The Cost of Coexistence between Bt Maize and Open Pollinated Maize Varieties in Lowland Coastal Kenya

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Selected Paper prepared for presentation at the Southern Agricultural Economics Association 41st Annual Meeting, Atlanta, Georgia, January 31 - February 3, 2009.

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Abstract

Kenya is currently in the process of introducing genetically modified maize (Bt maize). A major concern is that the Bt gene might cross into local varieties through cross pollination. Current regulatory strategies to ensure coexistence of the two cropping systems at the farm level rely on spatial isolation measures-separation distances and/or buffer zones. However, the interaction of practical measures and costs of spatial isolation with the farmer's economic incentive to plant a Bt maize crop have not been studied in Kenya. The purpose of this study was to analyze the technical and economic feasibility of the implementation of spatial coexistence measures. Using spatial geo-referenced data from the actual agricultural landscape in lowland coastal Kenya, the study finds that flexible separation distances hold the possibility of ensuring coexistence in the region, but will be difficult to implement and don't affect all farmers equally. Rigid buffer strips on the other hand are not consistent with the producers' economic incentive to plant a Bt maize crop.

Keywords: *Coexistence, Regulatory, spatial, Agro-ecological zone, GM crops*

Introduction

Kenya is currently in the process of introducing genetically modified maize. Since 1999, the Insect Resistance Maize project for Africa (IRMA), a joint collaboration between Kenya Agricultural Research Institute (KARI) and International Maize and Wheat Improvement Center (CIMMYT), has been working to develop conventional and transgenic-based insect resistant maize. The first conventional varieties have been released, and the transgenic varieties could be ready in the next year. Transgenic varieties are genetically engineered (GE) to express protein toxins derived from a soil bacterium *Bacillus thuringiensis* (Bt). Bt maize is expected to protect maize from stem borers (mainly the *Chilo partellus* and *Buseola fusca*), that have been reported to cause field crop losses of up to 13.5% nationally (De Groote et al, 2004).

However, a major concern related to the cultivation of Bt maize is that the Bt gene might cross into conventional maize varieties through cross pollination. Bt is a dominant gene (Eugene et al. 2003). If it crosses into conventional maize varieties, it will express itself in the conventional varieties and cause loss of unique conventional maize traits. Safety concerns have raised important scientific, economic and policy issues and have delayed the introduction of Bt maize. Kenya's maize production system relies primarily on small scale farmers who grow local varieties and recycle their seed seasonally. The local varieties are a vital source of genetic diversity and famers prefer them because of household preferences and/or risk aversion towards new varieties (Wekesa et al. 2003). Surveys by Kimenju and De Groote (2008) found that while Kenyan consumers are less concerned about food safety, they care about the environment and biodiversity. These concerns necessitate that none adopters of Bt maize and consumers be protected.

Given the importance of both production systems (GM and non-GM), coexistence[1] between the two becomes an important issue. Current regulatory and management plans rely on spatial and/ or temporal isolation strategies of the two cropping systems. In this region, maize is planted in two seasons. These seasons are often not clearly defined, so maize grows most of the year. Temporal separation in this setting is not realistic, leaving spatial separation as the only

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[1] Coexistence is the ability of farmers to make practical choices between conventional, organic and GM crops and is mainly concerned with the potential economic impact of the admixture of GM and non-GM crops (Demont et al.2008)

option. The most important spatial measures are separation distances and or buffer zones (Perry 2002; Ingram 2002).

In Kenya, land fragmentation is a major concern in that it may not allow farmers who opt to plant Bt maize to meet the specific separation distance requirements. Of interest is whether spatial isolation measures are technically and economically feasible under the current agronomic conditions in Kenya. The spatial distribution of existing crops (Belcher et al. 2006), the size of maize fields and the minimum regulatory distances between GM and non-GM fields (Beckmann et al. 2006; Ingram 2000; Demont et al. 2008; Messean et al. 2006) are important factors that affect coexistence. However, the interaction of these factors and practical measures together with the farmer's economic incentive to plant a Bt maize crop have not been studied in Kenya. Moreover, most studies on coexistence have been conducted using simulated data covering only a small section of the landscape.

In this study, using spatial georeferenced data, we consider isolation distances and buffer zones as the appropriate coexistence measures. We define separation distances as mandatory minimum distance requirements between Bt maize and conventional maize fields and buffer zones as separation measures that involves planting a strip of conventional maize crop around a Bt maize crop field. These measures are imposed on Bt maize producers. Our concern is that some specific separation levels may be impractical and or may not be proportional to the producer's economic incentive to plant a Bt maize crop.

To contribute to the understanding of this issue in Kenya, we characterize the spatial distribution of Open Pollinated Maize Varieties (OPVs) in the low tropics maize production zone in Kenya as defined by Hassan et al. (1998) and analyze the economic impacts of how this distribution may affect the implementation of different spatial isolation standards. Specifically, we document the distribution and concentration of local maize cultivars across the region; determine the size of maize fields, and the distances between maize fields across the agricultural landscape. Using these measures, we estimate the economic costs of different *ex ante* separation standards at the farm level.

This study does not aim to provide optimal separation measures. Rather, we make specific reference to isolation standards in other countries (Table I) planting Bt maize and use these as our guideline for assessing the economic impact and feasibility of potential separation measures in Kenya. Results from this study will provide empirical evidence to enable prediction of GM contamination and provide evidence for the feasibility of implementing different isolation strategies and hence guide in formulation of clear policy frame work to regulate Bt maize cultivation

The rest of the paper is structured as follows: after this introduction, section 2 briefly describes the importance of maize in Kenya and constraints to its production. The section ends with a brief description of the study area. In section 3, we derive a simple spatial conceptual model for analyzing the technical and economical feasibility of coexistence at the farm level. Section 4 deals with the methodology of spatial sampling and data collection, and the analytic framework. In section 5, we present and discuss results. The paper ends with conclusions and recommendations.

Background

Maize is the basic staple food in Kenya. It provides about 42% of the dietary energy intake for about 90% of Kenyans (Karanja and Oketch 1990). It is also an important source of income for farm households in the maize surplus regions. Despite the great efforts being made to increase maize production, demand has occasionally outpaced supply. Average maize production in Kenya is estimated at 81kg/capita, while consumption is estimated at 103kg/per capita (Pingali, 2001).

The causes of low production have been documented as poor soil fertility, weeds (especially parasitic striga), stem borers (Wekesa et al. 2002) and frequent droughts. Participatory rural appraisal studies have indicated that farmers perceive stem borers (mainly *Chilo partellus* and *Buseola fusca*) as the major challenge (Wekesa et al. 2002 and De Groote 2004). Field crop losses from stem borer infestation nationally are estimated to average 13.5% of the maize crop. In the coastal region, pre-harvest losses from stem borers were estimated at 9% and 6.1% in the long and short rain seasons, respectively. Measured maize crop yield in the low land tropical zone with stem borer infestation was estimated to be 1.36t/ha (De Groote 2004) compared to the potential yield of 1.5t/hac (Hassan, et al. 1998).

These pests are most destructive in the larval stage. After hatching, the larvae tunnel inside maize stalks and become difficult to control. They cause structural damage to stems and increase the likelihood of falling. Pests may also attack maize ears, making the cob vulnerable to rot. Conventional chemical spraying, although effective, is expensive and labor intensive. It is also difficult to time these applications and predict levels of infestations. Genetic engineering (GE), on the other hand, offers a promising alternative. With GE, a single gene is inserted into maize and the maize produces the Bt pest control agent from within the plant itself (Eugene et al.2003). The larvae that penetrate the plant tissues are killed when they ingest the toxins.

However biotechnology in Kenya is a sensitive issue and highly regulated. The IRMA project intends to study the environmental and regulatory systems and how transgenic varieties fit in the farming system. This calls for a critical assessment before these varieties are released into the agricultural system. It is this issue that the Kenyan regulatory authorities and IRMA hope to solve through scientific assessment.

Study Area

The study area is the low tropics maize production region, covering the administrative districts of Kwale, Mombasa, Kilifi and Malindi. These districts form the active maize production area of the coastal region. Coastal low land agroecological zone is divided into five subzones characterized by climatic, topographic, soil and other environmental features influencing agricultural productivity and development potential (Jaetzold and Schimidt 1983). These sub zones are used in this study as the reference spatial strata and are denoted as coastal lowland (CL): CL1 CL2, CL3, CL4, CL5 and CL6. CL1 falls outside the active coastal maize production area. Compared with other agroecological zones in Kenya, coastal lowland land is of low potential maize production, characterized by yields of 1.5tons/hec. Together with the mid-altitude and dry transitional zones, cover about 29% of maize area in Kenya but produce only 11% of the country's maize (Hassan, 1998).

Conceptual framework

Landscape structures are important when assessing the possibilities for spatial coexistence of GM and non-GM agricultural systems. In lowland coastal Kenya, the agricultural landscape is relatively fragmented and typically consists of a mix of several crops and grassland. The greater the area of land occupied by non-maize activities, the less land devoted to maize and the greater the expected distance between maize fields.

To analyze the economic feasibility of coexistence, the definition of the GM farmer's value function is important in guiding the decision to adopt or not to adopt Bt maize. The value (V) of the option to plant a Bt maize crop can be defined as the expected value of the difference between the profit (π) obtained from Bt maize cultivation as compared to the conventional crop after considering all costs C of the GM technology and coexistence.

(1) $$V = E(\pi - C)$$

Assuming that other costs are constant, the farmer is assumed to adopt the Bt crop when V is equal to or greater than zero. The expected costs related to coexistence are the costs of respecting *ex-ante* regulations. The value function for the GM farmer can then be formulated as:

(2) $$V = E[\pi\ (p, y) - C(s, reg)$$

where p is the price of maize, y is the difference in the per-hectare yields of the GM and conventional maize crop, s is the size of the maize fields, C is cost of *ex ante* regulation and *reg* is the enforced GM legal standard for the country. The variable *reg* is interpreted as the minimum distance (d) between the GM crop and the maize field's external limits.

The above framework can be used to assess the impact of regulation standards on a farmer's decision to adopt GM crops. One possibility is to evaluate the effect of the variable *reg* on the relevant farm size. The relevant farm size for the given problem is the dimension at which the value function is greater than or equal to zero. Since the farm is a single field, it is possible to determine and evaluate the relationship between the minimum adoption size (s) and the value V at a given mandatory separation distance. We can also fix s (take s as the average farm size across the agroecological zone), and then determine the feasibility of different separation distance standards, ie the isolation distance standard at which V is non zero and the proportion of farmers that may be affected at different separation levels.

Methodology

The general methodological framework is to first to determine the spatial distribution and concentration of local maize varieties using GIS arc view software and descriptive statistics and then use this distribution to empirically determine the technical and economic feasibility of different separation standards.

a) Spatial sampling design and data collection

Data was collected basing on a geographical sampling design. The design was based on the establishment of a left-right determination of points along an established line transect drawn perpendicular to a baseline (Figure I). 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); the length L of the baseline was estimated to be about 300km. On the baseline, 10 base points were selected at equal distance at an interval of 300/(n+1) with a randomized starting point where n is the number of desired transects. Starting on each base point, a secondary line 70km long was established perpendicular to the baseline. On each secondary line, 10 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.

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. From the initial points, two-km stretches of crop (maize or otherwise) were walked on a seven-km interval along each transect in the direction perpendicular to the baseline. At every point where 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: first and second crop depending on the percentage of the area occupied by a crop on a plot, and name of the varieties.

From the middle of the segment, a perpendicular shorter segment of one-km was walked, 500m on either side starting at the SW point, up to the NE point, in the direction parallel to the base line. Since the main variation was expected perpendicular to the coast, more segments were selected in that direction relative to the distance, and the segments were also longer in that direction. Transforming GPS readings to actual ground distance was obtained on a degree-to-Km equivalence using arcView software by triangulation. The average length of maize field sections and in-between plots were calculated from the segments and transition points. This information was then used to approximate the mean distance between maize fields, the mean plot size for a given spatial orientation, and the concentration and distribution of maize plots across the region.

The distance between maize fields was obtained by adding the distance from one maize field to the next field on the same segment. This is based on the assumption that the distance between maize fields on the same segment is equal to the shortest distance between the two fields. For simplest, maize fields were assumed to be square; otherwise fields were not oriented in a fully consistent way.

b) Spatial distribution

As indicated before, agro-ecological zones (AEZ) are used in this study as the reference spatial strata for analyzing the distribution and concentration of maize fields. The zones were indentified with the GPS sample points and located on the map using GIS arcview software. Mean sizes of maize fields and distances between maize fields per agroecological zone were computed as least square means. Comparison of the mean estimates of the size of maize fields and distances between maize fields across the zones were conducted using ANOVA. Since the design of the sampling was not entirely balanced across the study area, the generalized linear model (GLM) procedure was used to estimate mean variations. The GLM was estimated in SAS specifying AEZ as the class variable and the least square means calculated for size of maize fields and distances between maize fields as single effects.

c) Costs of coexistence

To determine the costs of coexistence, a simple field-to-field situation was considered (Figure 2). Consider two isolation scenarios: (i) the case of flexible minimum separation distance and (ii) the case of rigid buffer zone/strip. These measures are imposed on the Bt maize farmer. In case (i), we assume that any two maize fields will be separated by a certain distance that may compensate for the minimum isolation distance requirement, while in case (ii) we assume that a Bt maize field is closely surrounded by conventional maize variety fields. Under scenarios (i) and (ii), for squared fields of length a (m), the area of isolation is determined as in equation 1 and 2, respectively:

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

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

where A_{is} is area of isolation in the case of separation distance, $A_{is\ bs}$ is area of isolation-buffer strip, d is the regulatory minimum isolation distance and x is existing distance between maize fields.

Isolation area requirements mean that growers must forego benefits of the Bt crop on a portion of their planted field. The value of the crop lost in the isolation area is the cost of spatial coexistence. If the isolation area is planted with a conventional maize crop, crop loss for that area can be calculated as the difference between potential production in the absence of insect pests (potential yield from GM), and actual production. If the isolation area is not planted, crop loss is the yield that would have been obtained in that area had it been planted with Bt maize crop.

Economic evaluation is obtained by multiplying crop loss in the isolation area by the average maize prices:

(5) $$Cc = A_{is} (Y_b - Y_p) P$$

where Cc is the cost of coexistence, Y_p is the yield of conventional maize varieties, Y_b is the yield of GM maize crop or potential maize yield in the zone and P is the average market price of maize.

The benefits from Bt technology (the value of the yield gain due to planting GM maize) will be lost if a farmer cannot 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 from a cumulative distribution function of the distances between maize fields.

Results and discussion

Spatial distribution

Results for the distribution and concentration of maize fields are presented in Table II and Table III. Table II contains descriptive statistics of the length of maize field sections and the proportional concentration of maize fields per zone. Most maize farming activity is in zones adjacent to the sea in CL3 and transitional zone CL3-4. There is sparse concentration of maize fields in zone CL4.

Least square mean estimates of the sizes of maize fields and distances between them are included in table III. The estimated mean distance between maize fields was significant for each of the zones at 5% level. When the mean size of the distances between maize fields across the zones were compared, results indicated that there was no significant difference at the 5% level. Across the region, the estimated mean size of distances between maize fields was 129.2m. Results from this study indicate no clustering of maize fields was observed in individual zones even though it was expected that zones with high cultivar of local maize varieties near the coast would have fields that are in close proximity with the trend towards sparse as you move off the coast to the grazing highland areas

The estimated mean sizes of maize fields per sub zone are presented in table III. There was no significant difference between the mean sizes of maize fields across the zones. The size of maize fields across the region was estimated to be 1.73 hac. Relatively, sub zone CL5 has larger maize fields while CL4 has the smallest maize fields. Table III also includes the 95% confidence limits of the sizes of maize fields and distances between fields.

Implications of spatial distribution on technical feasibility of coexistence

To determine whether the available distance between maize fields is enough to allow for spatial isolation, we compare the mean distance between maize fields within the zone with the potential regulatory mandatory separation distance standard. The question at hand is what separation distance standards would be feasible under the current farming system. From the distribution of the distances between maize fields, the potential for coexistence is discerned if any neighboring farmland falls within the recommended separation distance.

Using a cumulative density function (Figure 3) for the distribution of distances between maize fields, the proportion of fields across the region that would not comply with particular minimum separation distance standards is estimated. The distribution of the distances between maize fields is skewed to the right with a mean size of 129.2m. Figure 3 shows that at a separation distance of 50m, 100m and 150m, approximately 43%, 48% and 52%, respectively, of the maize farmers 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.

Economic feasibility of coexistence

Within the region, the estimated mean size of maize fields is 1.7 hac which yields 0.59 t of maize above the yield of conventional maize varieties. At current maize prices ($225.75MT), this translates into USD 132.7 in benefits earned on average by Bt maize farmers in the region. These benefits are reduced if a maize field must be reduced to allow for coexistence. Assuming a border buffer strip, the potential costs of coexistence based on the mean size of maize fields that would result at different *ex ante* separation levels are included in Table IV. At a regulatory separation distance of 20m, the cost of isolation is $68.97 while at a regulatory separation distance of 50m, the cost is $125.56. At these regulatory separation levels, Bt maize benefits the grower $63.73 and $7.1 assuming border strip of 20m and 50m respectively.

Cost estimates in table IV are 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 is reduced due to isolation distance compensation. Table V gives a range of the potential costs incurred when maize fields are separated by a certain distance. From table V, on average across the region, the costs of isolation are approximately $38.98 when the minimum separation distance requirement is 150m. Under this scenario, Bt maize benefits the grower $93.72

A particular feature of separation distances is that they will not affect all farmers equally because the distribution of maize fields is not constant. The costs of observing separation distances would only be incurred in areas where the distance between maize fields is less than the minimum isolation distance standard.

CONCLUSIONS

The purpose of this study was to describe the spatial distribution and concentration of open pollinated maize varieties in lowland coastal Kenya and analyze how this distribution affects the economic and practical feasibility of the implementation of spatial coexistence measure. From the analysis of the available data, the following conclusions are drawn:

The distribution of the distances between maize fields is skewed to the right. Maize fields are in close proximity. Across the region, the estimated mean distance between maize fields was 129.2m and the mean maize field size was 1.7 hac. The size of the distance between maize fields and the size of the maize fields across the region didn't differ significantly by zone.

The gross economic benefits from planting GM maize in the region at current maize prices were approximated to be USD132.7. These benefits are lost by potential GM farmers unable to plant GM maize due to respecting coexistence measures. The economic consequences of coexistence are related to the opportunity cost of not growing GM maize. At farm level, this cost amounts to the difference in economic performance between the GM and non-GM maize varieties. At the region level, the economic effects will depend on the landscape affected, the size of fields and mandatory minimum separation distance. At a minimum separation distance of 50m, 100m and 150m, approximately 43%, 48% and 52%, respectively, of the farmers would not meet the minimum isolation distance requirements.

Separation distances hold the possibility of ensuring coexistence in the region, at the moment, there application is limited. They are difficult to implement in practice and are inconsistent with the regions agricultural heterogeneity of maize cultivation, i.e. they don't affect all farmers equally. Rigid buffer strips on the other hand are inconsistent with the producers' economic incentive to grow Bt maize beyond separation levels of 50m given the average farm size in the region. A high level of communication between neighboring farmers will be necessary.

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Tables and figures

Table I. Isolation distances (m) proposed by EU states to ensure coexistence for GM and Conventional Maize

EU member state	Isolation perimeter (m)
Sweden (forage)	15
Netherlands	25
Spain, Ireland, France	50
Czech Republic	70
UK (forage)	80
UK (grain)	110
Germany	150
Slovakia, Portugal, Belgium	200
Hungary	400
Luxembourg	800

Source: Yann, D. et al. 2008.
Adapted from the EC’s report on the Implementation of national measures on coexistence of GM crops with conventional crops

Table II. Average length (m) of the maize field sections

AEZ	Potential for crop production	Proportion number of Maize fields	Length (m) of maize field sections	
			Mean	Standard deviation
CL2	Medium, poor soils	not sampled		
CL3	High	0.32	81.5	103.4
CL 3-4	Medium	0.3	106.8	80.3
CL4	Low to medium	0.12	123.7	241.9
CL5	low	0.25	112.6	98.6
CL6	Lowest			

CL=Coastal lowland zone

Table III. The GLM Procedure, Least Square Means

AEZ	Distance between maize fields (m)				Size of Maize Field (hac)			
			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	158.0	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 5%

Table IV. Cost of isolation using buffer strips/zones

Isolation distance (m)	Size of isolation area (hac)	Maize crop lost t/hac	Cost of isolation ($/hac)
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*	-	-	-

*Not feasible   Price of maize = $225.75/MT

Table V. Cost of isolation, maize fields separated

Distance between fields(m)	Regulatory separation distance (m)	Size of isolation area (hac)	Maize crop lost in isolation area (t/hac)	Cost of isolation ($/hac)
	20.00	0.00	0.00	0.00
20.00	50.00	0.69	0.24	54.07
	100.00	1.45	0.50	112.94
	150.00	1.70	0.59	132.76
50.00	100.00	1.05	0.36	82.30
	150.00	1.61	0.56	125.56
100.00	150.00	1.05	0.36	82.30
129.20	150.00	0.50	0.17	38.98

Figures

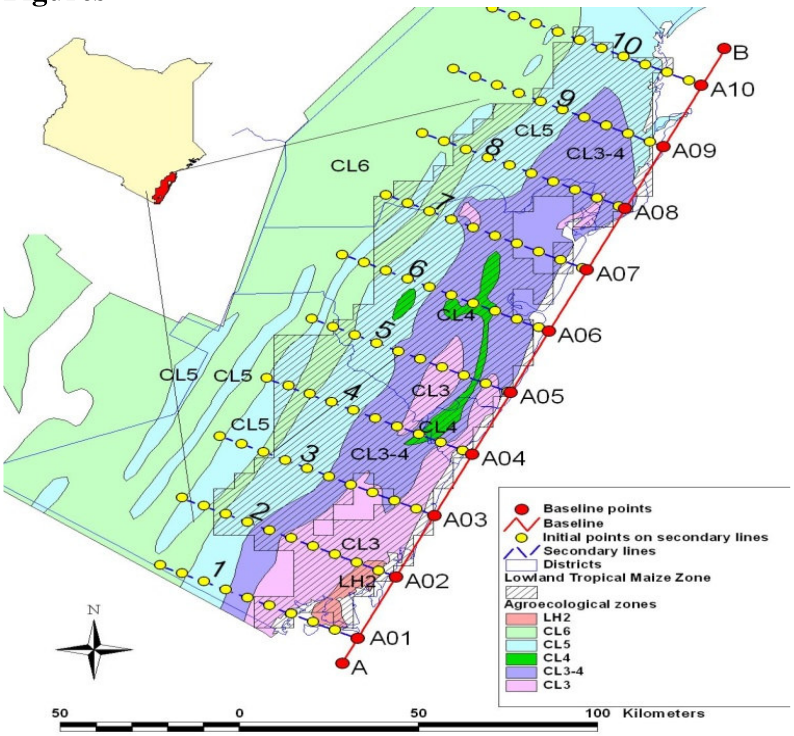
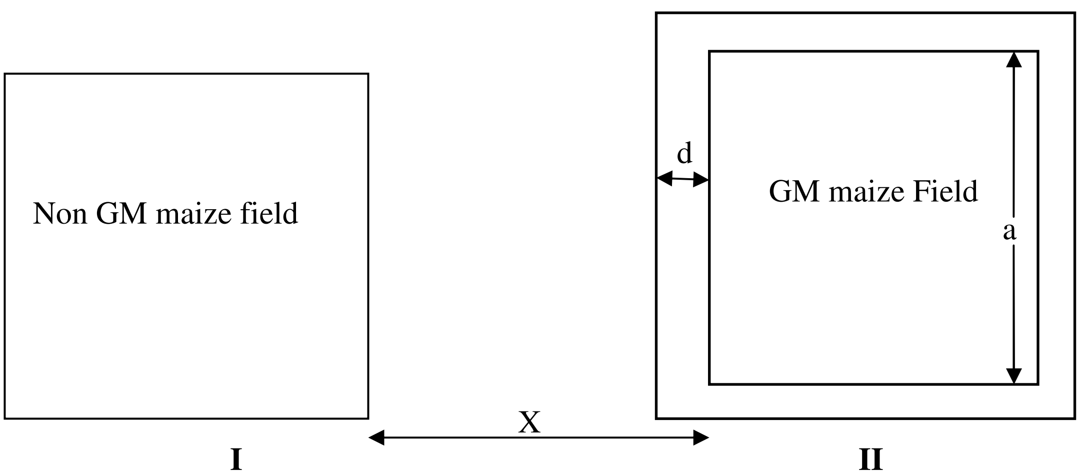


Figure 1. Agro ecological zones at the coast, with the sampling design



d = Minimum separation distant *x =Distance between maize fields*

Figure 2: Spatial layout of fields

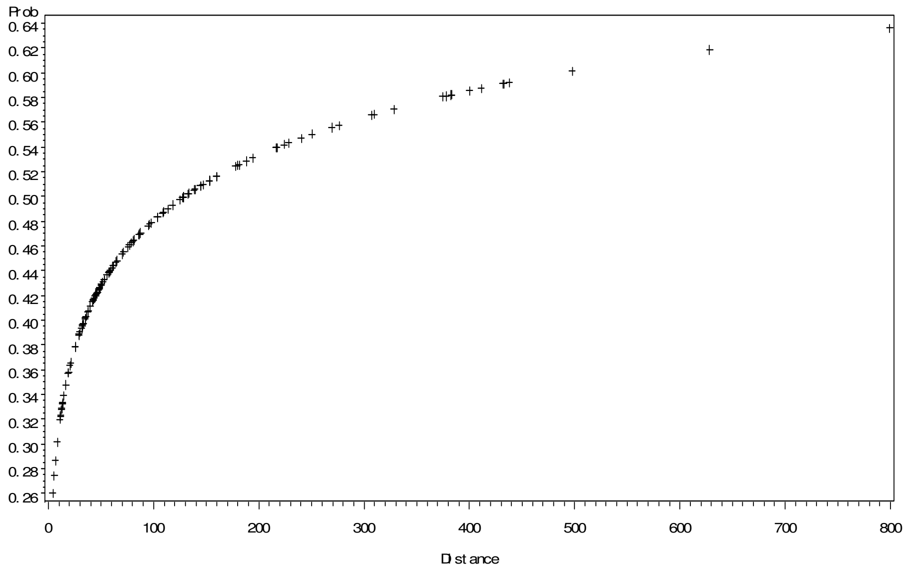


Figure 3: Cumulative distribution function for distance between maize fields