing countries, the introduction and development of biotechnology in Kenya followed global trends in the 1980s. The decisions to invest in traditional agricultural biotechnology applications were made in the mid 1970s and early 1980s for bio-fertilizers and tissue culture respectively. Initiatives in modern biotechnology R&D policy and programmes such as transgenic sweet potato, Bt. Maize and genetically-engineered livestock vaccines began in the early 1990s. The introduction of biotechnology in Kenya was made on the basis of its potential to alleviate poverty, hunger and malnutrition (Wafula and Falconi 1998).[16] However, some respondents said that such justification led to putting more emphasis on traditional biotechnology applications as opposed to modern ones. The declining government funding under the influence of SAPs equally limited the effectiveness of government to finance and coordinate agricultural biotechnology R&D activities.

As a result of donor funding, the country expanded biotechnology research and policy through capacity training opportunities and other forms of collaboration with national and international organizations (Makau and Kameri-Mbote 1995:103-123). But these initiatives made a limited contribution to the long-term strategy for achieving a critical mass of human resources needed to effectively engage in modern biotechnology. Furthermore, many of the modern biotechnology applications are yet to be used by farmers (Odame and Muange 2011).

b) Local capacity

An emerging concern regarding the acceptance of GM crops in Kenya is associated with lack of local level capacity to manage the potential health and environmental risks in particular, as efforts are underway to move some of the modern biotechnologies from research laboratories to farmers' fields. This follows the enactment of the Biosafety Act 2009 and the recently published Biosafety Regulations and Guidelines. Related to local capacity building is the issue of farmer empowerment.

c) Farmer empowerment

Representation and accountability of the producer groups involved in decisions about agricultural R and D prioritisation and resource allocation was a major concern of many respondents. In particular, the extent to which the research needs of different groups converge or diverge will restrict or support efforts to meet the technology requirements of less-commercially-oriented and less-organised groups.

7.3 Dynamics of biotechnology and smallholder farming

The new challenge for the concept of AIS is whether integrating biotechnology into the existing agriculture and agri-food systems will lead to the creation of most suitable innovations for smallholder farmers.

7.3.1 Innovation Systems

The general finding from analysis of national institutions and case studies defies the current definition of innovation systems and the myth of traditional versus modern agricultural biotechnology. For instance, Hall and Dijkman(2006) defines Innovation Systems (IS) as: "A network of organisations, enterprises, and individuals focused on bringing new products, new processes and new forms of organization into economic use, together with institutions and policies that affect their behaviour and performance".

Defining the concept of innovation systems this way tends to front more for new technologies and business, instead of focusing on the real problem of limited use of available technologies by smallholder farmers and the resulting high incidence and persistence of rural poverty. As argued by Prof. Paul Richards (personal communication, 24th June 2008): "…the problem of limited use of available technologies lies in understanding the 'context' –and not so much in the 'trigger mechanism'." For example, StrigAway technology (in Chapter 6) is a trigger mechanism for controlling striga or witch weed, but unless the problem of soil fertility is addressed, the effects of StrigAway technology on farmers' yields may not be significant. Promoters of StrigAway initiative have recognized that for its success, the technology must integrate other traditional farmer practices in Striga eradication. These include intercropping, uprooting and burning and push-pull (AATF 2006, Manyong et al. 2008; Odame and Muange 2011). This finding shows the relevance of linking new technologies with other technologies including indigenous knowledge (Warren 1992).

Despite the complexity or radical aspects of technical innovation, scientists in the transgenic sweet potato project combined modern knowledge of molecular sciences and farmers' innovations and landraces in the upstream research and education systems to develop transgenic sweet potato variety(ies) for smallholder farmers. In the case of the *Rhizobium* inocula project which involved simple (or incremental aspects) of technical innovation, the generation and adaptation of Biofix were confined to the knowledge of university scientists in the upstream research and education systems while StrigAway maize technology and TC banana case studies exemplify a back and forth learning process employed by both technology developers and end users.

7.3.2 Research and Education

It is becoming ever more apparent that there is a general problem with capacity development initiatives that aim solely at building physical infrastructure and competencies of academia and researchers to generate knowledge (and study findings). The failure to build capacity of complementary assets to put the existing and new knowledge into use and show how scientific resources will respond to society as a whole and get integrated with the rest of the economy is a key area of concern in debates on the role of science, technology and innovation (STI) in society.

This study has provided evidence that much of the problem of the NARS in Kenya emanates from the history of capacity building framework in S&T and the assumptions that informed good practice in the past 40-50 years (Chataway et al. 2005, World Bank 2006). It is evident that the government is investing in research and education sectors to increase the number of professionals in the field of biotechnology at both undergraduate and post graduate levels. However, the professional quality is low especially with respect to having necessary knowledge and skills to come up with useful biotechnology products. As noted through key informants at IARCs and NARS, "skills are taught theoretically but the practical applications are limited."

Further, a laboratory scientist at the MIRCEN Centre at the University of Nairobi reported that: "apparatus and equipment needed to isolate *Rhizobium* were adequate. But the challenge is the capacity to produce the inoculum in large quantities." Similarly research scientists at KARI said that laboratory equipment is usually available as long as proper funding for a particular project is available. As noted in the earlier chapters, during their education, scientists are not trained in how to communicate information with non-scientists, let alone with smallholder farmers.

For biotechnology to be harnessed to address needs of smallholder farmers in particular, and society in general, a key step would be training of scientists and equipping them with relevant knowledge and skills. The required framework for capacity should go beyond the mere symbolic pleas for researchers to work with farmers to develop, adapt to local conditions and rigorously test technologies (Hall and Dijkman al. 2006). Rather it encompasses a complex web of social relations and business dealings to share knowledge and develop value chains in diverse arenas.[2]

7.3.3 Bridging Institutions

Based on the case studies that were less successful, it is evident that there was lack of extension services to facilitate knowledge transfer. For instance, use of *Rhizobium* became successful after establishment of a partnership between MIRCEN and MEA Company Ltd. This implies that without a proper mode of communication between various value chain actors, any product no matter how good or effective is likely to fail.

FAO (2013) reports that linkages between research systems, extension services, and farmers are weak; researchers have little or no interaction at all with extension services and farmers, and do not reflect the farmers' needs, capacities and priorities in their research. "The lack of linkages has led in some cases to farmers adopting less than 10 percent of the crop varieties that they are offered." [22] This means that proper methods and feedback on information is critical because without a system of accountability, research can be conducted just for the sake of doing research.

The NARS framework embodied a top-down flow of knowledge and information (see also Chapter 2) whereby the feedback from end users was not given proper attention. This approach is basically linear and has a weak extension system since field extension officers are not accountable to farmers. Therefore, developing countries can learn from India's contemporary extension model which is market-led, diversified and more decentralized[3] (Swanson et al. 2008).

7.3.4 Business and Enterprise

This study has attempted to bring back evolutionary thinking into the IS perspective (which was hitherto borrowed from the industry model of 'profit-maximizing firm'), through a dynamic view of innovation process by reconstructing innovation histories of both relatively more and less successful biotechnology projects. For example, the study shows that the successes of TC banana and StrigAway maize technologies (Chapter 6) were due to a dynamic process of developing and deploying these technologies, and linking them to both market and policy in the national system. The projects were not just about developing biotechnology but also about interactive learning processes of bringing together scientific and local knowledge on production and marketing of bananas and maize. The interaction between the scientific knowledge and traditional knowledge needed market mediation for farmers to change their agronomic practices and begin to use inputs, access credit to buy fertilizer or pay for hired labour and market information for their products.

However, capacity building and entrepreneurship were lacking in both scientists and farmers. In addition, many farmers studied have limited access to land and quality water, lack access to credit, inputs, and knowledge. They are also faced with gender constraints to production.

These agro-ecosystem elements (viz. quality of soil and water and gender relations) are often ignored in general literature on the SI approach. This is also a key weakness of the AIS approach. Creating and strengthening the variety and diversity of emerging technologies in the local production systems of smallholders is crucial to the success of the innovation in a country such as Kenya, given its diverse agro-ecological and socio-economic conditions. Standardisation may be difficult to achieve in such systems (see Eicher 1999). This means that technologies from other areas will still have to be adapted to the local conditions in order to achieve a better fit. In the words of Colebatch and Larmour 1993) this is "going local". Therefore, if biotechnology is to be harnessed to address the needs of smallholder farmers, the key value chain actors need to be well equipped with diverse knowledge, including agro-ecosystems and value chain governance using biotechnology products. The key policy context issue here is whether farmers and the general public will be willing to accept biotechnology products. Public perception shaped by socio-cultural beliefs plays an important role in public acceptance of GMO foods.

7.3.5 Policy and Institutions

This study has examined the influence of international actors in modern biotechnology R&D funding priorities, legal and regulatory regimes, including intellectual property rights (IPRs) and biosafety regulations Glover and Newel 2003). IPRs mediate market exchange in modern biotechnology. This contrasts with conventional agricultural technology development process, where knowledge management is characterised by free exchange of information, materials and tools. Even where biotechnology involves donated technologies, there are still post-release IPR and biosafety concerns with respect to accessing innovations to smallholder farmers. The international regimes require the establishment of national Biosafety Regulations for assessing and managing risks in the governance of modern biotechnology. But developing countries, such as Kenya, still lack the technical and regulatory capacity to enforce Biosafety Regulations (Odame et al. 2003, Odame and Muange 2011).

Some of the policies and regulations reviewed in this study supported the production and utilisation of various agricultural products, while others did not. For example, the Biosafety Act of 2009 has elements that promote and also impede the production of various biotechnology products. Another controversial public policy was the recent ban on GMO foods. For biotechnology to be harnessed in addressing low productivity and food insecurity among smallholder farmers, such concerns will need to be critically analysed and addressed. In particular, women farmers can benefit from agricultural biotechnology if they are actively involved in its innovation process. Women farmers play a critical role in agriculture and rural production. They also employ indigenous knowledge in response to changing weather patterns and land use. But they lack access to modern knowledge and other resources such as credit and loan facilities.

7.3.6 Coordination of Linkages

Linking and coordination systems are recognised for establishing frameworks for capacity building and international transfer of modern technologies to developing countries (Velho 2004). *Rhizobium* inoculum was supported by a network of international and local public universities; the Transgenic Sweet Potato project was initiated by KARI and Monsanto, under the framework of the Agricultural Biotechnology for Sustainable Productivity (ABSP); the StrigAway initiative is a collaborative project of AATF/CIMMYT and BSF/KARI; and ISAAA AfriCenter partnered with KARI and grassroots organisations to promote TC banana technology in Kenya. The ever-expanding space for the third sector makes NGOs, CBOs, local and farmer associations' possible partners in the downstream knowledge networks.

The relative success of the StrigAway initiative is largely attributed to the coordination efforts of AATF and active involvement of NGOs and CBOs in input acquisition, exchange of information and knowledge, field days and marketing of output (Odame and Muange 2011). The less successful case studies, in contrast, are marked by lack of coordination and linkages between the knowledge domains. For instance, there was lack of oversight bodies for coordination, and where they exist, they are not well known by the public, let alone among the key players in agricultural biotechnology policy and programmes.

7.4 Policy implications

This study has several implications relevant to agricultural biotechnology policy debates. First, the study has attempted to apply the framework of innovation systems (AIS) to Kenyan agricultural biotechnology applications to underscore strengths and weaknesses in the country's agricultural development process. One important conclusion is that technological answers cannot be achieved independently of contemporary development concerns. The study has tried to show that biotechnology could be made part of the answer if its policy and programmes are developed in support of easing some of the contemporary agricultural development challenges.

Second, the study has attempted to incorporate evolutionary and dynamic thinking into the AIS approach (which is derived from business and industry models of the 'firm') by reconstructing non-linear innovation histories. For instance, the study shows that the successful deployment of TC banana and StrigAway maize projects were not just about developing biotechnologies, but about interactive learning processes bringing together scientific, local and other knowledge bases about production of bananas and maize and linking them to other governance systems. The interaction between scientific and traditional knowledge also needed market mediation for farmers to change their existing practices of production and begin to use improved seed and inputs, and gain access to credit to buy fertilizer or pay for hired labour and product markets.

Third, it is now becoming increasingly evident that there is a need to go beyond the typical capacity development approaches which focus mainly on physical infrastructure and technical competencies of researchers to generate knowledge and technologies. They need to move towards building and strengthening of complementary structures and a broader range of competencies aiming to put the existing knowledge into use, and to make scientific knowledge respond to the realities of rural economy and society.

Fourth, innovation capacity entails balancing the interest and influence of diverse actors in modern biotechnology R&D policy and programmes. Thus, developing countries such as Kenya need capacity and creativity to negotiate and manage information, funds, legal and regulatory frameworks in response to local realities. Fifth and finally, while coordination of diverse actors and their interests is difficult, the art of governing biotechnology innovation processes requires innovation brokers (individuals or organisations) to create space, seek opportunities and incentives to engage relevant actors at different stages of the innovation process.

7.5 Limitations of the study

This study sought to know whether the agricultural innovation systems (AIS) approach can be employed to harness biotechnology for sustainable productivity and food security of smallholder farmers. As already stated, the general theoretical literature on this subject and specifically in the context of biotechnology and African smallholder farming is lacking on several vital questions within innovation capacity discourse.

Although still evolving, the AIS concept is borrowed from the Systems of Innovation (SI) approach, which was based on business and industry studies of *firms* in the newly industrialising countries (NICs). Thus, applying the IS approach to the dynamics of agriculture biotechnology and smallholder *farming* in Kenya is challenging and required developing a working framework. These areas are relatively new and data for testing theories is lacking. Therefore, it is only possible to make empirical generalisations or generate appreciative theories on what influences agricultural biotechnology innovation policy process by identifying and describing functions that are *missing* or *inappropriate* and which lead to 'system failures' (Edquist 2001, Ikiara 2004).

The study has been carried out for more than a decade. The long duration has some disadvantages but could also be advantageous. The main disadvantage is outdated field data and information. It is advantageous because the detailed case studies have captured important and instructive processes of biotech innovation attempts in the past, from which much can be learned. The intervening time period has provided the opportunity to observe any further developments, although without the level of detail achieved in the original field studies.

For instance, the original *Rhizobium* inoculum technology in Chapter 4 and transgenic sweet potato in Chapter 5 did not work because they did not effectively reach the target smallholder farmers due to challenges along the innovation process. The author has attempted to update the original case study chapters and other chapters through secondary data, key informant interviews and focused group discussions (FGDs).

Using the latter methods, the author introduced TC Banana Technology and StrigAway Maize Technology in Chapter 6 as examples of biotechnologies that were claimed to be more successful in terms of deployment and use among smallholders. The author also used data and information obtained from his consultancy assignments, secondary literature and interactions with actors during workshops and meetings to update data and information.

7.6 Recommendations for Future Research

Kenya is faced with several agricultural development challenges that affect the growth and development of the agricultural sector. The findings of this study suggest some areas for further research in the area of rural innovation.

First, building on this study, an important area for future research is devising and empirically testing an AIS methodology for assessing the functioning of rural innovation systems and especially how they interact with society. It is difficult to sustainably deploy biotechnology or any other agricultural technology for that matter when its knowledge is not joined up with the existing innovation systems, which are also trying to address the contemporary agricultural development challenges, including problems of soil fertility, marginal land and especially those faced by agricultural youth.

Second, there is need for an effective market mechanism for inputs and output which allow farmers not only to access technologies and a range of services at fair prices but also to sell their output with low transaction costs. For farmer groups to do this they require a variety of skills, some of which studies have confirmed to be lacking, yet there are few initiatives to equip farmers with relevant knowledge and skills, especially in business and entrepreneurship (Heinrich et al. 2008).

Third, the evidence from national institutional analysis and case studies show that there was weak extension to facilitate knowledge transfer. In view of this weakness of the NARS and extension framework, Blum (2008) suggests there is a need for a study on agricultural extension systems which would reveal advisory needs versus current services offered in order to model effective extension systems, especially for GMOs.

Fourth and finally, the case studies of less successful agricultural biotechnology innovation show the lack of coordination and linkages between knowledge domains. For instance, there was lack of oversight bodies for coordination, and where they do exist, they are not well known by the public let alone among key players in agricultural biotechnology policy and programmes. An important area for future research is understanding the mechanisms for effective coordination and linkages that facilitate information flow within relevant groups.

7.7 Conclusion

The central argument of this study is that there are fundamental problems with existing systems in the utilisation of available agricultural technologies irrespective of technology types and characteristics. Evidence from both secondary literature and the cases studied show that in the Kenyan NARS, connections are the weakest links with respect to roads, seed supply systems, and information flows. On physical and human capacities, one key issue is whether NARS possess the relevant infrastructure and skills to creatively respond to the technical and social challenges of modern biotechnology. Another important observation is the weak capacity of the government to implement regulations. Furthermore, there seems to be lack of political support to the delivery systems, especially the grassroots delivery systems that should be closely linked to the rest of the economy.

In response to the broad research question: Can agricultural biotechnology be harnessed to improve sustainable agricultural productivity and food security of smallholder farmers in Kenya? It is not the problem of biotechnology or any other technology for that matter, but rather the arrangement of institutions that develop and deploy biotechnology.

From the AIS perspective, it is evident that different factors influence (promote/impede) biotechnology development in Kenya, especially in response to the needs of smallholder farmers. These factors include recurrent and emerging issues such as lack of funding, brain-drain and well-trained scientists migrating to developed countries in search of better job opportunities, weak performance of bridging institutions, lack of adequate technology and capacity to facilitate mass production, impeding policies, lack of coordination and linkages between key players in the different domains and the negative public perception of GM foods. Therefore, the art of managing biotechnology innovation processes requires coordination of diverse actors and their interests to create space for engagements and seek opportunities and incentives to link relevant actors at different stages of the process.

Notes

[1] www.sls.nau.nl Accessed 8th July 2013

[2] See also Hall, A. (2005)

[3] Swanson et al. 2008. A decentralized farmer led, market driven extension system. The ATMA model in India. IFPRI conference presentation. Addis Abbaba.

References

AATF (2006) *Delivering the Promise: Impacting Lives with New Technologies. Annual Report*, Nairobi: African Agricultural Technology Foundation.

AATF (2008) *Addressing Farmers' Constraints Through Scientific Intervention. Annual Report,* Nairobi: African Agricultural Technology Foundation.

AATF (2007) *Towards a Prosperous and Food Secure Africa: Progress and Promises. Annual Report*, Nairobi: African Agricultural Technology Foundation.

Acharya, S.S. and M.A. Mackay (2008) 'Socio-economic Impact Assessment of Tissue Culture Banana Industry in Kenya.' African Harvest Biotech Foundational International (AHBFI), Nairobi, Kenya

Action Aid (2003) 'GM Crops – going against the Grain', accessed 21 July 2010 <http://www.actionaid.org.uk/doc_lib/against_the_grain.pdf>.

Adenle, A., A. Sulayman, K. Sowe, P. Govindan, and A. Obijiofor (2012) 'Analysis of open source biotechnology in developing countries: An emerging framework for sustainable agriculture' *Technology in Society*. Accessed 26 October 2013 <http://www2.hcmuaf.edu.vn/data/hoainam/file/ppp/1-s2_0-S0160791X12000450-main.pdf>.

AGRA (2013) Africa Agriculture Status Report 2013 - Focus on staple crops. Nairobi: Alliance for a Green Revolution for Africa.

Alston, J. M., G. W. Norton, and P. G. Pardey. (1995) *Science under Scarcity*. Ithaca, NY: Cornell University Press.

Andrade, M., I. Barker, D. Cole, H. Dapaah, H. Elliott, S. Fuentes, W. Grüneberg, R. Aping, J. Kroschel, R. Labarta, B. Lemaga, C. Loechl, J. Low, J. Lynam, R. Mwanga, O. Ortiz, A. Oswald, and G. Thiele (2009) 'Unleashing the potential of sweet potato in Sub-Saharan Africa: Current challenges and way forward', CIP Working Paper. Lima: International Potato Center.

ASTI-KARI (2009) Agricultural science and technology indicators survey. Unpublished surveys. Washington, D.C. and Nairobi: Agricultural Science and Technology Indicators and Kenya Agricultural Research Institute

Bashaasha, R.O.M., C. Mwanga, O. p'Obwoya and P.T. Ewell (1995) *Sweetpotato in the Farming and Food Systems of Uganda. Farm Survey Report*. Nairobi: International Potato Center and National Agricultural Research Organization.

Bates, R. H. (ed.) (1989) *Beyond the Miracle of the Market: The Political Economy of Agrarian Development in Kenya*. Canada: Cambridge University Press.

Beintema, N. and Gert-Jan Stad (2008) 'Measuring Public Agricultural Research Investments: A Revised Global Picture', paper presented at an IFPRI International Conference on Advancing Agriculture in Developing Countries Through Knowledge and Innovation. Addis Ababa (7-9 April) Accessed 15 May 2013.

<http://www.ifpri.org/sites/default/files/publications/oc59.pdferry>

Beynon, J., S. Akroyd, A. Duncan and S. Jones (eds) (1998) *Financing the Future: Options for Agricultural Research and Extension in sub-Saharan Africa.* Accessed 23 May 2013 <www.opml.co.uk>.

Bennell, P. (2007) 'Promoting Livelihood Opportunities for Rural Youth', paper prepared for IFAD Governing Council Roundtable: Generating Remunerative Livelihood Opportunities for Rural Youth. UK: Knowledge and Skills for Development.

BIO-EARN. (2001) 'Safety in Biotechnology of Foods and Feeds', proceedings of a Kenyan workshop under the BIO-EARN Programme. National Council of Science and Technology, No.43/2002, Nairobi, Kenya.

Blum M.L. (2008) 'Indicators for Assessing the Status of Extension Systems and the Quality of Services' Paper presented at the IFPRI conference on Advancing Agriculture in Developing Countries through Knowledge and Innovation. Addis Ababa.
Accessed 15 May 2013
<http://www.ifpri.org/sites/default/files/publications/oc59.pdferry>

Boserup, E. (1970) *Women's Role in Economic Development*. New York: St. Martin's Press.

Brenner, C. (1999) *Integrating Biotechnology in Agriculture: Incentives, Constraints and Country Experiences*. Paris: OECD Development Centre.

Byerlee, D. (2002) 'Accessing Modern Science: Policy and Institutional Options for Agricultural Biotechnology in Developing Countries, World Development.' Accessed 27 July 2013 <www.kari.org>.

Byerlee, D and K. Fischer (2000) 'Accessing Modern Science: Policy and Institutional Options for Agricultural Biotechnology in Developing Countries'. Agricultural Knowledge and Information Systems (AKIS). Washington DC: World Bank

Cartridge, A. and D. Leraand (2007) (eds). *Towards an African Green Revolution: The Oslo Conference 2006*. Oslo: Yara International. Accessed 14 October 2013 <http://www.future-agricultures.com>.

Chataway, J., J. Smith, and D. Wield (2005) 'Partnerships for Building Science and Technology Capacity in Africa: Canadian and UK Experience', a paper prepared for the Africa-Canada-UK Exploration: Building Science and

Technology Capacity with African Partners, London (30 January – 1 February) Accessed 7 October 2013 <www.sls.wau.nl>.

Churchman, C. W. (1968) The Systems Approach. Dell Publishing Co., New York, USA:

Clark, N.G. (1995) 'The Interactive Nature of Knowledge Systems: Some Implications for the Third World', *Science and Public Policy* 22 (August).

Clark, N. (2001) 'Innovation Systems, Institutional Change and the New Knowledge Market: Implications for Third World Agricultural Development'. The Netherlands: UNU/INTECH Discussion Paper Series 2001-10

Cohen, D. W. and E.S.A. Odhiambo (1989) *Siaya. The Historical Anthropology of an African Landscape.* Athens: Ohio University Press.

Colebatch, H.K and P. Larmour (1993) *Market, Bureaucracy, and Community: a Student's Guide to Organisation.* London and Boulder, Colorado: Pluto Press.

Collier, L. and D. Lal (1986) *Labour and Poverty in Kenya 1900-1980*. Oxford: Clarendon Press.

Conway, G.R. an E. B. Babier (1990) *After the Green Revolution: Sustainable Agriculture for Development*. London: Earthscan Publication Ltd.

Cooke, J.G. and R. Downie (2010) 'African Perspectives on Genetically Modified Crops. Assessing the Debate in Zambia, Kenya, and South Africa.' A Report of the CSIS Global Food Security Project. Washington DC, USA: Center for Strategic and International Studies.

Cullet, P. (2001) 'Plant Variety Protection in Africa: Towards Compliance with the TRIPS Agreement', *Journal of African Law* 45(1). Accessed 14 May 2013
<www.gapsresearch.org>.

DeGrassi, A (2003) *Genetically Modified Crops and Sustainable Poverty Alleviation in Sub-Saharan Africa: An assessment of Current Evidence.* Burkina Faso: Third World Network Africa. <http://www.ielrc.com>.

Maina Muniafu (2012) 'Structure of Agriculture and Agricultural Policies', Nairobi:United States International University. Accessed on 12 August 2013 <http://www.slideshare.net>.

Drucker, P. (1969) *The Age of Discontinuity: Guidelines to Our Changing Society*. New York: Harper and Row.

Edquist, C. (2001) *Innovation Policy in the Systems of Innovation Approach.* Accessed 5 May 2013 <www.druid.dk>.

Edquist, C. (2000) 'Public Technology Procurement and Innovation Theory' Economics of Science Technology and Innovation, accessed 5 May 2013 <www.druid.dk>

Edquist, C. (1997) 'Product versus Process Innovation: A Conceptual Framework for Assessing Employment Impacts', Paris, March, 17 pp.

Accessed 25 September 2013 <http:// www.druid.dk>.

Edquist, C. (1993) "Commentary: National Systems of Innovation and Analytical Distinctions - a conceptual reflection", *International Journal of Human Factors in Manufacturing*, 01/1993.

Edquist, C. (ed.) (1997) *Systems of Innovation: Technologies, Institutions and Organizations.* London and Washington: Pinter/Cassell Academic.

Edquist, C. (2001) 'The Systems of Innovation Approach and Innovation Policy: An Account of the State of the Art', accessed on 15 January 2011 <http://www.druid.dk/conferences/nw/paper1/edquist.pdf>

Eicher, C. (1999) 'Institutions and the African Farmer', *Issues in Agriculture* 14, CGIAR

Eponou, T. (1996) '*Partners in Technology Generation and Transfer: Linkages Between Research and Farmers' Organizations in Three Selected African Countries'.* The Hague: International Service for National Agricultural Research.

Ernst & Young (2007) 'Global Biotechnology' *Report.* Accessed 25August 2011

<www.altassets.com/private-equity-knowledge.../nz11085.html>

____ (2008) 'Global Biotechnology' *Report.* Accessed 25 August 2011

<www.altassets.com/private-equity-knowledge.../nz11085.html>

_____(2012) 'Global Biotech' *Report.* Accessed 15 January 2014

<http://www.ey.com/Publication/vwLUAssets/Beyond_borders/$FILE/Beyond_borders.pdf >

Falconi, C. (1999) 'What is Agricultural Biotechnology Research Capacity in Developing Countries?' Accessed 5 May, 2013 <www.biosafetynews.com>.

Feinschreiber, R (1981) 'New Tax Benefits for Genetic Engineering R and D', GEN 1 (November/December).

Foeken, D. and N. Tellegen (1997) 'Proletarianisation, Land, Income and Living Conditions of Farm Labourers in Kenya', *The Journal of Peasant Studies*, 24 (4):296-313.

Accessed 21 September 2013

<http://www.ascleiden.nl/?q= organization/people/dick-foeken>

FAO (1991) 'The Role of Universities in National Agricultural Research Systems (NARS)'. FAO Research and Technology Paper 5, Report of the FAO expert consultation on the role of universities in the National Agricultural Research Systems held 10-22 March 1991. Rome: Food and Agricultural Organization

FAO (2013) 'The State of Food and Agriculture' Rome: Food and Agricultural Organization

FAC (2012) 'From Technology Transfer to Innovation Systems: Sustaining a Green Revolution in Africa' Future Agricultures Consortium *CAADP Policy Brief* 07/March

Freeman, C. (1987) *Technology Policy and Economic Performance: Lessons from Japan*. London: Pinter.

Freeman, C. (1988) 'Japan: A new national innovation system?', in G. Dosi, C. Freeman, R.R. Nelson, G. Silverberg and L. Soete (eds.) *Technology and Economy Theory*. London: Pinter. Accessed 25 October 2010 <www.enotes.com>.

Freeman, C. and C. Perez (1988) 'Structural Crises Of Adjustment: Business Cycles And Investment Behaviour', in G. Dosi, C. Freeman, R. Nelson, G. Silverberg and L. Soete (ed.s), *Technical Change and Economic Theory*. London: Pinter.

Gerthart J. (1975) *The Diffusion of Hybrid Maize in Western Kenya - Abridged by CIMMYT*. Mexico City: Centro Internacional de Mejoramiento de Maiz Trigo.

Heinrich, G., E. Charles, Z. Abebe, and R. Best (2008) 'Enabling Small Producers,' a paper presented at an IFPRI International Conference on Advancing Agriculture in Developing Countries Through Knowledge and Innovation. Addis Ababa (7-9April), Accessed 15 May 2013 <http://www.ifpri.org/sites/default/files/publications/oc59.pdferry>.

Gibbons, S (2000) 'Transgenic Sweet Potato Research Collaboration: A Case Study of ABSP Involvement in Kenya', *Linkages Newsletter* Fourth Quarter International Environmental Law Research Centre <Accessed on 12th July 2011. http://www.ielrc.org>.

Giller, K.E., F. Amijee, S.J. Brodrick, and O.T. Adje (1998) 'Environmental Constraints to Nodulation and Nitrogen Fixation of *Phaseolus vulgaris* L. in Tanzania. II. Response to N and P fertilizers and inoculation'. *African Journal of Crop Science* 6:171-178

Gitau, Z. K, E.C. Ngugi, R.W. Musyoki and J.G. Gethi (2006) 'Arresting the Scourge of Striga in Sorghum by Combining the Strengths of Marker-Assisted Backcrossing and Farmer Participatory Selection', a paper presented at the 12th KARI Biennial Scientific Conference, Nairobi, Kenya.

Glover, D (2009) 'GM Crops Ten Years On: The Undying Promise', Accessed 27 October 2010 <http://www.ids.ac.uk/news/gm-crops-ten-years-on-the-undying-promise>.

Glover, D. (2003) 'GMOs and the Politics of International Trade. Democratising Biotechnology: Genetically Modified Crops in Developing Countries', Briefing Series. Brighton: Institute of Development Studies.

Glover, D. and P. Newel (2003) Business and Biotechnology: Regulation and Politics of Influence. Brighton: Institute of Development Studies, *Biotechnology Policy Series* 17.

Government of Kenya (2004) 'Strategy for Revitalizing Agriculture 2004-2014'. Nairobi: Ministry of Agriculture and Ministry of Livestock and Fisheries Development.

Government of Kenya (2009) 'Economic Review of Agriculture'. Nairobi: Ministry of Agriculture and Ministry of Livestock and Fisheries Development.

Government of Kenya (2009) 'Biosafety Act 2009', accessed 30 May 2012 <http://www.kenyalaw.org/kenyalaw/klr_app/frames.php>.

Government of Kenya (2008) 'Kenya Gazette Supplement Bills 27th June 2008, Drafting of Biosafety Bill 2008'. Nairobi: Government Printer.

Government of Kenya (1965) Sessional Paper Number 10 (1965) 'African Socialism & its Application to Planning in Kenya'. Nairobi: Government Printer.

GRAIN (2006) 'Swapping Striga for Patents: Yet another Quick Fix for Africa's Farmers?'

Accessed 5 April 2011 <http://www.grain.org/seedling/?id=440>

Hall, A. and J. Dijkman (2006) 'Capacity Development for Agricultural Biotechnology in Developing Countries: Concepts, Contexts, Case Studies and Operational Challenges of a Systems Perspective', Working Paper Series #2006-003, UNU Merit. Accessed 22 May 2012

<http://www.merit.unu.edu/publications/wppdf/2006/wp2006-003.pdf>

Hall, A.J. (2007) 'Origins and Implications of Using Innovation Systems Perspectives in the Design and Implementation of Agricultural Research Projects: Some Personal Observations', UNU-MERIT Working Paper 2007-013. Maastricht: United Nations University — Maastricht Economic and Social Research and Training Centre on Innovation and Technology.

Hall, A. and N. Clark (1995) 'Coping with Change, Complexity and Diversity in Agriculture: The Case of Rhizobium inoculants in Thailand'. *World Development*, 23(9):1601-1614.

Hassan and Karanja (1997) 'Increasing Maize Production in Kenya: Technology, Institutions and Policy', in Byerlee D. and C.K. Eicher (eds) *Africa's Emerging Maize Revolution*. Boulder, Colorado: Lynne Rienner Publishers.

Herbeson, J.W. (1973) Nation-building in Kenya: the role of land reform: Northern University Press (Evanston)

Hinchee, M. (1998) 'Development of Virus-resistant Sweetpotato', in Ives, C.L. and B.M. Bedford (eds) *Agricultural Biotechnology in International Development,* pp. 89-95. New York: Cabi Publishing. Accessed 25 May 2010 <http://ielrc.org>.

IFPRI (2012) 'State of Affairs' Assessment of Agriculture Biotechnology for Africa, a commissioned paper for the African Development Bank. Nairobi: Environment and Production Technology Division, International Food Policy Research Institute.

Ikiara, M. (2004) 'Agricultural Biotechnology Partnerships in Kenya', in Velho, L (ed.) Agricultural Biotechnology Research Partnerships in Sub-Saharan Africa. Achievements, Challenges and Policy Issues, UNU-MERIT Technology Policy Briefs 3:1, pp. 3-4. Accessed 16 May 2013 <www.ielrc.org>.

ISAAA (2012) 'Global Status of Commercialized Biotech/GM Crops: 2012'. Brief 44-2012: Executive Summary, accessed 14 January 2014 <http://www.isaaa.org/resources/publications/briefs/44/executivesummary>Accessed>

INIBAP (2005) Annual Report 2004. Montpellier: International Network for the Improvement of Banana and Plantain.

IITA (2008) 'Banana and Plantain in Africa: Harnessing International Partnerships to Increase Research Impact', Conference at the Leisure Lodge Resort Mombasa, Kenya 5–9 October 2008. Mombasa: Communication Office, International Institute of Tropical Agriculture, accessed 14 July 2012 <http://musalit.inibap.org/pdf/IN090340_en.pdf>

Ives, C.L and B.M. Bedford (eds) (1998) *Agricultural Biotechnology in International Development*. London: CABI Publishing, UK Biotechnology in Agriculture, Series no. 21

James, C. (2008) 'Global Status of Commercialized Biotech/GM Crops: 2007', CropBiotech Special Edition Press Release of ISAAA Brief No. 37-2007, February 13, 2008

Jansen, W., C. Falconi, and J. Komen (2000) 'The Role of NARS in Providing Biotechnology Access to the Poor: Grassroots or an Ivory Tower?', in Qiam, M., A.F. Krattiger, and J. Von Braun (eds) (2000) *Agricultural Biotechnology in Developing Countries: Towards Optimizing the Benefits for the Poor*. Boston: Kluwer Academic Publishers.

Kameri-Mbote, P. and P. Cullet (1999) 'Agrobiodiversity and International law', *Biopolicy* 22 Nairobi: African Centre for Technology Studies

Kanampiu, F.K., J.K. Ransom, and J. Gressel (2001) Imazapyr Seed Dressings for Striga Control on Acetolactate Synthase Target-site Resistant Maize. *Crop Protection* 20:885–895.

Kanampiu, F.K., J. K. Ransom, D. Friesena, J. Gressel, (2002) 'Imazapyr and Pyrithiobac Movement in Soil and from Maize Seed Coats to Control Striga in Legume Intercropping', *Crop Protection* 21: 611-619.

Katungi, E., A. Farrow, J. Chainu, L. Sperling and S. Beebe (2009) 'Common Bean in East Africa and Southern Africa: A Situation and Outlook Analysis', International Centre for Tropical Agriculture, accessed 10 April 2013. <http://www.icrisat.org/what-we-do/mip/projects/tl2-publications/research-reports/rr-common-bean-esa.pdf>

Khasiani, S. (1991) *Groundwork: African Women as Environmental Managers*. Nairobi: African Centre for Technology Studies.

Ransom, J.K., D. Friesena, J. Gressel, (2002) 'Imazapyr and Pyrithiobac Movement in Soil and from Maize Seed Coats to Control Striga in Legume Intercropping', *Crop Protection* 21:611-619.

Kapinga, R.E., P.T. Ewell, S.C. Jeremiah and R. Kileo (1995) 'Sweet Potato in Tanzania Farming and Food Systems: Implications for Research', CIP Sub-Saharan Africa Region. Nairobi: Kenya/Ministry of Agriculture.

KARI (2000) *For Alleviation of Hunger and Poverty', KARI/Monsanto Virus Resistant Sweet Potato Project, KARI*. Nairobi: Kenya Agricultural Research Institute Accessed 10 July 2012 <http://www.ielrc.org>

Kenya Daily Nation Newspaper (2000-2002), Agricultural Biotechnology in Kenya; ccessed 15 January 2003

<http://www.nationaudio.com/News/Daily Nation>

Kitay, J. and R. Callus (1998) 'The Role and Challenge of Case Study Design in Industrial Relations Research', in K. Whitfield and G. Strauss (eds), *Researching the World of Work: Strategies and Methods in Studying Industrial Relations,* pp.101-12. Ithaca: ILR/Cornell University Press.

Kingiri, A.N., and A. Hall (2012) 'The Role of Policy Brokers: The Case of Biotechnology in Kenya: Regulatory Policy Brokering', Review of Policy Research, African Centre for Technology Studies (ACTS), Nairobi.

Klerkx, L. and C. Leeuwis (2009) 'The emergence and embedding of innovation brokers at different system levels: Insights from the Dutch Agricultural Sector'. *Technological Forecasting and Social Change,* 76:849-860.Lam, L. (2004) 'Work Roles and Careers of R&D Scientists in Network Organizations'. Paper to be presented at DRUID Summer Conference 2004 on Industrial Dynamics, Innovation Development; Copenhagen, Denmark, June 14-16, 2004.

Accessed 10th April 2013.
http://www.druid.dk/uploads/tx_picturedb/ds2004-1309.pdf

Lubembe, C.K (1968) *The Inside of Labour Movement In Kenya.* Kenya: Equatorial Publishers.

Lundvall, B.A. (ed) (1992) *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning.* London: Pinter.

Makau, F. B and P, Kameri-Mbote (1995) 'Biotechnology in Kenya', in Juma, C., J. Mugabe and P. Kameri-Mbote (eds) (1995) *Coming to Life: Biotechnology in African Economic Recovery*, Kenya and London: African Centre for Technology Studies and Zed Books.

Rosegrant, M. W. (2012), *Global Overview of Agricultural Biotechnology.* Washington DC: Environment and Production Technology Division, International Food Policy Research Institute.

Mango, N.R. (1999) 'Integrated Soil Fertility management in Siaya district, Kenya', Managing Africa' Soils No. 7. Wageningen: The Department of Sociology of Rural Development, Wageningen Agricultural University.

Manyong, V.M, A.D. Alene, A. Olanrewaju, B. Ayedun, V. Rweyendela, A.S. Wesonga, G. Omanya, H.D. Mignouna and M. Bokanga (2008) 'Baseline Study of Striga Control using IR Maize in Western Kenya: An Agriculture Collaborative Study on Striga Control', a paper prepared for African Agricultural Technology Foundation (AATF), Nairobi.

Massola R (1992) 'Plant Biotechnology in Sub-Saharan Africa Today', in A. Sasson and V. Costarini *Plant Biotechnology for Developing Countries*, Wageningen, The Netherlands: CTA/FAO.

Mechlem, K. (2010) 'Agricultural Biotechnologies, Transgenic Crops and the Poor: Opportunities and Challenges. Human Rights Law Review.'

Accessed 3 August 2013

<http://gnhre.org/virtual-research-repository/ biotechnology/agricultural-biotechnologies-transgenic-crops-the-poor-opportunities-challenges-k-mechlem/>

Rangnekar, D. (2013) 'Geneva Rhetoric, National Reality: The Political Economy of Introducing Plant Breeders' Rights in Kenya' in *New Political Economy.* London: Routlege Routledge and the Taylor & Francis Group,

Smale, M. and H. de Groote (2003) 'Diagnostic Research to Enable Adoption of Transgenic Crop Varieties by Smallholder Farmers in Sub-Saharan Africa'. *African Journal of Biotechnology* 2(12): 586-595.

McNamara, J. (2008) 'ICT and Agriculture Innovation: Trends and Opportunities', a paper presented at an IFPRI International Conference on Advancing Agriculture in Developing Countries Through Knowledge and Innovation, Addis Ababa (7-9April), Accessed 15 May 2013.

<http://www.ifpri.org/sites/default/files/publications/oc59.pdferry>

Microbial Resource Centre (MIRCEN) (1990) *MIRCEN Newsletter* 4 (1) University of Nairobi.

Millstone, E. and T. Lang (2008) *The Atlas of Food. Who Eats What, Where, and Why,* second edition. London: Earthscan Publishers.

MOA&RD (1990-2000) Annual Reports of Food Production. Nairobi: Ministry of Agriculture.

MOA&RD (2001-2008) *Annual Reports of Food Production.*, Nairobi: Ministry of Agriculture.

Jones, M. (2008) 'Using Knowledge and Innovation in Pro-poor Agricultural Research', a paper presented at an IFPRI International Conference on Advancing Agriculture in Developing Countries Through Knowledge and Innovation. Addis Ababa (7-9April). Accessed 15 May 2013.

<http://www.ifpri.org/sites/default/files/publications/oc59.pdferry≥

Morris, M. and D. Hoisington (2000) 'Bringing the Benefits of Biotechnology to the Poor. The role of the CGIAR Centers', in Qaim, M., A.F. Krattiger, and J. von Braun (eds) *Agricultural Biotechnology in Developing Countries: Towards Optimizing the Benefits for the Poor*, Boston: Kluwer Academic Publishers.

Mose, L.O., H.O. Nyangito and L.G. Mugumieri (1997) 'An Analysis of the Socio-economic Factors which Influence Chemical Fertilizer Use among Smallholder Producers in Western Kenya', in Ransom, J.K. et al. (eds). *Maize Productivity Gains through Research and Technology Dissemination: Proceedings of the Fifth Eastern and Southern Africa Regional Maize Conference.* Arusha, Tanzania, June 1996.

Mugendi, D.N (2011) 'Comparative Analysis of the Current and Potential Role of Legumes in Integrated Soil Fertility Management in East Africa' Fighting Poverty in Sub-Saharan Africa The Multiple Roles of Legumes in Integrated Soil Fertility Management, accessed 5 October 2013

<http://www.betweenreads.com.au/book/fighting-poverty-in-sub-saharan-africa-the-multiple-roles-of-legumes-in-integrated-soil-fertility-management.do>.

Mungai, N. (2000) 'Transgenic Sweet Potato Could End Famine', Environment News Service.

Nassul, S. K. (2012) Yield Effects of Tissue Culture Bananas in Kenya: Accounting for Selection Bias and the Role of Complementary Inputs. *Journal of Agricultural Economics*, 63(2): 444-464.

NACBAA (1991) National Advisory Committee on Biotechnology Advances and Their Applications *Report* Nairobi: Ministry of Research, Technical Training and Technology.

NCST (1998) *Biosafety Framework for Kenya Prepared under the UNEP/GEF Pilot Biosafety Enabling.* Nairobi: National Council of Science and Technology, Ministry of Science and Technology.

Nelson, R.R. (1987) *Understanding Technical Change as an Evolutionary Process.* Amsterdam: Elsevier.

Nelson, R.R. and N. Rosenberg (1993) Technical Innovation and National Systems. Introductory chapter in R. R. Nelson (ed) and S. Winter (1982) *An Evolutionary Theory of Economic Change.* Cambridge, MA: Harvard University Press.

Nelson, R.R. (ed.) (1993) *National Innovation Systems: A Comparative Study*. Oxford: Oxford University Press.

Ngunjiri M., A. Abubakar, A.O. Okech and P.T. Ewell (1993) 'Sweet Potato in the Food Systems of Four Regions of Kenya: A collaborative survey report by KARI, CIP, and the collaborative study of Cassava in Africa COSCA'. Nairobi: Kenya Agricultural Research Institute.

North, D.C. (1990) *Institutions, Institutional Change and Economic Performance.* Cambridge: Cambridge University Press.

Nyoro, J. and J. Ariga (2004) 'Preparation of an Inventory of Research Work Undertaken in Agricultural/Rural Sector in Kenya', Working Paper 14, Nairobi: Tegemeo Institute of Agricultural Policy and Development.

Odame, H. (1997) 'Biofertilizer in Kenya: Research, Production and Extension Dilemma', *Biotechnology and Development Monitor*,

Odame, H. and Mbote, P. (2000) 'Agricultural Biotechnology Assessment in sub-Saharan Africa: a Case Study of Kenya', a paper prepared for the Regional Workshop on Building National Biotechnology Innovation Systems: New Forms of Institutional Arrangements and Financial Mechanisms organised by ACTS, Nairobi (6-8 December). Accessed 24 June 2010 <http://www.ids.ac.uk>; <http:www.ierlc.org> <http://www.ielrc.org/content/n0206.pdf

Odame, H. (2002a) 'Smallholder Access to Biotechnology: Case of Rhizobium Inocula in Kenya,' *Economic and Political Weekly*, Vol. XXXVIL, No. 27, 6 July 2002. Accessed 12 October 2013 <http://www.ids.ac.uk>

Odame, H. (2002b) 'Innovation and Policy Process: Case Transgenic Sweet-potato in Kenya' *Economic and Political Weekly*, Vol. XXXVIL, No. 27, 6July 2002. Accessed 6 October 2013 <http://www.ids.ac.uk>.

Odame, H., K.P. Mbote and D. Wafula. (2003) 'Governing Modern Agricultural Biotechnology in Kenya: Implications for Food Security'. Biotechnology Policy Series No 20. Brighton: Institute of Development Studies Sussex,. Accessed 16 October 2013 <http://www.ids.ac.uk >

Odame, H. and O. Okumu (2010) 'Biosafety Regulation: Opening Up the Debate: Lessons from Kenya and Philippines', proceedings of the International Workshop, held at African Institute for Capacity Development (AICAD), Jomo Kenyatta University of Agriculture and Technology (JKUAT), Nairobi, (15-16 November).

Odame, H. and E. Kangai (2013) 'Agribusiness Public Private Partnerships: A Country Report of Kenya', Rome: Food and Agricultural Organisation of United Nations.

Odame, H. and E. Muange (2010) 'Can Agro-dealers Develop the Green Revolution in Kenya?' Accessed 26 August 2013 <http://www.future-agricultures.org>.

Odame, H. and E. Muange (2011) 'Agro-Dealers and the Political Economy of Agricultural Biotechnology Policy in Kenya', Working Paper 033, Future Agricultures Consortium.

Odhiambo, B. (2000) 'Institutional Experiences in Implementation of the National Biosafety Regulations and Guidelines in Kenya', a paper presented at a National Workshop on Experiences with and the Future of Kenya's Biosafety System, Nairobi, Grand Regency Hotel (26 April) Accessed 15 October 2013, <http://www.biosafetynews.com>.

Odhiambo, W.O., H.O. Nyangito and J. Nzuma (2004) 'Sources and Determinants of Agricultural Growth and Productivity in Kenya', Discussion Paper No. 34. Nairobi: Kenya Institute for Public Policy Research and Analysis, accessed 15 October 2013 <http://www.ielrc.org>.

Oikeh, S.O. (2009) 'Developing Water Efficient Maize for Africa', a paper presented at 3rd African Grain Summit on Linking Farmers to Markets: Stimulating Agricultural Productivity in Africa, Dar es Salaam (4-6 November)

Accessed 21 July 2011 <http://www.graintradesummit.com/dl.asp?f=02_Friday+November+6th+2009%2F0830-0930%2FSylvester+Oikeh+-Developing+Water+Efficient+Maize+in+Africa.pdf>.

Ogendo, A.A.O.M and O. Joshua (2001) 'Response of Common Bean to *Rhizobium* Inoculation and Fertilizers', *The Journal of Food Technology in Africa,* 6(4): 121-125.

Olembo, N. (2001) 'Elements of Intellectual Property and the Intellectual Property Rights Policy in Kenya', proceedings of a regional workshop on Development of Intellectual Property Rights Management System organized by (NCST) and (KIPO), Maasai Mara Serena Hotel, Kenya (6-7 December) NCST Publication no. 44, Kenyan BIO-EARN Publication No. 3. Accessed on 12th July 2012

<http://www.ids.ac.uk>.

OFAB (2012) Open forum on agricultural biotechnology in Africa ()report (Vol. VI) ISBN 978-9966-1748-0-2 Kenya chapter, Nairobi

Paarlberg, R. (ed.) (2009) *Starved for Science: How Biotechnology Is Being Kept out of Africa* Cambridge: Harvard University Press.

PR Newswire (2008) 'Record Venture Capital and Heated Deal Environment Propel Global Biotechnology Industry Forward', 20 May. Accessed 26 July 2013 <http://www.thefreelibrary.com/Record+Venture+Capital+and+Heated+Deal+Environment+Propel+Global...-a0179180999>.

Qaim M. (1999) 'Assessing the Impact of Banana Biotechnology in Kenya'. ISAAA Brief No. 10. New York: International Service for the Acquisition of Agri-Biotech Applications.

Rajalahti, R. (2008) 'Agricultural Innovation Systems: Why this Approach', Concept Note prepared for the World Bank, Washington DC

Rukuni M, M.J. Blackie and C.K. Eicher (1998) 'Crafting Smallholder-driven Agricultural Research Systems in Southern Africa', *World Development* 26(6):1073–1087.

Sande, T. Van de (1994) 'The Politics of Biotechnology: on the Exposure of Trojan Horses', *Biotechnology and Development Monitor*, 19: 24

Schumpeter, J.A. (1939) *Business Cycles: A Theoretical, Historical and Statistical Analysis of the Capitalist Process.* 2 vols. New York: McGraw Hill.

Scoones, I. and D. Glover (2009) 'Africa's Biotechnology Battle'. *Nature* 460: 797-798.

Senker J. (ed.) and R. van Vliet (1998) *Biotechnology and Competitive Advantage: Europe's Firms and the US Challenge.* Cheltenham: Edward Elgar Publishing.

Smale, M. and H. de Groote (2003) 'Diagnostic Research to Enable Adoption of Transgenic Crop Varieties by Smallholder Farmers in Sub-Saharan Africa'. *African Journal of Biotechnology* 2(12): 586-595.

Sorrenson, M.P.K. (1967) *Land Reform in the Kikuyu Country: A Study of Government Policy*. Nairobi: Oxford University Press. Spielman, D.J., F. Hartwich and K. von Grebmer (2007) 'Public–Private Partnerships in International Agricultural Research', Research Brief No. 9, IFPRI.

Spielman, D.J. and D. Kelemework (2009) 'Measuring Agricultural Innovation System Properties and Performance: Illustrations from Ethiopia and Vietnam.' IFPRI Discussion Paper 00851. Washington DC.

Spielman, D.J., J. Ekboir and K. Davis (2009) 'The Art and Science of Innovation Systems Inquiry: Application to Sub-Saharan African Agriculture', *Technology in Society*, 31: 399-405

Ssali, H and S.O. Keya (1986) 'The Effects of Phosphorus and Nitrogen Fertilizer Level on Nodulation, Growth and Dinitrogen Fixation of Three Bean Cultivars', *Tropical Agriculture* (Trinidad) 63: 105-109.

Ssali, H. (1988) 'Rhizobium phaseoli Inoculation Trials on Farmers' Fields in Kenya', *East African Agricultural and Forestry Journal* 53: 151-157.

Stamp P. (1989) *Technology, Gender and Power in Africa: Technical Study*. Ottawa: International Development Research Council.

Swanson, B.E., K.M. Singh and M.N. Reddy (2008) 'A Decentralized, Farmer-Led, Market-Driven Extension System: The ATMA Model in India. IFPRI Conference presentation. Addis Abbaba. Accessed 15 April 2012

<http://www.ifpri.org/sites/default/files/S05a2-Swanson.pdf>

Technoserve (2007) 'Choosing Between Strategies: Adapting Industry Approaches to Specific Value Chain Analysis: Using Three Comparative Commodities', Small Enterprise Development Workshop. Gerzensee Center, Switzerland (11-12 January) Accessed 15 June 2011 <http://www.technoserve.org/assets/documents/smallenterprisedevelopmentworkshoptimpiperpresentation.pdf>.

Townsend, P. (1993) *The International Analysis of Poverty*. New York: Harvester Wheatsheaf.

UNESCO (2007) 'Science in Africa: UNESCO's Contribution to Africa's Plan for Science and Technology to 2010', United Nations Education and Science Council. Accessed on 12th July 2012

http://unesdoc.unesco.org/images/0015/001504/150449e.pdf

Velho, L. (2004) 'Agricultural Biotechnology Research Partnerships in sub-Saharan Africa. Achievements, Challenges and Policy Issues. *United Nations University-MERIT Technology Policy Briefs* 3(1) 1-6.

Wafula, J. and C. Falconi (1998) 'Agricultural Biotechnology Research Indicators', Kenya Discussion Paper No. 98-9 September 1998, The Hague: International Service for National Agricultural Research. Accesed 5 October 2010 <www.ids.ac.uk>.

Wambugu, F. M. (2001) Modifying Africa. How Biotechnology Can Benefit The Poor and Hungry. Accessed 5 August 2013 <http://www.ielrc.org>.

Wambugu, F.M. and R. Kiome (2001) 'The Benefits of Biotechnology for Small-Scale Banana Producers in Kenya', ISAAA Policy Brief No. 22-2001. Accessed 5 August 2013 <http://www.ielrc.org>.

Wambugu, F.M. (2003) 'Development and Transfer of Genetically Modified Virus-resistant Sweet Potato for Subsistence Farmers in Kenya', *Nutrition Reviews* 61(6). Accessed 5 August 2013

<http://www.alibris.com/books/author/Wambugu,-Florence-M>.

Warren, D. M. (1992) 'Using Indigenous Knowledge for Agriculture and Rural Development', a Concept Paper for Exploring the Potential Utility of the Global Network of Indigenous Knowledge Resource Centers for International and National Agricultural Research Centers. Ames, Iowa: CIKARD, Iowa State University.

Wekundah J. (2004) 'Intellectual Property, Partnerships and People', Nairobi: Biotechnology Trust Africa. Accessed 21 March 2013 <www.knowlegde.cta.nt>.

Wekundah, J. (2000) 'Document on National Capacity Building in Biotechnology'. Nairobi: Kenya Agricultural Biotechnology Platform.

Van Wijk, J., J.I. Cohen and J. Komen (1993) 'Intellectual Property Rights for Agricultural Biotechnology: Options and Implications for Developing Countries. ISNAR Report no 3. The Hague.

Winstone, C.L. and J.F. Lipscomb (2007) *The History of Kenya Agriculture*. Nairobi: University Press of Africa.

Woolmer P.L and C.N. Savala (2007) 'Striga Management through Herbicide Resistance: A Public-Private Partnership in Action', a paper presented at AAAE Conference, *AAAE Conference Proceedings* 489-496

Woolmer P.L and M. Omare (2005) 'Ua Kayongo Hybrid Maize, The Striga Killer: A New Approach to Controlling Parasitic Striga for Kenyan Maize Producers', a report prepared for African Agricultural Technology Foundation, Nairobi, Kenya

Woolmer P. L., J.H.P. Kahindi and N. Karanja (1996) 'Nitrogen Replenishment in the East African Highlands through Biological Nitrogen Fixation and Legume Inoculation', a paper presented at the African Association of Biological Nitrogen Fixation Conference in Cote d'Ivoire.

World Bank (2006) *Enhancing Agricultural Innovation: How to Go Beyond the Strengthening of Research Systems*. Washington, DC: World Bank. Accessed 14 October 2010 <www.ids.ac.uk>.World Bank (2007) *World Development Report 2008: Agriculture for Development,* Washington DC, USA: The International Bank for Reconstruction and Development and The World Bank.

World Bank (2009) *Agribusiness and Innovations Systems in Africa*. Washington, DC: World Bank.

World Bank (2012) *Agricultural Innovations Systems: An Investment Source Book*. Washington, DC: World Bank.

Resume

Born in Kenya in 1956, Hannington Odame was admitted to the ISS PhD Programme on the basis of a B.Sc. in Agricultural Economics from the University of Guelph, Canada (1990) and an MA in Development Studies (Agricultural and Rural Development) from the Institute of Social Studies (1996). Previously he had obtained a Diploma in Farm Management from Egerton University, Njoro, Kenya in 1979.

He is currently Executive Director of the Centre for African Bio-Entrepreneurship (CABE) in Nairobi; Regional Coordinator of the East African Hub of the Future Agricultures Consortium (FAC), and also co-convenor of FAC's Science, Technology and Innovation (STI) theme group.

He has over 25 years of experience, facilitating agricultural knowledge sharing and specializes in Agricultural Innovations Systems (AIS). He has contributed to a book published by the World Bank titled "Agribusiness and Innovation Systems in Africa. Hannington's strong interpersonal skills enables him to network with people passionate about uplifting the livelihoods of the rural poor.