THE COST OF COEXISTENCE BETWEEN BT MAIZE AND OPEN POLLINATED MAIZE VARIETIES IN LOWLAND COASTAL KENYA

By

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Preface

This study was carried out to assess the spatial distribution of open pollinated maize varieties (OPVs) in lowland coastal Kenya and analyze how this distribution affects coexistence between Bt maize and OPVs. The specific objectives of this research were to determine the size of maize fields, distances between maize fields and the changes of these parameter in the agricultural landscape across the lowland coastal Kenya region. These data are used to analyze the economic and practical impacts of alternative separation distances and buffer zone sizes.

The study was carried out in two stages. First was to describe the spatial distribution of OPVs using agroecological zones as the reference spatial strata. Arc view software and descriptive statistics were used for this analysis. Geo-referenced data was collected for this purpose in lowland coastal Kenya using a hand held GPS. Secondly, from the spatial distribution of OPVs, costs of coexistence were directly approximated.

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DEFINITION OF ABBREVIATIONS USED IN TEXT

BMELV:	The Federal Ministry for Nutrition, Agriculture and Consumer Protection
CBAC:	Canadian Biotechnology Advisory Commission
CIMMYT:	International Maize and Wheat Improvement Centre
DEFRA:	Department of Environmental, Food and Rural Affairs
EARO:	Ethiopian Agricultural Research Organization
EU:	European Union
FAO:	Food and Agriculture Organization of the United Nations
IRMA:	Insect Resistance Maize project for Africa
ISAAA:	International Service for the Acquisition of Agro-Biotech Applications
KARI:	Kenya Agricultural Research Institute
NIAB:	National Institute of Agricultural Botany
GPS:	Geographical Position System
SCIMAC:	Supply Chain Initiative on modified Agricultural Crops
USA EPA:	United States of America Environmental protection agency

CHAPTER I

INTRODUCTION

Biotechnology and Agricultural Systems

There is growing optimism that genetically modified (GM)[1] crops offer one of the best alternative solutions to world hunger. Genetic modification can increase production, lower cost of food and raise yield on marginal lands (Clive 2007). Optimism is high among supporters of the technology that GM crops will revolutionize world agriculture especially in developing countries in a way that will improve food security and increase rural income. This technology however, is not yet popular in Africa and few GM crops have been released to African small holder farmers.

There is also growing concern about the effect of GM crops on agricultural systems (FAO 2004). An issue of concern regarding the cultivation of GM crops in the agricultural landscape is that GM crops could cross pollinate with non-GM crops. This could lead to unwanted GM genetic material in non-GM crop production system (Miguel 2005; Yann et al. 2007). Since GM and non-GM crops have different economic and cultural values, the presence of GM material in non-GM crops has economic and commercial implications in the context of acceptability and marketability of conventional crops. In event that unwanted GM material is above the tolerable threshold, it could

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[1] Crops produced from genetically modified organisms that have had their DNA altered through genetic engineering.

trigger the need of a GM label on a crop intended to be non-GM. This could cause loss of income due to lower prices but also additional costs of labeling.

To fully exploit the benefits from both agricultural systems, spatial coexistence[2] measures have been suggested (Ma and Reid 2004; Saak 2004). The most important of these is separation distances (Ingram 2000; Perry 2002). To date, it is the only technique considered in the European legislation for coexistence between genetically modified and conventional maize varieties to limit cross pollination to below acceptable threshold levels of 0.9% according to EU regulation No.1829/2003.

However, the question of adequate isolation distance is still a subject of debate. In the European Union (EU) for example, since 2001, member states have developed and others are still developing a range of minimum separation distance standards to ensure coexistence of GM maize and the non-GM crop (Table I-1). Most recently, the European Commission's Joint Research Centre (JRC) reported in 2006 that separation distances of 50m and 100m are required to achieve threshold levels of 0.9% and 0.5%, respectively.

Table I-1. Separation Distance (m) guidelines from selected countries

Country	Maize crop	
	Conventional	Organic
1. UK	110	*300
2. German	150	300
3. Spain	50 and 4 rows	
4. Netherlands	25	250

Source: 1.DEFRA, 2006, *SCIMAC 2001, 2.BMELV 2007, 3.MAFF 2005, 4.gmo safety.eu

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[2] The principle that farmers should be able to freely cultivate crops of their choice using the production system they prefer (conventional, organic or GM).

For the case of developing countries, however, the need to ensure the safety of biotech agriculture poses enormous challenges. Distinctive differences exist between the agricultural systems in developing and developed countries. These differences affect the dimension of risks and benefits from GM crops (Cleveland and Soleri 2005). Consequently, risk management and regulatory approaches applicable to developed countries currently cultivating GM crops may not be suitable for developing countries. Despite these concerns, GM crops are slowly finding their way into agricultural lands of developing countries.

In this study, focus is on *ex ante* regulations to ensure coexistence between Bt maize and open pollinated maize varieties in Kenya using two alternative measures: isolation distances and buffer zones. The concern is that excessive separation distance requirements may impose restrictions on potential Bt maize farmers and may not be proportional to the farmers basic economic incentives to plant a GM crop. Moreover, a particular separation distance measure may not be practically feasible at the farm level. To contribute to the understanding of this issue in Kenya, we characterize the spatial distribution of Open Pollinated maize Varieties (OPVs) in the lowland coastal region and determine how this distribution is likely to affect the implementation of separation distances as a coexistence measure.

Coexistence in the Kenyan agricultural context

Kenya is currently in the process of introducing genetically modified maize for large scale cultivation in the agricultural landscape. Since 1999, the Insect Resistance Maize project for Africa (IRMA), a joint collaboration between Kenya Agricultural Research Institute (KARI) and International Centre of Improvement of Wheat and Maize

(CIMMYT), has been working to develop transgenic based insect resistant maize. However, comprehensive policies and regulations to guide the cultivation of these varieties in the agricultural landscape are still lacking.

Biotechnology in Kenya is a highly sensitive issue and therefore, the IRMA project has to study the environmental, social and regulatory systems and how it fits in the farming system (Mugo et al. 2005). Not all varieties will be transformed and some farmers want to keep their local varieties (Kimenju and De Groote 2008). Attention is also paid to regulating innovations in biotech agriculture so that no risk is posed to the export trade of Kenya’s agricultural products.

With reference to the proposed large scale cultivation of Bt maize, there is uncertainty as to whether both types of crops/varieties can coexist within the same maize agricultural system without compromising the economic and cultural value of each other. A particular issue of concern is whether coexistence between Bt maize and conventional maize varieties is feasible under the current Kenyan agronomical conditions. There is need to develop policies that are cost effective, proportionate and specific to particular cropping systems which should guarantee that both GM and non-GM crop production can take place in the same agricultural landscape in compliance with the legal standards applicable at farm.

Studies have shown that the adoption and cultivation of GM crops is affected by the size of the farm and the minimum distance requirements (Messean et al. 2006; Beckmann et al. 2006). The smaller the farm size relative to the minimum distance requirements, the higher the transaction costs of coordinating the planting of the GM crop. Also, it is known that the spatial distribution of pollen donating and recipient fields has an important influence on the possibility of cross pollination (Ingram 2000). Against this background, a question arises: how is the spatial distribution of local maize varieties in Kenya likely to affect coexistence at the farm level? From this perspective, it becomes of interest to examine the feasibility of different separation standards or measures given the spatial distribution of existing maize crop.

Land fragmentation due to population pressure or the tenure system is a major concern in Kenya to the extent that it may not allow farmers who opt to plant Bt maize to meet the specific separation distance measures if maize fields exist in close proximity. Unfortunately, no information is available as to the extent of this fragmentation. Moreover, the distance between maize fields, the size of maize fields and the diversity and distribution of conventional maize varieties within the region have not been studied or documented.

Research has shown that once Bt maize is introduced into an agricultural landscape, there is a high probability that cross pollination with conventional varieties will occur (Miguel 2005). The risk of cross pollination between Bt maize and local maize varieties on neighboring plots is a negative spatial externality because of the costs it may impose on neighboring farmers (Saak 2003). Such costs may include farmers' loss of taste and variety preferences, price premium of their crops/products in the market and farmers having to change their cropping system (Berthaud and Gepts 2004).

From a policy perspective, to reduce or minimize externality exposure and or concentration, spatial separation measures must be imposed on GM producers. This implies additional costs to GM producers due to separation. Of interest is the economic cost of separation at the farm level across the region. What is the cost of establishing isolation distances and /or buffer zones for GM maize production? Whereas there is growing empirical literature that analyzes the effect of distance dependent externalities on optimal land-use, there are only few economic models that explicitly address this issue (Saak 2004).

An important aspect of research aimed at understanding the potential of gene flow and the costs associated with its control or management at the farm level is the spatial distribution of the existing compatible crops and their evidence concerning the potential for spreading GM characteristics (Belcher et al. 2005).To contribute to the understanding of this issue, we characterize the spatial distribution of Open Pollinated Maize Varieties (OPVs) in the low tropics maize production zone in coastal lowland Kenya as defined by Hassan et al. (1998).

The study will document variety diversity across the region and determine the size of maize fields, distances between maize fields and the change of these parameters in agricultural landscape across the lowland coastal Kenya region. The study will then analyze the practical and economic impacts of the *ex ante* regulation(s) of different separation distances and buffer zone measures. Cost effects and wider economic impacts of coexistence on the agricultural sector or the agro-food chain are not explicitly tackled in this study; rather, consideration is made of the economical aspects of the application of different isolations measures as the case may apply to lowland coastal Kenya. The study draws lessons from other countries already growing genetically modified crops/maize to inform the regulatory debate in Kenya.

Understanding the spatial distribution of open pollinated maize varieties will provide empirical evidence to enable prediction of the posibility of GM contamination and provide a basis for developing strategies that will offer a clear policy framework for GM and non GM crop coexistence in the agricultural landscape. This study will also provide evidence of the practical and economical feasibility of different isolation strategies to regulate coexistence between Bt maize and conventional maize varieties in lowland coastal Kenya. In brief, this study is intended to act as a working document to guide the Bt maize regulatory framework in order to balance the tradeoff between risks and economic benefits.

The rest of the paper is structured as follows: the next section that follow provides background on the importance of maize in Kenya and identifies constraints to maize production and the need to increase production using the Bt technology. This is followed by a section on coastal maize production system and biotech regulation in Kenya and ends with a description of the study area. A section for further reading is included as an appendix. A methodology section describing conceptual frame work, data collection and analysis is shown. Next, results are presented and discussed. The paper ends with conclusions and recommendations on policies and future areas of research.

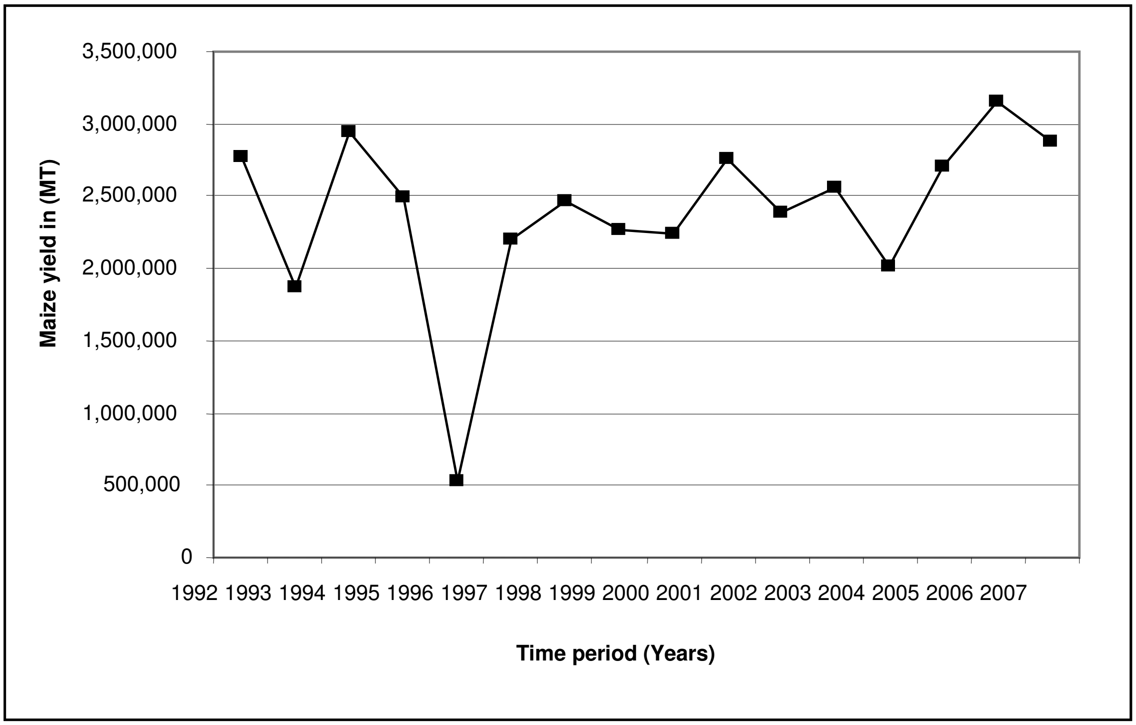
Background

Importance of maize in Kenya

Maize is the basic staple food in coastal Kenya grown by nearly all households primarily for subsistence purposes (Pigali 2001 and Waaijenberg 1994). Maize provides about 42% of the dietary energy intake for about 90% of Kenyans (Karanja and Oketch 1990). It is associated with household food security such that a low-income household is considered food insecure if it has no maize stock regardless of other foods the household has at its disposal (Waaijenberg 1994). Maize also doubles as a main source of income for the farm households in the maize surplus regions.

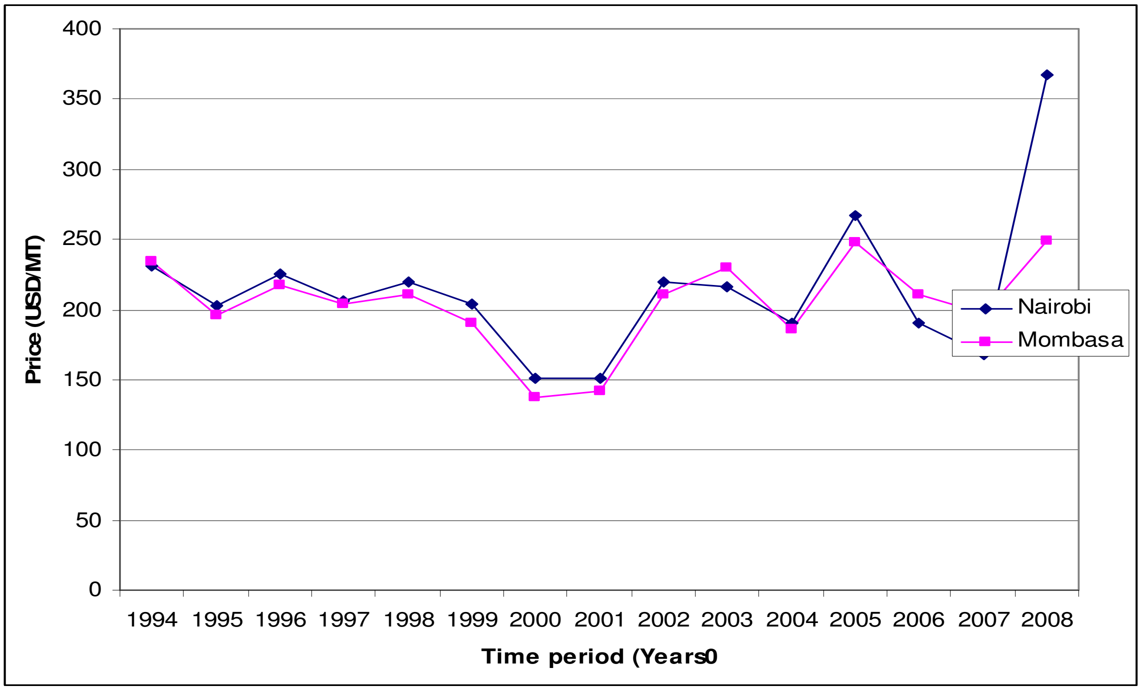
Despite the great efforts being made to increase maize production, the demand has occasionally outpaced supply, requiring importation of large quantities of maize grain. Average maize production per capita in Kenya is estimated at 81kg/capita, while consumption is estimated at 103kg/per capita (Pingali 2001). While population has continued to grow at a steady pace 2.9% per annum (De Groote 2001), maize yields have stagnated (figure I-1) and have not kept up with demand. Nationally, maize production declined rapidly in the mid 1990s. Although production has since recovered, growth in production has been small.

Prices of maize in Kenya are among the highest in the region, and continued to rise especially in the last five years (figure I-2), progressively diminishing access to food for the poorer sections of the population. With the removal of the high import tariff on maize in 2000, it was hoped that the private sector would cover the deficit (FAO 2002). Nevertheless, deficit vulnerability to access maize on the market continues to hurt the poorer section especially in areas of low production like the coastal region (Wekesa et al. 2003). Annual maize production in Kenya is 2.3 million tons produced on 1.5 million hectares at an average grain yield of 1.5 t/ha. Growth rate in maize production is low. For example from 1988 to 1999, growth rate averaged –1.3% (Pingali 2001). Production of the crop has continued to fluctuate over the years and lags behind demand.



Source: Regional Agricultural Trade Intelligence Network, 2008

Figure I-1. Maize production in Kenya, 1992-2007



Source: Regional Agricultural Trade Intelligence Network, 2008

Figure I-2. Average Maize Price at the Coast (Mombasa) and Nairobi

Constraints to maize production in Kenya

The causes of low production have been documented as poor soil fertility, losses due to weeds (especially parasitic striga) and stem borers (Wekesa et al. 2002). Frequent occurrences of droughts in the region are also to blame for insufficient domestic production (Bancy 2000). Farmers spread the risks of maize production through a number of strategies including growing of local open pollinated varieties (De Groote 2002). The various challenges have made farmers suspicious of new maize varieties and to their local varieties.

Surveys have indicated that farmers perceive stem borers as the major challenge to maize production (Wekesa et al. 2002 and De Groote 2004). Field crop losses from stem borer infestation (mainly by *Chilo partellus* and *Buseola fusca*) nationally is estimated by farmers to average 13.5%, valued at Kenya shillings 5.6 billions (De Groote et al. 2004). Throughout the coastal region, pre harvest losses from stem borers are estimated to cause a yield loss of 9% and 6.1% in long and short rain seasons respectively (De Groote 2002). Within the region, Ely et al. (2004), reports a pre-harvest loss due to stem borers as estimated by farmers to range around 15%. These losses often become hard hitting in smallholder maize production households, sometimes forcing farmers to abandon their fields.

Pests are most destructive in the larval stage. After hatching, the larvae tunnel inside maize stalks and become difficult to control. Once inside the maize plant, pests' feeding may lead to dead heart, reductions in the number of ears, or structural damage increasing the likelihood of falling in high winds. In other instances, pests attack maize ears making the cob vulnerable to cob rots (Mwangi and Ely 2001).

Severe infestations of pests often results when the temperature is warm and humidity is high, characteristic of sub-Saharan Africa. The problem of pest infestation is expected to persist and worsen in the near future and over the long-term because global climate change models forecast higher temperatures that will promote higher pest populations within the region (Hulme 2005).

Conventional methods of pest control that employ chemical spraying (usually organophosphates and pyrethroids), although effective, are expensive to buy and apply. As a result maize fields are rarely treated. In instances where chemical spraying is applied, pests appear to be defeating these applications and gaining an upper hand through resistance to conventional chemical sprays. Besides, there is a difficulty of timing these applications and the resulting difficulties in eradicating the pest once it has infested the crops (Mwangi and Ely 2001). The use of pesticides is also hampered by unpredictable levels of infestation and wash off of pesticides when it rains, often leading to sub optimal results.

Bt maize

Biotechnology, in particular genetic engineering (GE), offers an alternative efficient approach to pest management practices (Eugene et al. 2003). A promising GE technology is Bt maize, in which a single gene (from entomopathogenic bacteria *Bascillus thuringeniensis*) is inserted into maize, producing the Bt pest control agent from within the plant itself. The insecticidal proteins produced by Bt have enabled a uniquely effective tool for the control of a wide range of insect pests (Eugene et al. 2003). The Bt maize plant produces the toxins throughout the various tissues over its life-cycle. The larvae that penetrate the plant tissues are killed when they ingest the toxin produced in the Bt maize (Mwangi and Ely 2001).

To counter insect infestation in Kenya, IRMA has been using both conventional breeding and Bt technology to develop maize varieties adapted to East Africa. Bt maize is expected to protect maize from stem borers, while saving on production costs and reducing pesticide residues in the environment. In addition to Bt genes protecting maize plants from stalk borers, research has also shown that *Bt* maize has the potential to increase yields by 5% in the temperate maize growing areas and 10% in the tropical areas of Kenya (Owur et al. 2004).

However, there is controversy and concern about the nutritional and environmental safety of these crops. While GM crops are very popular in North and South America, Europe and Japan have largely been hesitant to adapt them so far (FAO, 2004). African countries where the technology has not been popularized are caught in the middle; should they follow America's scientific or Europe's precautionary approach? These countries already face agricultural surpluses, so a new pest control method is not in their major interest and they have consumers who are very wary of the quality of their food and the effect of agriculture on the environment. Africa, however, faces food shortages, so a balance has to be struck between food security and conservation safe agriculture.

Kenya's maize production system relies primarily on smallholder agriculture that accounts for 70-80% of total production (Adrian 2002). These farmers use minimal inputs and open-pollinated varieties (OPVs) of seed, mainly the local varieties (Wekesa et al. 2003). The local varieties are a vital source of genetic diversity for breeding locally adapted varieties and there seems to be a general consensus for the need to conserve them. A study by Kimenju and De Groote (2008) showed that whereas the Kenyan population is not worried about the nutritional safety of GM foods, there is concern about the safety of these crops in the environment.

People are worried that GM crops could cross pollinate with related plant species and cause loss of unique varieties and environmental harm by creating new or more problematic weeds (Miguel 2005 and Eugene et al. 2003). Fortunately, maize is foreign to Africa with its center of origin being Central American and thus no potential wild relatives in Kenya. Therefore, the risk of ‘super weeds’ is not likely to be significant in Kenya and Africa generally.

Safety concerns have led to stiff regulations in the introduction and commercialization of GM crops. Since the Bt gene is dominant (Eugene et al. 2003), it could cross into local landraces or closely related species and express its traits in the offspring. In East Africa, farmers often recycle their maize seed, so non-adopters of Bt maize will face difficulties if they choose to keep their varieties genetically pure.

Although some have argued that local varieties are not static but evolve over time, farmers and conservationists argue that these varieties evolve according to local needs and growing conditions (Berthaud and Gepts 2004). Therefore those farmers who want to keep their varieties intact should be protected. Wekesa et al. (2002) observes that the use of local or improved seed is largely associated with factors related to risk evasion of the losses associated with new varieties whose performance is either not known or associated with high input levels and the unavailability of seed.

Strategies of controlling insect pest resistance and minimizing or eliminating gene flow are based on spatial or temporal separation, with a minimum distance or time maintained between Bt maize and other maize varieties (Ma and Reid 2004; Saak 2004; Perry 2002; Ingram 2000). In this region, maize is planted in two seasons, but often these seasons are not clearly defined, and so maize is planted during most of the year. Temporal separation is this setting is not realistic, so spatial separation is the only option.

However, for these strategies to succeed and be accepted by farmers, they must be economically viable and conform to the existing cropping system. Thus, there is a need to identify feasible and cost effective coexistence measures that are applicable at the farm level. It is this issue that the Kenyan regulatory authorities and IRMA hope to solve through scientific assessment and involvement of stake holders including farmers.

CHAPTER II

LITERATURE REVIEW

Maize production in Coastal Kenya

Coastal lowland has remained a distinct maize production zone for cultural reasons. Sorghum and millet were important among the Mijikenda (the major agricultural ethnic community in the region) but are gradually disappearing (Waaijenberg 1994). The maize baseline survey of the year 2002 in the four districts of coastal Kenya (Kwale, Mombasa, Kilifi and Malindi) confirmed that coastal farm households grow a wide diversity of local maize varieties. Some of these varieties are grown alongside hybrids, including Pwani Hybrid-PH1 and PH4 and coast composite (CC) maize (Wekesa et al. 2002).

Maize crop variety diversity has been documented on a spot basis but variation across the coastal agro ecological zone in terms of diversity and quantity/acreage has not been quantified. Maize production systems follow the low-input agricultural system which dominates the region, an inherent factor of low incomes of the farm households. Although, improved varieties have been diffusing more gradually into more marginal production environments where yield potential is low, the adoption rate of these varieties remains low (Wekesa et al. 2002)

Maize improvement work at the coast began in 1952 and a number of varieties have been developed for the region since then. Maize production potential in this region is a function of the interactions of the availability of rain, competition of weeds, occurrence of pests and diseases as well as the actual management practices. Average maize yields are far below the potential for the region (Waaijenberg 1994 and Wekesa et al. 2003).

Unused land is diminishing or is of marginal quality or just unsuitable for maize production (Kenya Soil Survey 1987). Therefore, enhancing the productivity of the farm and of fragile, marginal land ecosystems through improving the existing maize varieties is the surest way of producing the extra maize grain required to feed the population. Kenya's government policy objective for the maize sub-sector is to encourage increased production so that self-sufficiency and food security can be achieved.

Biotechnology regulation in Kenya

The government of Kenya has since the mid 1980s embarked on structural adjustment programs aimed at spurring economic growth through investing in modern science and technology (Hannington et al. 2003). Although biotechnology has been considered a driving force to spur growth in the agricultural sector, the country still lacks specific policy and a legal framework for biotechnology.

Recent biotechnology research initiatives have mainly reflected the interests of the concerned organization with minimum inter-organization interaction and influence from donors (Hannington et al. 2003). This has raised fears that current biotechnology will evolve in a vacuum, with no consideration of the impact on agricultural systems or integration within the national development frame work. However, Kenya is currently ahead of most African nations in adoption of this genetic technology, with field tests of virus resistant sweet potatoes and Bt maize under way, and trials of Bt cotton recently approved.

Regulatory assessment for release of transgenic crops is work done by the Kenya's National Biosafety Committee of the National Council for Science and Technology (NCST) in conjunction with institutional biosafety committees; Kenya Plant Health Inspectorate Service, the Kenya Bureau of Standards and other stakeholders (Mwangi and Ely 2001). The NCST developed the biosafety guides in 1998 and has since been guiding confined field trials of biotech crops including Bt maize, viral resistant transgenic sweet potatoes, cassava resistant to cassava mosaic virus and Bt cotton which has gone through one season of confined field trial.

Recently the Committee of the National Council for Science and Technology, in consultation with other stakeholders, initiated and enhanced the development of a draft biotechnology policy document. The document has been presented to the minister responsible. More discussions and consultations are however still ongoing among stake holders. Once the bill is legislated, Kenyans will have an internationally recognized Bio-safety framework within which to tap the enormous benefits of biotechnology.

Although this has been called a significant step in the right direction by supporters of the technology, especially for a country like Kenya that heavily depends on agriculture, developments in agricultural biotechnology require slow and careful policy planning and implementation in order to improve food security of smallholders and reduce possible negative and socio-economic impacts of technology. Kenya is also a signatory to the Cartagena biosafety protocol; this makes it *a priori* for ecological assessment before releasing transgenic materials to the environment.

Study Area

In order to understand how the spatial distribution of local maize varieties is likely to affect the implementation of coexistence measures (separation distances) in Kenya, we present a case study of the low tropics maize production zone at the coast. The low tropics maize production region covers the administrative districts of Kwale, Mombasa, Kilifi and Malindi. These districts form the active maize production zone of the coastal region. Coastal lowland Kenya stretches from the sea, which receives ample amount of rain, to the far west and North West that receives barely 600 mls of rainfall a year, often poorly distributed.

Throughout the year, rainfall is bimodal; the major rainy season (long rains) begins in April and lasts until July, while the short rains are expected from October to November. The area covers Lunga-lunga in the south coast to Magarini in Malindi district-north coast. Coastal low land is divided into five zones characterized by climatic, topographic, soil and other environmental features influencing agricultural productivity and development potential (Jaetzold and Schimidt 1983).

Agro-ecological zones

The potential for agricultural production and development in a region is determined by physical factors, primarily by soil and climatic conditions as well as the interaction of socioeconomic, cultural and technological factors, such as farm sizes, level of farming and management practices. These factors at any given point in time, determine levels of agricultural production obtainable from any given land area. Therefore development plans to meet food needs should be based on consideration of both ecological and social-economic factors (FAO 1994). The agroecological zonation (AEZ) approach provides a useful evaluation of this potential and maintains an appropriate scale for regional development planning.

Six major agro ecological zones for maize can be identified across Kenya (Hassan 1998). From east to west, there are the lowland tropics on the coast, the mid-altitude and dry transitional zones. These three zones are characterized by low yields (less than 1.5tons/ha); although they cover 29% of maize area in Kenya, they only produce 11% of the country's maize. In the central and western province is the highland tropics zone, which is bordered on the west and east by the moist transitional zone-transitional between mid altitudes and highlands. These zones have high yields (more than 2.5t/ha) and produce 80% of the maize in Kenya on 30% of the area. Around lake Victoria is the moist mid-altitude zone, which produces moderate yields (1.44tons/ha). This zone covers 22% of the area and produces 9% of maize in the country.

The current study is concerned with the lowland tropics at the coast. The lowland coastal zone is subdivided into 5 sub zones called coastal lowland (CL): CL2, CL3, CL4, CL5 and CL6. These zones are characterized by climatic, topographic, soil and other environmental features which influence the potential of agriculture development (Jaetzold and Schmidt 1983). Annual rainfall distribution decreases from CL2 to CL6 with CL2 receiving annual rainfall of more than 1,200mm while CL6 receives less than 600mm. And the potential for crop production decreases in a similar manner as the altitude rises from the lowland zones to highland zone (Table II-1).

The area receives on average annual rainfall ranging from 400mm in the hinterland to over 1,200mm at the coast. There are several soil types across the region.

They differ in depth, texture, physical and chemical properties. The eastern coastline has strongly weathered soils called *ferasols*. There is a gradual transition from *acrisols, luvisols*, and *planosols* to the less weathered *cambisols* and *lithosols*. This transition reflects the decreasing mean annual rainfall (Jaetzold and Schmidt 1983).

Table 0-1. Coastal AEZ attributes as reflected by Jaetzold et al. 1983 Classification

AEZ	Temp (°C)	Altitude (m)	Rainfall (mm)	Natural Vegetation
CL2	24-30	0-900	1,000 – 1,600	Moist and dry forest
CL3	24-30	0-900	800 – 1,400	Dry forest and moist woodland
CL4	24-30	0-900	600 – 1,100	Dry woodland and bushland
CL5	24-30	0-900	450 - 900	Bushland
CL6	24-30	0-900	300 - 550	Bushland and scrubland

CHAPTER III

METHODOLOGY

Study design

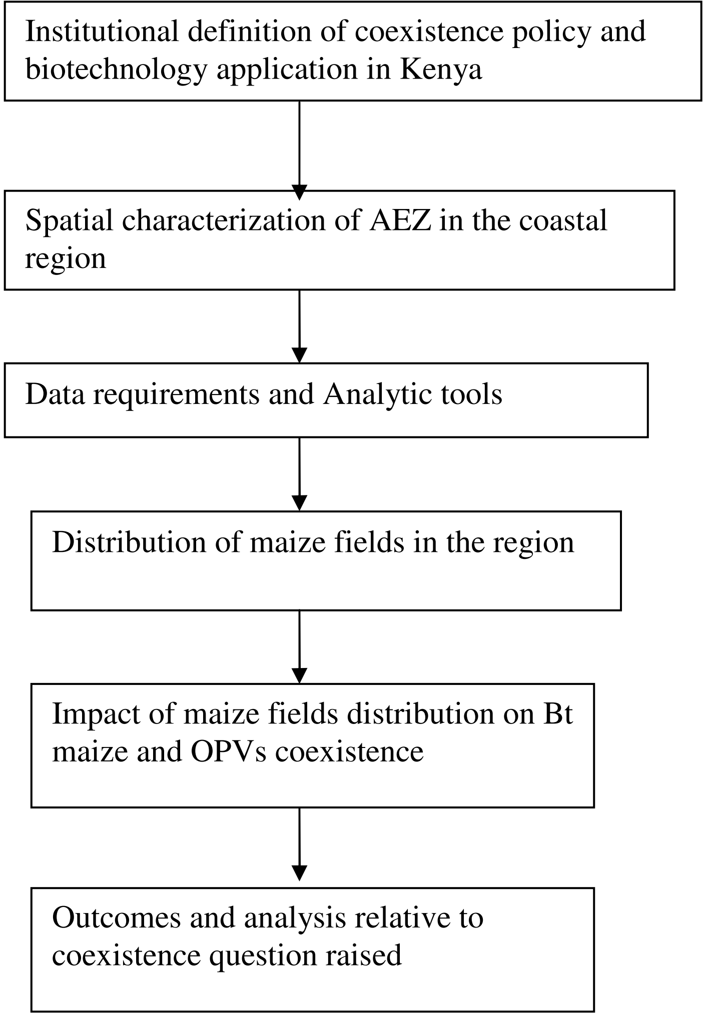


Figure III-1. Design of study

Conceptual /Theoretical frame work

Spatial distribution of OPVs

A farmers' choice of which crop or variety to grow can be examined from the theory of household farm production (Benin et al. 2004). In this theory, farm production decisions are determined by input and output prices, farm physical characteristics as well as household preferences. Farm production decisions are constrained by a fixed production technology that combines labor and an allocation of fixed land among different crops and varieties, given the physical conditions of the farm.

Farmers operate in an environment of risk and uncertainty. As they make decisions, they take into consideration the underlying risks such as partial or complete crop failures (Anderson and Dillon 1992). Decision making under uncertainty requires choices among probability distributions of different outcomes (Dillon 1977). For farmers in lowland coastal Kenya, adjusting to and managing such risk means allocating land to different crops and varieties depending on how the crop or variety yields against the challenge of drought, pests and diseases and poor soil fertility as well as the input cost-output price relationship. The relation of these factors varies across the agro-ecological zones.

The decision to grow a certain crop/variety may be dependent on external factors such as market prices of other farm enterprises (Benin et al. 2004). Dillon (1977) developed models depicting different response processes, each with output Y giving $Y_1 \ldots. Y_n$ outputs and r response processes and fixed total returns of $\sum P_n Y_n$. Throughout the landscape, OPVs are interspersed with other land uses such as other crops, trees and land area used as fallow/grazing land as well as the physical structures including settlements. The greater the area of land devoted to non-maize uses, the less the land devoted to maize, and the greater the expected distance between maize fields.

Hence, throughout the landscape, the spatial distribution and concentration of OPVs (Sa) is a function of the distances between maize fields (Z_i), the size of the maize fields (S_f) and the biophysical variables that influence crop productivity in the region: altitude (T), soil type (S) and rainfall (R)

$$(1) \qquad Sa = f(S_f, Z_i, T, S, R)$$

However, according to Jaetzold and Schmiddt (1983), coastal lowlands (CL) of Kenya can further be subdivided into six sub agroecological zones (CL1 to CL6), according to the biophysical variables climatic, topography and soil. From the above, the spatial distribution and concentration of OPVs can be established using the variance component analysis to determine the within AEZ variability of OPVs.

Coexistence

A major assumption is that Bt maize will confer production benefits to producers and will thus be grown in this region. The benefits of Bt maize can be calculated as the extra yield estimated through crop loss assessment. However, it is also important to recognize that GM crops can be negative externality generators and non-GMs recipients to the externalities. The result is that the immediate border neighbors are located at greater externality risk which decreases the greater distances away from the generator (Saak 2003; Perry 2002).

Since farming takes place in an open environment, there is a risk of gene flow between Bt maize and non-Bt maize, and it can have economic implications where the two types of crops have different values on the market. It is assumed that consumers will continue to value the distinction between Bt and conventional crops. This will demand identity preservation at the farm level (Belcher et al. 2005). This calls for feasible and cost-effective measures to guarantee that GM and non-GM crops can be grown within the same area/zone without compromising the economic and biological value of the other. In trying to understand these measures and determine the costs associated, it is important to understand the spatial distribution and concentration of OPVs across the agricultural landscape. It would also be helpful to understand the factors affecting this distribution as modeled in expression (1), but those data (altitude, rainfall and specific soil type) were unavailable at the time this research was concluded.

Data

A spatial sampling design was based on systematic selection of points along an established line transect drawn perpendicular to a baseline. The data were collected by walking randomized linear sections and georeferencing each transition in vegetation (Figure III-2). Transition points were georeferenced by identifying them with latitude and longitude points. First a baseline was set out, consisting of the coast line that falls into the lowland tropic maize zone as defined by Hassan et al. (1998) and the length of the baseline estimated to be about 300km. On the baseline, n base points were selected at equal distance (systematic sampling) at an interval of 300/(n+1) with a randomized starting point; where n is the number of desired transects and n is set to be 10.

Starting on each base point, a secondary line was established perpendicular to the baseline, with length 70 km. On each secondary line, n points were selected systematically at equal distance 70/n. The first point was randomly established from a probability space of between 1 and 7 using Microsoft excel. With a base point randomly selected on the first segment, 9 more points were selected. So for each secondary line, there is 1 base point, and 9 other points, so that n=10.

The baseline was drawn by hand on a physical map. The starting point was drawn on the map and the coordinates derived from it. From there, the coordinates of the other (initial) points were calculated through extrapolation, based on the distance of one decimal degree, longitude and latitude. Each of the initial points was located in the field with a GPS.

Along the transect lines, observations were made at every land use transition. Every time the vegetation changed, at the border of a field, or where a field was left to fallow, a transition point was marked and georeferenced using a hand held GPS. At each point georeferenced on the segment, the following additional information was collected: Owner of the plot, first and second crop (if the land was double cropped) depending on the percentage of the area occupied by a crop on a plot and name of the varieties.

Along the line transects, initial points at intervals of 2km on a 7km section were identified in the direction perpendicular to coast. At the middle of each 2km interval, a perpendicular shorter segment of 1km was walked, 500m on either side starting at the SW point, up to the NE point, in the direction parallel to the base line. Transforming GPS readings to actual distance on the ground was conducted on a degree to Km equivalence using arc view software.

From the segments and the transition points, we calculated average length of maize fields and distances between maize fields. Using this information, we estimated average maize plot size and the distribution of the distance between maize plots. Note that since the main variation is expected perpendicular to the coast, more segments were selected in that direction relative to the distance (Fig III-2).

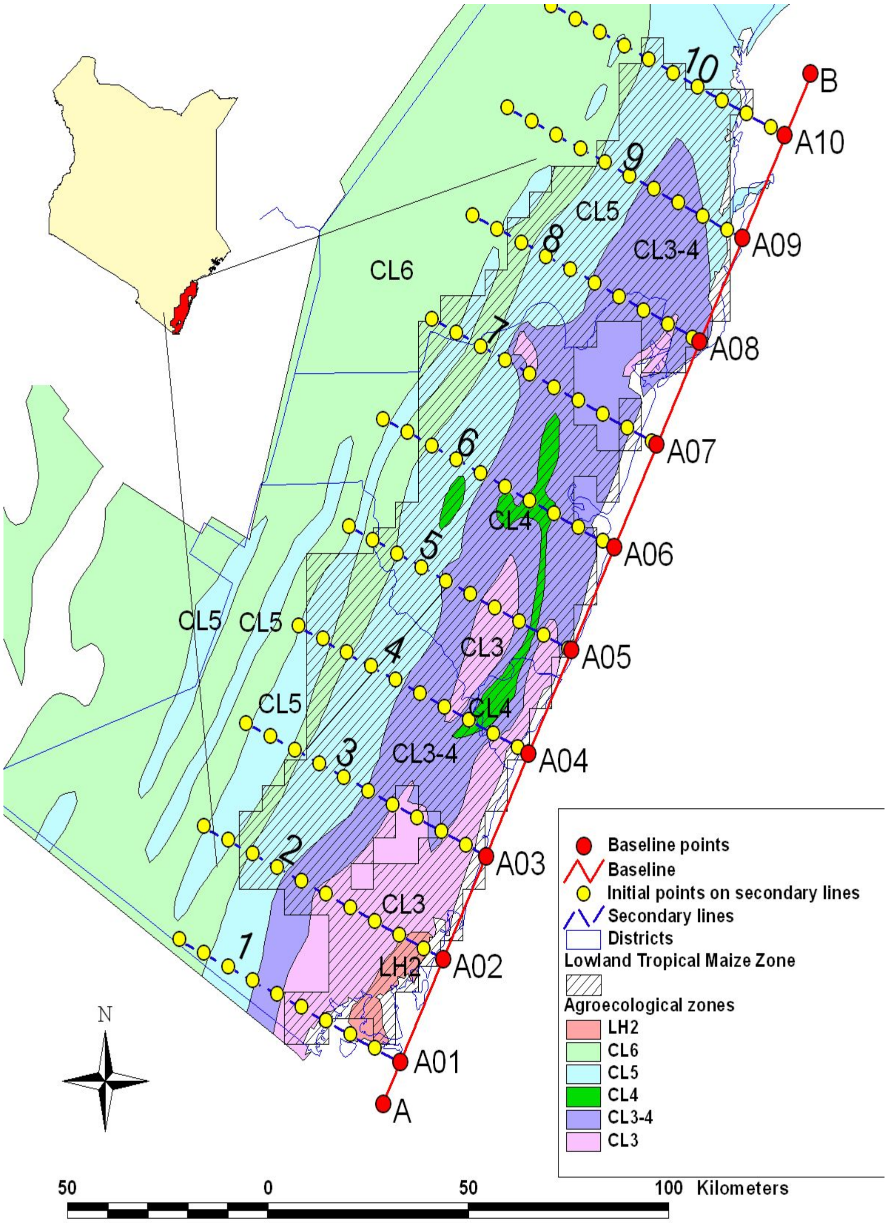


Figure III-2. Agro ecological zones at the coast, with the sampling design

Analytic framework

Size of fields and distances between maize fields

Risk management by farmers is demonstrated by their decisions to grow or not certain crops (Dillon 1977). This gives rise to a probability of intercepting a maize field or not along a section of an established transect. Throughout the landscape, OPVs are interspersed with other land uses. This is true in lowland coastal Kenya where farm households use a given piece of land for diversified farm activities. The greater the area of land devoted to non-maize uses, the less the land devoted to maize, and the greater the expected distance between maize fields.

From our sampling, data was recorded in latitude and longitude degrees. Transforming GPS readings to actual distance on the ground was conducted on a degree to Km equivalence. Actual distance on ground was obtained by finding the distance between latitudes and longitudes. This can easily be viewed in a three dimensional coordinate system with the x-axis in the longitudinal plane, the xy plane containing the equator and the z-axis along the earth's axis. Let the vectors in the longitude and latitude directions be OA and OB, where OA is the difference in latitude $\Delta lat = lat_2 - lat_1$, and OB is the difference in longitude $\Delta long = long_2 - long_1$. The actual distance between the two points was then obtained by triangulation.

From the segments and the transition points, we calculated average length of fields and distance between maize fields. The distance between maize fields was obtained by adding the distance to the next field on the same segment. In the first approximation, we assumed the distance between the first two maize fields on a segment were equal to the shortest distance between the two fields. In this study, maize fields were assumed to be square. This was taken as a simplest case scenario, otherwise field were not oriented in a fully consistent way. Once we obtain the distance between fields and size of fields, we then estimate the mean distribution of these parameters across coastal lowland Kenya agroecological zones.

Modeling Distributions

Statistical enhancements in the univariate procedure have provided greater details in modeling distributions (SAS Institute, Inc. 1979) as well as fitting and visualizing a wide range of parametric distributions through graphic displays (Nathan 1999). Histograms are among such displays that have become useful for visualizing a data distribution (Snee and Pfeifer 1983) and suggesting which distribution the data fits for modeling purpose (Nathan 1999). The procedure has become a convenient tool for decisions when comparing distributions of quantitative variables (SAS Institute, Inc. 1999).

By this procedure, graphics and statistical tests were used as hypotheses testing and preprocessing methodology about the distribution of spatial data of open pollinated maize varieties. Since many statistical tests require data to be approximately normally distributed, it is important when investigating data distributions that a test for normality be performed (Shapiro and Wilk 1965).

To improve judgment about the distribution of the data, a combination of graphical and statistical tests were used to investigate the goodness of fit for normality and other distributions. Graphics include histograms and probability density plots (Figure III-3). The statistical tests Kolmogorov-Smirnov, Cramer-von Mises and Anderson-Darling were applied to improve judgment and hypothesis testing.

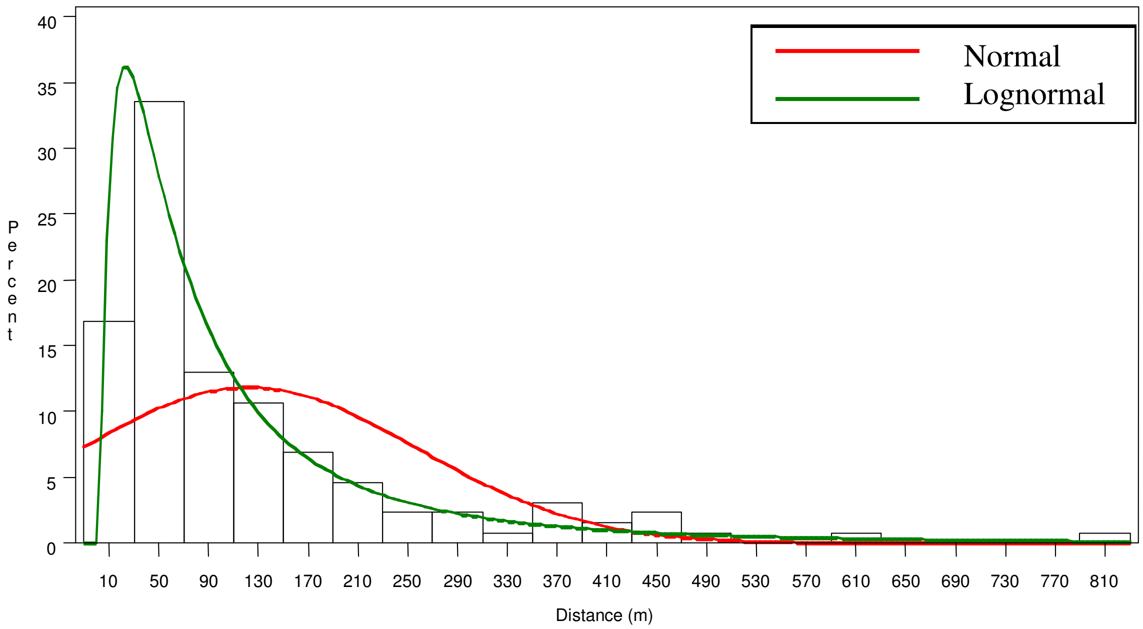


Figure III-3. Histogram with Normal and lognormal curves superimposed

Model Specification

The MEANS procedure was used to provide descriptive statistics for the size of maize fields and in-between distances within AEZ based on moments. Mean distances between maize fields and mean plot sizes of fields per agroecological zone were estimated using the least square means method. A comparison of the mean estimates of the size of maize fields and distances between maize fields across the zone was then performed in ANOVA.

Since the design of the sampling was not entirely balanced across the study area (i.e. more segments were selected in the direction perpendicular to the coast and the segments were long in that direction relative to the segments sampled parallel to coast), we used the generalized linear model (GLM) method for estimating mean variations.

The GLM procedure is better suited to perform ANOVA for unbalanced data typically by portioning the variations in a variable's values between and within several groups or class (SAS OnlineDoc, Version 8). Agroecological zones (AEZ) were used as the reference strata for analyzing the spatial distribution. The model below was fitted using proc glm procedure in SAS specifying AEZ as the class variable.

$$y_{ij} = \mu + \beta_i Cl_i + \varepsilon_{ij} \tag{2}$$

i =1,..6 and, j=1... nth observation.

This model is equivalent to a multiple regression model with dummy variables. The model was fitted as an ANOVA regression by the identification of class which is a reference to the dummy variables representing the AEZ's.

Determining costs of coexistence

The methodology used to determine costs of coexistence in this study was the one described by Menrand and Reitmeier (2006) and used in economic impact assessment of coexistence measures by Reitmeier et al. (2006) in European agriculture. Based on this methodology, figure III-4 and figure III-5 shows an illustration of the spatial layout of the different measures used to control cross pollination in the maize crop. It is assumed that a farmer who grows Bt maize will bear the responsibility of implementing the farm management practices and the relevant costs.

Size of Isolation area

In figure III-4, square GM maize fields are assumed to be adjacent to non-GM maize fields. By law, the GM maize farmer would be required to leave an isolation perimeter (buffer zone) of distance *d* on both sides of the GM maize field. On the isolation area, it is assumed that the farmer plants an alternative crop. This crop is assumed to be of less economic value than GM maize but meets the requirement of good farming practice. The alternative crop in this study was assumed to be conventional maize. Planting conventional maize varieties in the isolation area is a good alternative because it ensures the requirement of good farming practice. Apart from the harvest, conventional maize crop would acts as pollen trap and a strategy for insect resistance management.

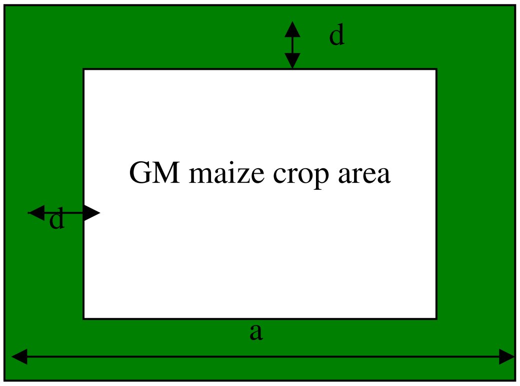


Figure III-4: Illustration of using isolation distance perimeter to avoid cross pollination in maize crop

There is reduced yield of the maize crop in the isolation area. The value of the crop lost in the isolation area is a cost due to coexistence measures. If the isolation area is planted with conventional maize crop, crop loss for that area is the difference between potential production in the absence of insect pests, or the yield from GM, and actual production.

For square maize fields of length a, requiring an isolation distance d, the area of isolation is determined as follows:

$$A_{is} = a^2 - (a-2d)^2$$

where

A_{is} = area of Isolation

a = length of square field

d = minimum separation distance

The illustration in figure III-4 above assumed that maize fields are close or adjacent to each other. However, maize fields are separated from each other by a certain distance. The general framework of this scenario is illustrated in figure III-5.

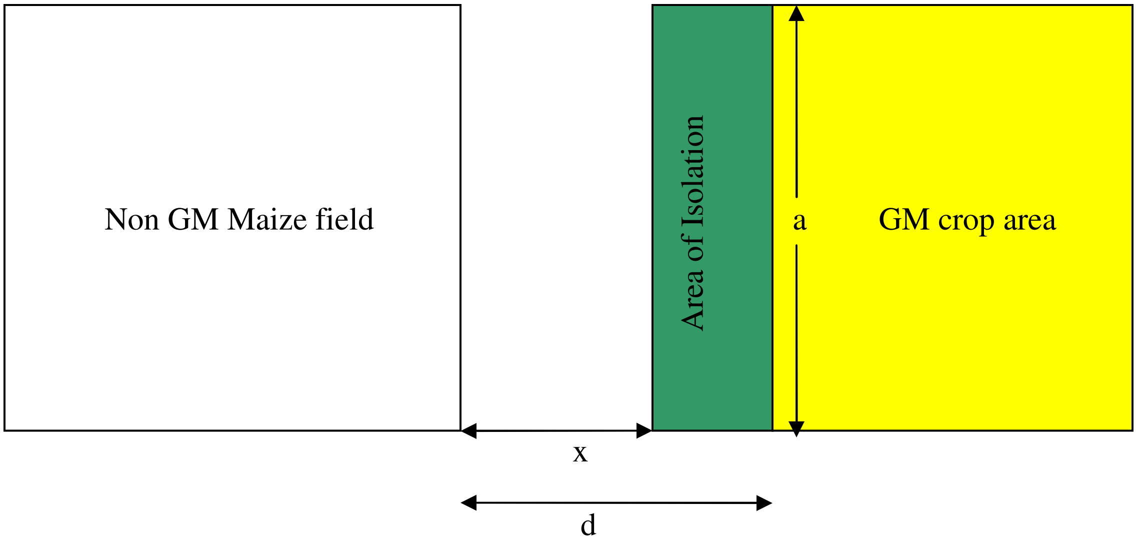


Figure III-5: Illustration of spatial layout of maize fields separated

From the illustration in figure III-5 below, the area of Isolation was determined as follows:

$$A_{is} = (d-x)a$$

where

A_{is} = area of Isolation

a = length of square field

x = mean distance between maize fields

d = minimum separation distance

Following the illustrations above, costs of coexistence were determined in two stages. First, the economic performance in terms of yield of Bt maize is calculated for representative field sizes across the lowland agroecological zone. Secondly, costs of different minimum separation distance measures are approximated.

Using trial data, maize yield with and without stem borer infestation have been determined for the six major agro ecological zones in Kenya. (De Groote et al. 2004). Measured maize crop yield in the low land tropical zone with stem borer infestation was estimated to be 1.36t/hec, compared to the potential yield of 1.5t/hec (Hassan et al. 1998). Research has also shown that yields from Bt maize are estimated to be10% higher than the yields from conventional maize varieties in the tropical areas (Clive 2003). For the case of lowland coastal Kenya, 10% increase in yield due to Bt maize translates into 1.496 t/hac or 1.5t/hec.

Economic evaluation of the cost of coexistence is obtained by multiplying the amount of crop loss in the separation distance area or Isolation perimeter by the current maize prices. In this study, we used the average monthly maize prices at the coastal town of Mombasa as reported by the Regional Agricultural Trade and Intelligence Network (RATIN). Prices averaged were of the period from December 2006 to March 2008, equivalent to USD 204.8/MT.

The value of the crop lost or cost of coexistence was calculated as follows:

$$C_{is} = A_{is} (Y_b - Y_p) P;$$

where

C_{is} = cost of coexistence

A_{is} = area of isolation

Y_p = yield of conventional maize varieties

Y_b = yield of GM maize crop

P = price of Maize crop

The benefits from Bt technology is the value of the yield gain due to planting GM maize but will be lost if a farmer is unable meet the minimum requirements of isolation distance to allow for coexistence. At the regional level, the likely proportion of farmers who would be affected at different minimum isolation distance requirement is determined graphically from a cumulative distribution curve. Results are shown in the sections that follow.

CHAPTER IV

RESULTS AND DISCUSSION

In this chapter, a comparative description of variety diversity and distribution of maize that farmers grow is shown. In the section that follows, results of the distribution of the size of maize fields and the distances between maize fields by agro ecological zone are presented. A discussion of the implication of the spatial distribution of maize fields on the implementation and feasibility of coexistence measures is made. And lastly, the cost effect of different separation distance measure is presented and analyzed.

Maize varieties

From the survey data, different maize varieties grown by farmers were identified. Local varieties are popular in the region, except in CL4 and CL5 where improved and hybrid varieties are almost equally popular (Figure IV-1). Farmers continue to plant local maize varieties even when the hybrid and improved varieties are available, but with a growing number of farmers planting hybrid and improved varieties as in CL4 and CL5. Coastal Kenya maize farmers generally grow both local, hybrid and improved varieties but utilize only one or two varieties per plot. Hybrid varieties are not popular among farmers in CL4 but also less of maize farming activity in the zone; while in CL3, maize farming activity is high with most farmers growing local varieties. Hybrid varieties identified include PH1, PH4 and the Coastal composite.

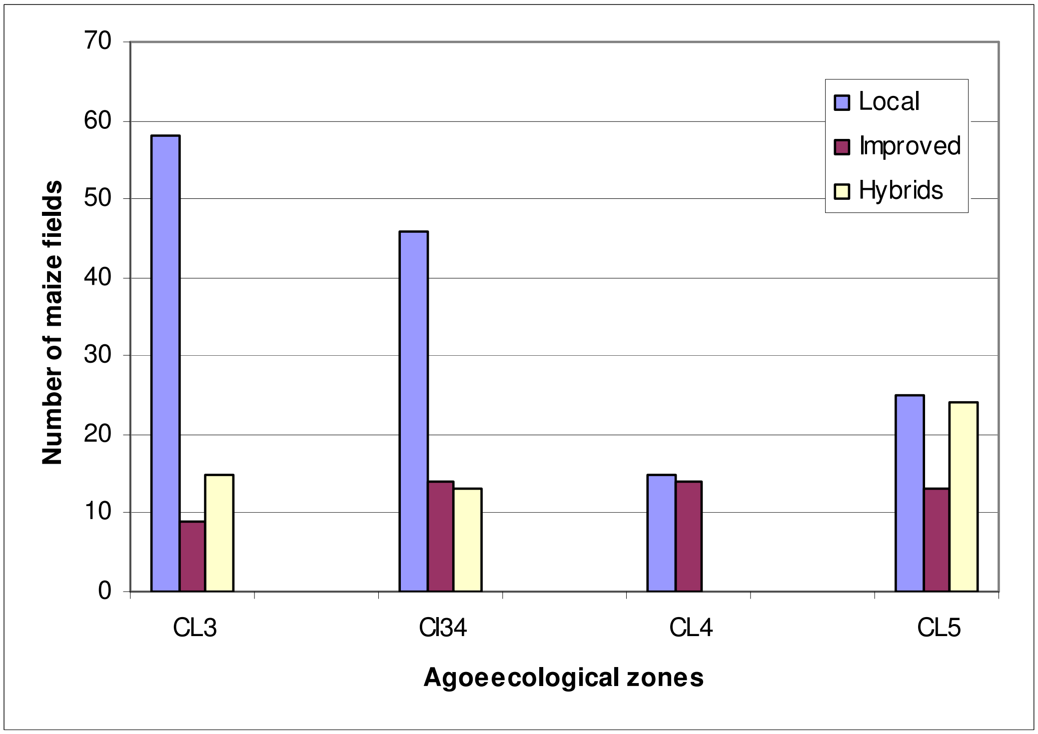


Figure IV-1. Maize Varieties by group at the Coast

A common practice observed in the region is planting two or three maize varieties in one maize plot especially in CL3 and CL3,4. Surveys also revealed that farmers frequently plant improved, hybrid and local varieties alongside each other which leads to the crossing of local varieties with improved and hybrid varieties. This has been reported as the traditional way of enhancing the genetic diversity of local maize cultivars (Berthaud and Gepts 2004). While this may be an indication that crop to crop genetic mix-up is frequent in the region and thus leading to genetic erosion of local varieties, it is a deliberate willingness by farmers to improve the performance of their varieties in terms of yield and resistance to both biotic and a biotic risks to production. Across the region, therefore, an issue arising from a scientific perspective is that any new variety traits may be diluted and lose efficacy especially in crops like maize that are reported to have a high degree of out crossing.

Farmers continue to value the distinction between varieties on a range of traits such as good taste, ease of preparation and appearance. Reasons for continued popularity of local maize varieties are attested to by survey observations from farmers who say that most improved or hybrid varieties do not outperform land varieties in yield and other production risks. Coastal Kenya maize farmers also consider that some local varieties growing in marginal lands hold potential value for local adaptation.

While adequate time has elapsed since introduction of most hybrid and improved varieties in the region, adoption rate and hence popularity of these varieties is generally still low. Surveys of farmers conducted in 1998 indicated that 70% of the farmers still plant local varieties and only 22% plant hybrid varieties (Wekesa et al. 2003). Given the low adoption rates of improved and hybrid varieties, it is unlikely that Bt maize will dominate maize plantings in the region.

Spatial distribution

Following the univariate procedure described above, spatial data was displayed in histograms. Histograms with superimposed fitted density curve (s) are shown in Figure III-3. Based on a Shapiro-Wilk statistic W = 0.7537 with a P-value of 0.0001, the null hypothesis is rejected to conclude that the data is not normally distributed. Other tests such as the Kolmogorov-Smirnov, Anderson-Darling and Cramer-Von Mises statistic all resulted in P-values less than 0.01 (Table IV-1), confirming the conclusion that the data are not normally distributed.

The histogram shows that the distribution is skewed to the right and the fitted density curve indicates that the normal curve does not fit the histogram well. An alternative distribution useful for fitting data that are skewed to the right is a lognormal

(Nathan, 1999). The fitted curve and statistical tests show the lognormal distribution fitting the data. The p-values for the lognormal distribution are larger than the usual cutoff values of 0.05 and 0.10, which indicates not to reject the null hypothesis that the data are lognormal distributed. An exponential distribution does not fit the data well as the lognormal. From the lognormal distribution, the mean of the distribution of the distance between maize fields is 129.2m with a standard deviation of 189.2m (Table IV-2).

Table IV-1. Goodness of Fit Test for Distributions

Test	Normal		Lognormal		Exponential	
	Statistic	Pvalue	Statistic	Pvalue	Statistic	Pvalue
Kolmogorov-Smirnov	0.18992	0.01	0.05212	0.25	0.09293	0.057
Cramer-Von Mises	1.83334	0.005	0.06161	0.236	0.22755	0.047
Anderson-Darling	10.10251	0.005	0.39976	0.427	1.36671	0.045

Table IV-2. Fitted Distribution Parameters

Distribution	Distance (m)	
	Mean	Std Dev
Normal	122.9	134.9
Lognormal	129.2	189.2
Exponential	122.9	122.9

Table IV-3 shows the mean length of maize fields and the proportion in number of OPV fields by agro ecological zone. Most of the maize farming activity is concentrated in zones CL3 and CL3,4 near the coast line. The agricultural landscape is typically fragmented consisting of a mix of grasslands and several crops with maize as the major crop. Evidence from the land tenure system adds to the complexity of the subdivisions of land into small plots among family members making it difficult to expand agricultural production or consolidate land use for one major production activity.

The size and distribution of maize fields is presented in Tables IV-4 and Table IV-5. Field size on average ranges from 0.25hec to 2.2hec, with a wide variation from the mean distribution. The estimated size of maize fields is 1.73hec (Table IV-5). From the generalized linear model for ANOVA (Table IV-6), there is no significant difference (at 5% level) between the sizes of maize fields across the agroecological zones (CL3, CL3,4, CL4 and CL5). The smaller F-value and larger P-value (Pr>F) indicate that the differences in means of the size of maize fields a cross the region are not significantly different. From the means procedure, the estimated mean sizes of fields within zones are significant at 0.005 levels (Table IV-5). CL5 has maize fields that are relatively large of estimated size 2.2hec, while CL4 has the smallest maize fields (0.25hec). Table IV-5 also includes the 95% confidence limits of the sizes of maize fields

Table IV-4 and table IV-5 further shows the mean distance between maize fields per zone. Table IV-5 includes the 95% confidence limits of the distances between maize fields. From the means procedure, the mean distance between maize fields is significantly different from zero for each of the zones at 0.05 levels.

However, from the analysis of variance, when the size of separation distances is compared across the agro-ecological zones, results (table IV-7) indicate that there is no significant difference between the sizes of distances separating maize fields across lowland coastal Kenya. The smaller F value and larger P-value (Pr>F) indicate that the differences in mean sizes of distances between maize fields is not significant. Across the region, the estimated mean size of distances between maize fields is 129.2m (Table IV-

7). The mean distances between maize fields ranges from 112.1m in CL3 zone to 158.2m in CL4.

Table IV-3. Average length (m) of the maize fields

AEZ	Potential for crop production	Rainfall distribution	Percent number of Maize fields	Length (m) of maize field sections	
				Mean	Standard deviation
CL2	Medium, poor soils	>1200		not sampled	
CL3	High	1000-1200	32	81.5	103.4
CL 3-4	Medium	NA	30	106.8	80.3
CL4	Low to medium	900-1000	12	43.1	26.6
CL5	low	700-900	25	112.6	98.6
CL6	Lowest	<700	-		

CL=Coastal lowland zone, NA=available

Table IV-4. Size and distribution of maize fields

AEZ	Climate	Farming system	Sample size	Field size (hec)		Distance (m) between maize fields	
			(N)	Mean	Standard deviation	Mean	Standard deviation
CL2	Humid	Sugarcane					
CL3	semi-humid	Coconut/Cassava	78	1.7	3.9	112.1	158.1
CL 3-4	Transitional	Cashewnut/Cassava	73	1.8	2.6	127.7	126.5
CL4	Transitional	Livestock and millet	30	0.25	0.24	158.2	139.6
CL5	semi-arid	Ranching	62	2.2	3.3	122.9	100.1
CL6	Arid						

Table IV-5. The GLM Procedure, Least Square Means

AEZ	Distance between maize fields (m)				Size of Maize Field (hec)			
			95% CL for Mean				95% CL for Mean	
	Mean	Std error	Lower	Upper	Mean	Std error	Lower	Upper
CL2		Not Sampled						
CL3	112.1	19.0342	67.8	156.6	1.7	0.45999	0.60	2.80
CL3,4	127.7	21.2289	87.7	167.6	1.8	0.51303	0.90	2.60
CL4	158.2	42.9853	58.3	258.1	0.25	1.0388	0.08	0.42
CL5	122.9	25.2418	84.8	161	2.2	0.61	0.94	3.50
CL6		No maize fields found						

Mean Estimates are significant at 0.005

Table IV-6. The GLM Procedure: Size of Maize Fields

Dependent Variable: Size of fields

Source	DF	Sum of Sq	Mean Sq	F Value	P>F
Model	3	28.568	9.522788	0.88	0.4522
Error	127	1370.464	10.791059		
CorrTotal	130	1399.032			
	R-Square	Coeff Var	Root MSE	Size: Mean	
	0.020420	190.1068	3.284975	1.73	

Table IV-7. The GLM Procedure: Distance between Maize Fields

Dependent Variable: Distance between Maize Fields

Source	DF	Sum of Sq	Mean Sq	F Value	P>F
Model	3	19314.398	6438.133	0.35	0.79
Error	127	2346629.25	18477.396		
CorrTotal	130	2365943.64			
	R-Square	Coeff Var	Root MSE	Distance: Mean	
	0.008164	110.5926	135.9316	129.2.	

Results from this study have shown that maize fields are relatively small, of mean size 1.7hac, across the region with an estimated distance between maize fields of mean 129.2m. No clustering of maize fields is observed in individual zones even though it was expected that zones with a high cultivar or proportion of local maize varieties near the coast would have fields that are in close proximity, and tending towards sparse (greater separation distances) as you move off the coast to the grazing highland areas.

Implications of the spatial distribution of maize fields on coexistence

Results of the spatial distribution of maize fields across lowland coastal Kenya indicated that the estimated mean size of maize fields is 1.7hec. The range of the field sizes is 0.25hec to 2.2hec and the mean distance between maize fields is 129.2m. Further, results indicated that the difference between the sizes of maize fields across the lowland agro-ecological zones is not significantly different. The same is true for the distances between maize fields.

In terms of coexistence using separation distances, reference is made to countries growing GM maize and which have in place minimum standard separation distance measures. Spain, the leading country in the European Union growing GM maize, is a good European example. According to Spain's Ministry of Agriculture Guide lines of 2005, four rows of conventional maize are recommended for farms less than one hectare; while for larger farms, four rows of conventional maize and a separation distance of 50m is considered sufficient to keep out-crossing below 0.9%. (See table I-I for listed countries). Most recently, the European commission's Joint Research Centre (JRC) reported in 2006 that separation distances of 50m and 100m are required to achieve threshold levels of 0.9% and 0.5%, respectively, for fields less than 5hec.

From the literature of coexistence, minimum separation distance requirements are region/area specific. The risk of gene flow also depends on other factors including wind direction, adoption rate of the GM crop and other biological factors. It remains to be seen what separation distance standard will be stipulated for Kenya given the physical characteristics of its maize farming system.

Using the cumulative density function (Figure IV-2) for the distribution of the distances between maize fields in lowland coastal Kenya, the proportion/percentage number of fields/farmers across the region that would be affected at particular *ex ante* minimum distance regulation can be discerned. Figure IV-2 shows that at a separation distance of 50m, 100m and 150m, approximately 43%, 48% and 52% respectively of the maize fields would not meet the minimum isolation distance requirement. For these farmers to meet the stipulated minimum separation distance, they would have to reduce their maize fields.

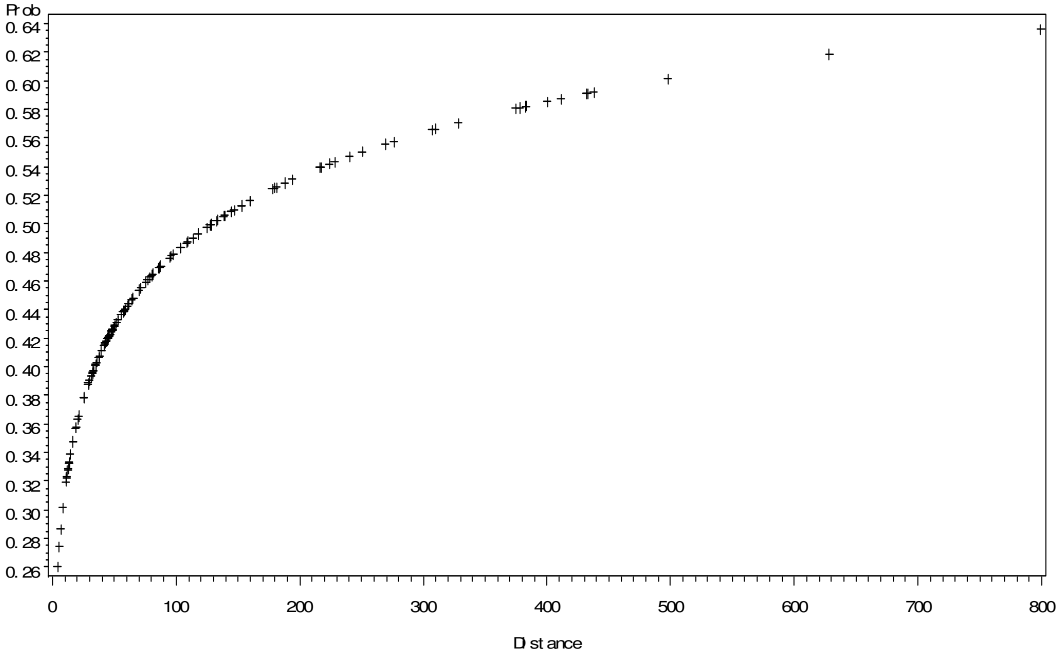


Figure IV-2: Cumulative distribution function

On the agro-ecological zone level, the proportion or percentage number of farms/farmers that would be affected at particular minimum separation distance standard is shown in table IV-8. Table IV-8 was obtained from the cumulative distribution curve (as in figure IV-II above) for each of the agro ecological zones.

Under the current farming system, table IV-8 shows that at a separation distance of 100m, 71% of the farmers in CL3 would not comply with this measure while 37% of the farmers in CL5 would not meet the standard. A separation distance standard of 20m would result into 21% of the farmers in CL3 not complying while only 3% and 6% of the farmers in transitional zone CL3,4 and CL5, respectively, would not comply. CL4 shows no change in farmer non-compliance levels (27%) between separation levels of 50m and 20m while CL3,4 shows a significant drop in non compliance when the standard separation distance is lowered from 50m to 20m.

While no prediction of the extent of gene flow can accurately be made for the case of this region, results from the distribution of maize fields indicate that there a high percentage of farmers will be affected at minimum separation distance of 100m . While separation distance of more than 50m is not applicable to a large extent in CL3, it is possible within CL3,4 and CL4. More consideration of these containment options is presented in table IV-9.

In this consideration, the general principal that a farmer introducing GM crops should bear the responsibility of implementing the farm management measures necessary to limit mixing of GM and non-GM crops is not applicable in the region. The need for neighborhood cooperation will be essential in achieving coexistence. Note that standard distance measures in this study are used to give a cautious side of minimum standard requirements and applicability.

Table IV-8. Applicability of buffer zones as a function of particular separation distance

AEZ	CL3	CL3,4	CL4	CL5
Mean distances (m)	112.1	127.7	158.2	100.1
Proportion of fields that would not comply with particular buffer zones				
100m	0.71	0.46	0.42	0.37
50m	0.52	0.24	0.27	0.33
20m	0.21	0.03	0.27	0.06

Table IV-9. Potential rules for Bt Maize coexistence and their practicability in coastal Kenya.

Specific rules/containment options	Comments on practicability
1. Zoning	1. Needs specific organization, difficult to implement
2. Specific isolation distances	2. No problem with some fields, but needs to control on large area and requires neighborhood cooperation
3. Barriers such as buffers	3. Difficult, needs specific crop rotation system
4. Temporal separation	4. Time costly and difficult to arrange among farmers

Analyzing costs of coexistence

Maize yield is expected to increase by 10% if a farmer grows Bt maize. At current maize prices ($225.75/t), this translates into USD 78.1/hec in benefits to farmers who switch from growing conventional maize varieties to Bt maize. These benefits exclude the cost of technology (such as cost of seed). Within the region, the estimated mean size of maize fields is 1.7hec which yields 0.59t of maize above the yield of conventional maize varieties. This translates into USD 132.7 in benefits earned on average by Bt maize farmers in the region. These benefits are lost by potential GM maize farmers unable to plant Bt maize due to respecting coexistence measures.

In the strict sense, if farmers are required to leave an isolation perimeter (buffer zone), farmers would have to reduce their GM maize fields to allow for this separation requirement (see figure III-4). The potential costs of coexistence based on the mean size of maize fields that would result were calculated using an economic model at different ex ante separation levels (Table IV-10). Results in table IV-10 indicate that at a mandatory separation distance of 20m, a Bt maize farmer incurs a lose of approximately $69 while at the level of 50m, the farmer loses $125.6. Table IV-11 shows a range of costs that would be incurred in CL5, a zone with relatively large fields.

Table IV-10: Cost of isolation at varying minimum separation levels

Isolation distance (m)	Size of isolation area (hec)	Maize crop lost in isolation area (t/hec)	Cost of isolation ($/hec)
20.00	0.88	0.31	68.97
25.00	1.05	0.36	82.30
50.00	1.61	0.56	125.56
100.00*	(1.22)	(0.42)	(94.92)

*Standard measure is infeasible given size of maize field of 1.7hec

Table IV-11: Cost of isolation for maize field of 2.2hec

Isolation distance (m)	Size of isolation area (hec)	Maize crop lost isolation area (t/hec)	Cost of isolation ($/hec)
20.00	1.03	0.36	80.17
25.00	1.23	0.43	96.31
50.00	1.97	0.68	153.58
100.00**	1.93	0.67	150.96

**Standard measure is infeasible given size of maize field of 2.2 hec

Cost estimates shown above in table IV-10 were based on the assumption that maize fields are adjacent to each other. From the distribution of the distances between maize fields, the mean separation distance between maize fields across the region is

129.2m. Where maize fields are separated, the cost of isolation reduced. Table IV-12 gives a range of the potential costs incurred when maize fields are separated. For fields which are completely outside the isolation distance area, there would not be any costs.

Table IV-12: Cost of isolation, maize fields separated by a certain distance

Distance between maize fields	Minimum Isolation distance (m)	Size of isolation area (hec)	Maize crop lost isolation area (t/hec)	Cost of isolation ($/hec)
20.00	20.00	0.00	0.00	0.00
	50.00	0.39	0.14	30.55
	100.00	1.04	0.36	81.46
	150.00	1.69	0.59	132.37
	200.00	2.35	0.81	183.29
50.00	100.00	0.65	0.23	50.91
	150.00	1.30	0.45	101.83
	200.00	1.96	0.68	152.74
100.00	150.00	0.65	0.23	50.91
	200.00	1.30	0.45	101.83
129.20*	150.00	0.27	0.09	21.18
	200.00	0.92	0.32	72.09

*Mean separation distance between maize fields across the region

From table IV-12, on average across the region, the cost of isolation would be USD 21.18 when the mandatory separation distance requirement is 150m. At a minimum separation distance of 200m, the cost of isolation approximates USD 72.1. Farmers, whose fields are separated by a mean distance of 129.2m, would not incur any cost at minimum isolation distances below 129.2m. Thus, the costs of observing separation distances would be incurred only in areas where the mean separation distance between maize fields is less than the minimum isolation distance standard.

Perspective

Results from this study suggest that a high proportion of farmers will not be able to meet a defined separation distance of 50m or greater. To meet the minimum separation distance standards, farmers would have to undertake changes in their farming practices: co-operation with adjacent farmers will be required. Family farmers use their traditional experience with respect to specific natural, biological and technical conditions. Therefore, no uniform measures of good agricultural practice can be defined by legislation, unless these measures are flexible and adapted to the maize crop farming system, and cost-effective.

Due to the spatial and temporal variability of the cropping system, unless there is consensus among farmers, isolation distances measures of 50m or greater, will be difficult to implement. According to economic wisdom, a rational farmer will decide on what to grow on the basis of his perceived net benefits, taking into account costs and cropping risks, including liabilities. Ultimately however, the separation distance standard that is set will determine whether co-existence is practical. If Bt maize is to be grown on a large scale, monitoring will be important in ensuring that measures to maintain coexistence are working.

CHAPTER V

CONCLUSION

This study set out to describe the spatial distribution of open pollinated maize varieties in lowland coastal Kenya and analyze how this distribution affects the economic and practical feasibility of the implementation of coexistence measures (separation distances). The study used both primary and secondary data. Primary data was systematically generated by means of a hand held Geographical Positioning System (GPS) and farmer surveys across lowland coastal Kenya. Secondary data was a review of the existing coexistence studies and economic performance of Bt maize.

Results indicate that local maize were popular among farmers in the low altitude areas near the sea, while hybrid and improved varieties were somewhat more popular in the highland areas. Most of the local maize varieties were concentrated in the CL3 and CL3,4 zones. Maize fields on average ranged from 0.25hac to 2.2hac with an estimated mean size of 1.7hac across the region. No significant difference was found between sizes of maize fields across the coastal agro-ecological zones. CL5 has larger maize fields averaging 2.2hac and CL4 has the smallest maize field sizes averaging 0.25hac.

The estimated mean distance between maize fields was 129.2m. The distribution of the distance between maize fields was skewed to the right, with statistical tests showing that it is lognormally distributed. There was no significant difference found between the sizes of the distances separating maize fields across the coastal agro-ecological zones.

The economic benefits of planting GM maize in the region at current maize prices were approximated to be USD78/hac. These benefits are lost if a potential GM maize farmers is unable to plant GM maize due respecting minimum isolation distance standards. For potential GM maize farmers who reduce their maize fields to allow for the minimum separation distance requirement, these benefits are partially offset. Across the region, results from this study showed that, at separation distances of 50m, 100m and 150m, approximately 43%, 48% and 52% respectively, of the farmers would not meet the minimum isolation distance requirement.

In terms of coexistence using separation distances, if farmers are required to leave an isolation perimeter (buffer zone), farmers would have to reduce their GM maize fields to allow for this separation requirement. The potential costs of coexistence based on the mean size of maize fields that would result were calculated using an economical model at different separation levels. Results from this study indicate that at a separation distance of 20m, a Bt maize farmer would incur a cost of approximately $69 which would offset the benefits from USD78 to USD9; while at a separation distance level of 50m, the farmer would incur a cost of $125.6 which would offset the benefits from planting GM maize crop to a loss of USD47.6. Given a mean size of maize fields of 1.7hac, an isolation perimeter of distance 100m would also not be economically viable but also unpractical.

Results from the distribution of the distances between maize fields indicated that the mean separation distance is 129.2m. Because of the distance between maize fields, the cost of isolation is reduced due to area compensation. Taking a mean separation distance of 129.2m between maize fields, on average across the region, the potential cost of isolation would be USD 21.2 when the minimum mandatory separation distance requirement is 150m. At a minimum mandatory separation distance of 200m, the cost of isolation approximates USD 72.1. Farmers whose fields are separated by a mean distance of 129.2m would not incur any cost at minimum isolation distances below 129.2m. Consistent with Ingram (2000) separation distance recommendations, **a**t separation distances of 150m and 200m, the costs of separation represented 27.2% and 92.4%, respectively, of the gross benefits.

From the spatial distribution of maize fields, too little information is available to prescribe specific minimum separation distance requirements. However, separation distances have the possibility of safe guarding the interests of those farmers who opt not to adopt Bt maize. At the moment however, their application is limited. With the fragmented nature of farms and land tenure system in the region, a high level of communication between neighboring farmers will be necessary to ensure the measures are implemented and adhered to. In most of the cases, Bt maize growers will not be in a position to grow a maize crop independently of neighbors while at the same time observing the appropriate separation distance or buffer zone. Careful monitoring of post-release will be essential to ensure the continued segregation at the farm level.

To date, countries where Bt maize has been commercialized on the African continent have reported significant economical benefits and no significant damage to the environment (Huesing and Leigh 2004; Yousouf et al. 2002 and Vitale et al. 2007). But the lack of observed negative effects so far does not mean they cannot occur.

Much remains unknown. Also, regulatory systems are incomplete and people who manage them are not perfect as has been argued by GreenFacts (2005). Meanwhile, science is moving rapidly. Concerns related to gene flow and pest resistance are being addressed by scientific and management techniques on a case by case basis. While science cannot declare any technology completely risk free, appropriate regulation will be essential to command the trust of both producers and or consumers.

Limitations and Recommendation

Due to data limitations, this study was not able to take into account wider economic impacts of coexistence on the agricultural sector or the agro-food chain. Also, the study did not consider the temporal variability of open pollinated maize varieties. Improved data availability would enable a richer empirical analysis of wider economic impacts of coexistence measures. Further research would help address any gaps left by this study.

From the agronomic aspect, farmers are going to remain at the center of attention. To enable them to implement coexistence measures, it is important that they are provided with information and educational programs that will take full account of their specific agriculture characteristics.

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APPENDIX:

Trends in agriculture biotechnology

In facing the increasing pressures of population growth, proportional greater increases in the demand of food, and dwindling stocks of suitable land resources, the global agricultural research community has made tremendous strides in developing new, high yielding varieties to void the Malthusian nightmare (Stanley et al. 2004). Indeed the last two decades have witnessed a revolution in the techniques of genetic modification, with associated optimism about the benefits to be gained from the construction of genetically modified (GM) plants. Scientists have viewed this technology as anew set of tools while industry has viewed it as an opportunity for increased profitability.

The transition from basic discoveries to applications is occurring at a fast pace. However, the challenge of formulating pro-active policies to exploit these technologies in a way that allows for social acceptance and appreciation is also real (Miguel 2005). These concerns merit continued attention on a case-by-case basis in order to ensure that these technologies have the maximum positive impact on agriculture with minimum risk (Eugene et al. 2002). Moreover, prudent use of these technologies will be an important aspect in maintaining their usefulness in the long run.

While there has been a slow adoption of Bt technologies in European countries- due to human health and environmental risk concern (Ely et al. 2004; FAO 2004), over the past decade acreage of farmland under GM crops has increased world over (Clive

2006). Since the first commercial production of Bt crops in 1996, there has been a substantial increase of acreage to 102 millions and the number of farmers has grown to 103 million. Growth in acreage continued at a sustained double digit growth rate of 12% equivalent to 30 million acres (ISAAA annual report 2007). However, biotechnology agriculture remains concentrated in the industrialized countries. The American continent is by far the largest producer with USA alone accounting for half of world production (table V-1).

Although most GM crops are produced in the developed economies, there has been significant increase in the developing world as well. For example, S. Africa has moved from crop trials to the commercialization of the production of Bt Cotton and Bt maize, though however, without environmental testing. According to the 2007 ISAAA report, South Africa is now ranked number eight in the world with a total biotech crop hectarage of 1.8 million, almost a 30% increase over the 1.4 million hectares in 2006. The major increase in 2007 was in biotech maize notably in white maize, most of it used for food.

The fact that there is significant increase in number of farmers and farms growing GM crops and that the total area in these crops is increasing annually (e.g. 11 percent increase in area between 2004 and 2005 and 12 percent in 2007) is evidence of the commercial success of this production technology (Guillaume 2006 and ISAAA report 2007). While this success is well acknowledged and documented, key constraints to regulation still remain especially in developing countries where appropriate cost effective and responsible regulations are limiting. Besides, the relatively poor and heterogeneous environments in which farmers in developing countries operate complicate the development of relevant agro-technologies.

Finding the balance between food security and Conservation

The benefits and costs of introducing Bt crops into an agricultural landscape have been work reviewed in scientific journals recently (Miguel 2005; Ma, and Reid 2005; Terrance et al. 2000). The benefits range from increased crop yield, enhanced food nutrition status to farmers' cost saving as well as reducing the amount of pesticide residues in the environment. Evidence from South African farmers' experiences point to significant economic benefits (including small scale farmers) and describe the most significant advantages as being pesticide cost savings, better crop management, and increased yield as well as labor cost savings especially with the cotton crop (Yousouf et al. 2002; Huesing and Leigh 2004). Vitale et al. (2007) found significant positive economic impacts in terms of revenue to small scale cotton and maize farmers in Mali (West Africa) as well as benefits to consumers.

On the other hand however, the risks are outlined as potential effect on non-target species, the possibility of out-crossing with compatible neighbors and the possibility of resistance development to target species as well as risk to human health. Contrary to the predicted economic benefits, environmentalist and some economists have argued that the introduction of these varieties have brought several negative impacts to small and large holding farmers including cost-price squeeze whereby the ballooning costs of modern farming technology have consistently swallowed any increases in farm income (Miguel 2005).

The Kenyan government and other stakeholders face the task of assessing the benefits from Bt technology but also the highly uncertain risks to the Kenyan agricultural system. The potential dispersal of transgenes from genetically modified maize into local landraces of maize and the possible emergency of resistant pest strains, raises important scientific, economic and policy concerns (Terrance et al. 2000 and Miguel 2005). Already, the Concerns over consumer and environmental safety have been raised by the Kenya Consumers' Organization and environmental groups such as the Greenbelt Movement; but debate about safety at present is mainly between the government and research circles (Mwangi and Ely 2001).

The release of GM crop varieties has been received with mixed reactions by producers where resistance has been argued on fact that the first generation of GM crops presents autonomous (technological-push) than induced (demand-pull) innovations (Belcher et al. 2005). Assuming that consumers continue to distinguish between GM and non-GM food, this demand for identity preservation means that farmers will continue to plant some non-GM food crops and their products will require certification that they don’t contain a GM contamination beyond a benchmark value (Belcher et al. 2005).

Maize pollination essentially relies on wind dispersal of pollen. As such, levels of cross pollination are generally closely related to distance of receptor plants from pollen donating plant, with the level of cross-pollination falling rapidly the further away the recipient plant is from the pollen source (Perry 2002). Cross fertilization rates also vary with time of planting, variety differences, presence of volunteer maize plants from an earlier crop, size of the fields and the presence or absence of buffer crops and barriers (Graham 2003).

Using separation distances for controlling cross pollination requires knowledge or assumptions of other parameters during crop production and these need also to be considered when developing guidelines for crop separation and thresholds for cross pollination. In a recent report by NIAB of UK, factors such as relative size and shape of donor and recipient fields, spatial arrangement of donor and recipient crops and the distance between fields and their spatial and geographic arrangement are considered to have significant influences on the levels of cross pollination and implementation of isolation measures (NIAB report 2006).

The issue of spatial externality in agriculture has been studied by many researchers. Saak (2004) and Saak (2003), gives a review of cases arising from incompatibility between GM and non GM crops growing on neighboring farms. The case he presents in the review provides ideal examples of a negative spatial externality. Belcher et al (2005) provides evidence of the likelihood of spatial contamination using a simulated model. He finds that the potential cost associated with GM crops in an agricultural landscape is linked to the spatial distribution and interaction of the crops and that parameterization of the simulation model requires incorporation of the existing evidence concerning the potential for spreading GM characteristics to other non-GM crops through cross pollination.

In principle, farmers should be able to cultivate crops of their choice-coexistence, be it GM maize or conventional maize varieties (Graham and Barfoot 2003). This kind of system will help in exploiting market opportunities as well as upholding different cultural values but also protecting biodiversity. But there is no easy solution, or widely accepted model, for putting coexistence into practice. At the farm level, technical and management measures based on isolating crops need to be applied. Miguel (2005) notes that since agriculture production takes place in the open, it is unlikely that primary production systems (non GM farms) can coexist simultaneously or adjust to GM farms without the risk of genetic contamination.

The choice between GM and conventional crops can also be viewed as a choice between economics and values. Economically, keeping the current cropping system is accepting the yield losses caused by pests but also adopting Bt varieties is a social cost which can be equated to the total utility foregone from non-GM crops based on the community preferences and values for the diverse maize/crop genotypes. Farmers, seed developers, traders and food companies want to be able to cater for different niche markets, driven by consumer demands. Freedom of choice is thus important to Bt maize growers who want to be able to adopt different production systems as they wish as well as family farmers and indigenous communities, who often choose crop varieties for their religious or cultural values, special flavor or cooking qualities (Berthaud and Gepts 2004).

In general, biotechnological agriculture development is currently compromised by the need for short-term economic sustainability; the question arises: how can economic signals or support mechanisms be developed which will cause farmers to act economically yet maintain the sustainability of their cropping system? To encourage farmers to take rational economic decisions and be biologically responsible, the relative prices of agricultural products will need to be considered, and systems-based budgeting required. A move to sustainable cropping will only take place if all participants- farmers inclusive are involved in key decision making.

However, Delegating responsibility to farmers raises two issues: (a) how are spatial and temporal variability, and externalities accommodated; and (b) what measurements should be chosen? Given the differences in climatic and market conditions as well as the social values, it may be more helpful to refer to agricultural biotechnological development in terms of spatially dispersed cropping system domains, rather than large contiguous zones based on climate.

Table V-1. Global Area of Biotech Crops in 2007: by Country (Million Hectares)

Rank	Country	Area (million hectares)	Biotech Crops
1*	USA*	57.7	Soybean, maize, cotton, canola, squash, papaya, alfalfa
2*	Argentina*	19.1	Soybean, maize, cotton
3*	Brazil*	15	Soybean, cotton
4*	Canada*	7	Canola, maize, soybean
5*	India*	6.2	Cotton
6*	China*	3.8	Cotton, tomato, poplar, petunia, papaya, sweet pepper
7*	Paraguay*	2.6	Soybean
8*	South Africa*	1.8	Maize, soybean, cotton
9*	Uruguay*	0.5	Soybean, maize
10*	Philippines*	0.3	Maize
11*	Australia*	0.1	Cotton
12*	Spain*	0.1	Maize
13*	Mexico*	0.1	Cotton, soybean
14	Colombia	<0.1	Cotton, carnation
15	Chile	<0.1	Maize, soybean, canola
16	France	<0.1	Maize
17	Honduras	<0.1	Maize
18	Czech Republic	<0.1	Maize
19	Portugal	<0.1	Maize
20	Germany	<0.1	Maize
21	Slovakia	<0.1	Maize
22	Romania	<0.1	Maize
23	Poland	<0.1	Maize

* 13 biotech mega-countries growing 50,000 hectares, or more, of biotech crops

Source: Clive James, 2007.

VITA

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Scope and Method of Study:

The purpose of this study was to assess the spatial distribution of open pollinated maize varieties (OPVs) in lowland coastal Kenya and analyze how this distribution affects the economic and practical feasibility of the implementation of coexistence measures between Bt maize and OPVs. The study used both primary and secondary data. Primary data was spatially generated by a hand held GPS and farmer surveys in lowland coastal Kenya. This data was analyzed using GIS arc view software and the least squares mean procedure. Agroecological zones were used as the reference spatial strata. Secondary data was a review of the existing coexistence studies and economic performance of Bt maize. This information is analyzed and used to determine the economic and practical impacts of the different coexistence measures in lowland coastal Kenya.

Findings and Conclusions:

The findings showed that local maize varieties are popular in the region, most of it grown in zone Cl3 along the coast. However, hybrid and improved varieties are equally popular in Cl4 and Cl5. The size of maize fields didn't differ significantly between zones. The estimated mean size of maize fields across the region was 1.7hec. The distribution of the distances between maize fields was skewed to the right with an estimated mean size of 129.2m across the region.

Consistent with Ingram (2000) separation distance recommendations, we found that at separation distance of 100m, 150m and 200m, approximately 48%, 52% and 53%, respectively, of the farmers would not meet the minimum isolation distance requirement. Consistent with Ingram (2000) separation distance recommendations, we found that at separation distance of 100m, 150m and 200m, approximately 48%, 52% and 53%, respectively, of the farmers would not meet the minimum isolation distance requirement. These benefits are partially offset by reduction of GM maize fields to allow for spatial separation. On average across the region, the cost of separation was found to be approximately USD21.2/hec and USD72.1/hec if the minimum separation distance is 150m and 200m respectively. At separation distances of 150m and 200m, the costs of separation represented 27.2% and 92.4%, respectively, of the gross benefits.

Advisor's Approval: Dr. Jeffrey Vitale