# Crop Biotechnology for Africa:
# Who Will Gain From Adopting Bt Maize In Kenya?

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**Abstract**

Bt maize in Kenya is a promising biotechnology innovation for poor households. Econometric prediction from a trait-based model of variety adoption indicates that the choice of host variety has equity and efficiency implications related to heterogeneity in maize growing environments and pest pressures, as well as the differences among farm households in terms of wealth, income, and market access.

**Key Words:** *Maize, Bt, Adoption, Area allocation*,

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The biotechnology innovations that hold greatest promise for smallholder farmers in Sub-Saharan Africa are those that tackle production constraints in both food and cash crops, but which pose little risk of endangering trade. However, little has been documented at the farm-level on the possible bottlenecks on the adoption of transgenic varieties of staple food crops such as maize. In addition, few biotechnology products have been released to farmers in less industrialized agricultural economies until recently, and most economic analyses of impacts have been conducted primarily on experiences in the U.S. with commercial crops. For cash crops, empirical evidence on adoption of Bt cotton in Argentina (Pray et al.), China (Thirtle et al.), India (Qaim), Mexico (Qaim and de Janvry) and South Africa (Traxler et al.) is growing. In Kenya *Bt* maize is an example of such an innovation that is currently under development.

Though Kenya has experienced substantial success in maize breeding (Gerhart, Hassan), numerous factors still contribute to stagnation in production, including a decline in soil fertility (Lynam and Hassan), reduced profitability of fertilizer use (Heisey and Mwangi), a decline in public research investments (Hassan and Karanja), and biotic pressures due to agricultural intensification. Stem borers, in particular, cause significant yield losses in maize (De Groote 2002, De Groote 2003a), but genetic transformation offers the opportunity to insert *Bt*-resistance into any one of a number of Kenya's leading or less popular maize varieties. However, the choice of host variety can have important implications because of differences among farm households in terms of varieties they prefer, tolerance perceptions, asset endowments, education, market access and heterogeneity in maize growing environments.

More so, poorly developed seed markets, weak extension services and cash flow problems facing most smallholder farmers in Sub-Saharan Africa have often frustrated farmers' ability to benefit from conventional varieties that might perform well in their fields (Smale and Jayne). Though seed may be neutral to the scale of farm operation some important aspects of its technology may favour adoption, which must be addressed in order for research investment to pay off.

## Economic importance of maize and stem borers

Agriculture remains the leading sector in Kenya's economy, providing employment to more than two-thirds of the population, contributing about 26% of the real Gross Domestic Product (GDP) and producing almost all of the country's food supply (Republic of Kenya 1997). Though other food and cash crops have gained in economic importance relative to maize in more densely populated areas, Kenyans have one of the highest rates of per capita maize consumption as food in the world, at 103 kg per annum (http://faostat.fao.org).

After independence in 1964, Kenyan smallholder farmers adopted maize hybrids as rapidly as did farmers in the U.S. "corn belt" during the 1940s (Gerhart). Since then, Kenya has sustained one of the highest cumulative adoption rates for improved maize in Sub-Saharan Africa (Smale and Jayne). In the high-potential zones for maize production, adoption rates for improved varieties have reached a ceiling of nearly 90% of maize area (Hassan, Ouma et al.).

However, food production has continued to lag behind population growth. Stem borers have been identified as one of the most destructive pests limiting maize productivity gains. Kenya alone suffers crop losses due to stem borers that are estimated at 13.5 % of the harvest, amounting to 400,000 tons of maize with a value of US $90 million (De Groote 2002). Participatory Rural Appraisals (PRAs) indicate that stemborer is the most critical insect problem perceived by farmers

(De Groote, et al.). Despite the devastating effects of the pest, cash and labor constraints restrict the use of insecticides by farmers. *Bt* maize has proved to be a safe and effective product, having undergone rigorous testing for food and feed safety, providing environmentally friendly and effective control of targeted pests, with resistance durability extending beyond seven years (James). Furthermore, research has established that the *Cry 1Ab* gene in *Bt* maize has the potential to increase yields by 5% in the temperate maize growing areas and 10% in the tropical areas of Kenya (Clive).

Faced with stagnating and even declining funding, decision makers in research systems are under increasing pressure to allocate their available budgets efficiently. The likelihood that the technologies are adopted has a strong influence on the efficiency of research investments. Hence, prediction of *Bt* maize adoption is crucial to guide the priority setting process. Equally important is the identification of the type of farmers most likely to adopt, to steer public research towards those who need them most: resource poor farmers.

**Conceptual framework**

With transgenic technology, any crop variety is a potential host for an improved trait. Transgenic varieties consist of targeted traits inserted into a host variety that provides other attributes of interest to farmers. In Kenya, maize genetic backgrounds for gene insertion would include any of the hybrids, improved open-pollinated varieties or local varieties.

To address the Economics of maize stem borer problem in Kenya and the role of Bt maize in production environment we develop a trait-based adoption model of agricultural innovations (Feder et al., Feder and Umali) within the farm household framework (Singh, Squire, and Strauss). Farmers' land allocation decisions about whether to grow a maize variety, and the extent of land allocation to the variety can be understood for Kenyan smallholder farmers in the context of household decision-making rather than profit maximization. In this theoretic framework, the agricultural household maximizes utility over a set of consumption items ($C_f$) generated on the farm, a set of purchased consumption goods ($C_{nf}$), and leisure ($l$). The utility a household derives from various consumption combinations and levels depends on the preferences of it members. Preferences are in turn shaped by the characteristics of the household $\Omega_{HH}$ , such as the age or education of its members, and wealth.

(1) $$\underset{C_f, C_{nf}}{Max}\, U(C_f, C_{nf}, l; \Omega_{HH})$$

Amounts of farm produce consumed on farm ($C_f$) or sold are chosen from a vector $Q$ of farm outputs. Decisions are constrained by a fixed production technology that combines purchased inputs (X), labour ($L$), and an allocation of a fixed land area ($A=A^o$ ) among crops and varieties, given the physical conditions of the farm ($\Omega_F$). Each set of area shares ($\alpha_{ij}$) among crops and varieties sums to unity when the seasonal land constraint binds, mapping into outputs through the expression of genes in traits ($\delta$) and technical input-output coefficients. That is, at any point in time, each unit of seed of a crop or variety generates an expected level of output to sell or consume, based on the germplasm it embodies, inputs applied in its production, and growing environment. The choice of area shares implies a level of farm outputs, and vice versa. The farm output function can then be expressed as:

(2) $$Q = F(\alpha, X, L \mid A, \delta, \Omega_F)$$

The objective function can then be expressed as:

(3) $$\underset{1>\alpha_{11}, \alpha_{ij}, \ldots \alpha_{mn} \geq 0; C_f, C_{nf}, X, L}{Max} V(C_f, C_{nf}, l; \Omega_{HH})$$

Subject to : production function: $Q$= *equation (2)*
labour constraint: $T$= *equation (4)*
cash constraint: *equation (5)*

Where the choice variables are area shares ($\alpha_{ij}$), other production inputs, and consumption levels. Interior solutions may not be found for each crop and variety, and some area shares may be censored at zero.

Choices about the allocation of household labour and purchased labour are constrained by total time ($T$) available for farm production ($H$) and leisure ($l$),

$$(4) \qquad T = H + l \, .$$

Expenditures of time and money cannot exceed full income. Full income in a single decision-making period is composed of the net farm earnings (profits) from crop production, of which some may be consumed on farm and the surplus sold, and income that is "exogenous" to the season's crop and variety choices, such as stocks carried over, remittances, pensions, and other transfers from the previous season ($Y^0$):

$$(5) \qquad p_f(Q_f - C_f) - p_x X - wL + Y^0 = p_{nf} C_{nf} + wH \, .$$

A special case of the model is profit maximization. When all relevant markets function perfectly, farm production decisions are made separately from consumption decisions. The household maximizes net farm earnings subject to the technology and expenditure constraints and then allocates these with other income among consumption goods. The production and consumption decisions of the household cannot be separated when labour markets, markets for other inputs, or product markets are imperfect. Then, prices are endogenous to the farm household and affected by the costs of transacting in the markets. For a good that is not traded, no surplus is sold ($Q$ - $C_f$=0) and the shadow price that governs the choices of the household is determined by the internal equation of supply and demand for the good, expressing the household's valuation of the good. Market constraints on production and/or consumption can be expressed as functions of exogenous market characteristics $\Omega_M$. The specific characteristics of farm households (represented by vector $\Omega_{HH}$) and markets (represented by vector $\Omega_M$) influence the magnitude of transactions costs involved in market exchanges and through the shadow price, the household's choices.

When consumption and production decisions are not separable, the optimisation of equation (3) with respect to equations (2), (4) and (5) lead to a reduced form equations (6) expressed in optimal area allocations among crops and varieties as functions of a vector of prices (including wage), farm size, exogenous income, and vectors of farm household, farm physical, and market characteristics:

(6) $$\alpha^* = \alpha^*(p, A^0, Y^0, \delta, \Omega_{HH}, \Omega_F, \Omega_M).$$

**Our approach is also influenced by Lancaster's (1966) theory of consumer choice. Maize varieties are bundles of attributes, each variety supplying its own expected levels of attributes given its genotype and interactions with the environment (Smale, Bellon, and Aguirre). Farmers "consume" seed as a production input, and in the non-separable household model, they also consume the harvest as a production output. Relatively few adoption models have treated variety attributes other than crop yield explicitly (for example, Adesina and Zinnah ). Here, in addition to expected yield constructed through elicitation of triangular distributions (Hardaker, Huirne, and Anderson ), we introduce the trait targeted for gene insertion, tolerance to stemborer.**[1]

## Methods

### *Data*

Using a geo-referenced map developed by the Kenyan Agricultural Research Institute to define maize production domains by elevation and rainfall, a stratified sampling design was used to select 806 households in 5 agro-climatic zones and 81 sub-locations (villages) in Kenya. The zones formed the strata, and sub-locations the first stage. Following De Groote (1996), optimization was done

[1] Variety demand derived from the demand for attributes has been fully developed in the theoretical framework of the agricultural household model by Edmeades (2003).

based on the Kenya Maize Data Base (KMDB), to obtain a precision of 5-10 % Root Mean Square Error (RMSE) for each agro-ecological zone for key maize variables; maize area, yield, household size and acres under major three varieties. A structured questionnaire was then administered to the sampled farmers during 2002 and 2003.

*Variables*

Instead of measuring the share of maize area planted to modern varieties as in a conventional adoption model, the dependent variable in the econometric analysis is the share of maize area allocated by the farm household to a potential host variety for *Bt* resistance. Explanatory variables (Table 1) are empirical measurements of conceptual variables indicated by the reduced form equation (6). Prices do not vary among households within villages and are not included.

Farm size releases the binding land constraint for all crops including maize and is also an asset, enabling access to inputs and product transport. In the adoption literature it is typically associated with fixed factors that enhance the chances of growing modern varieties; on the other hand, it may relate to diversification in Kenya's changing agricultural economy. Expected yields should influence net profits from maize for commercially-oriented hybrid growers, though local varieties are often grown for attributes not directly related to grain yield, such as fodder, taste in cooking, or post-harvest processing. Independent of variety, tolerance to stemborer is hypothesized to affect adoption positively.

More fertile soils would likely be planted to hybrids whose response is steeper, and less fertile to well-adapted local varieties. The relative importance of maize in the total cultivated area could be associated with greater specialization in hybrids or inability to intensify through use of hybrids. As men are educated, they are typically drawn out of staple food production; as women who remain on the farm gain schooling, often they have better access to information and new techniques. Wealth, extension contact, market access and hired labor are typically associated positively with growing hybrids and negatively with growing local varieties.

[ Table 1]

*Econometrics*

To predict changes in the likelihood of adoption and maize area allocation to those varieties that are candidates for insertion of Bt resistance, we employ a trait-based two-stage Heckman model of variety choice following the theoretical framework of the household farm (Edmeades). Traits include subjective yields and loss to stem borer.

Heckman's model is used for two reasons. First, as is consistent with the structure of the Heckman model, variety choice includes a discrete decision to grow as well as a continuous, land allocation decision. The land allocation decision is conditional on the decision to grow the variety. Secondly, only farmers growing a given variety could report triangular yield distributions and tolerance to stemborer, imposing a sample selection bias. The first stage of Heckman's model is a probit model that estimates the probability the farmer grows the variety under study. The second stage, or the selection equation, uses the probit coefficients to linearly regress area allocation against factors that influence the variety area allocation, to arrive at consistent estimators. Mathematically, the first stage is expressed as:

$$(7)\ Z^{\circ} \equiv \alpha X \oplus \varepsilon$$

This is a Probit equation, where $z^o$ = is the probability of growing the variety ($z^o$=1 if household grows host variety and $z^o$=0 otherwise), 'X'= is a vector of exogenous factors namely household, farm and market characteristics.

The probit regression is simultaneously regressed with the area share selection equation expressed as:

$$(8)\quad \alpha^{\Theta} \equiv \beta X \oplus \varepsilon$$

This is the linear selection regression for area share, where $\alpha^{®}$ = is the area allocated to the host variety, ***X***= is a vector of exogenous factors namely variety characteristics, household characteristics, farm characteristics and market characteristics (Heckman).

When 806 observations were examined, it was evident that large proportions register a zero value in the dependent variable not because farmers opt not to choose a variety from among the set available to them, or because of seed supply constraints, because the variety is not adapted to that agroclimatic zone. The Kenya national research system has a maize-breeding program for each of its distinct, well-defined growing environments (Hassan). Before estimating the Heckman model, we eliminated these zeros (Appendix A lists all varieties grown by farmers surveyed in each agroclimatic zone).

Next, for the purposes of this paper, we identified the three most frequently grown maize varieties that are possible candidates for insertion of *Bt* resistance: 1) H614, a hybrid bred for the high potential maize growing environments in the highlands and the moist mid-altitude zones; 2) PH4, a hybrid bred for the lowland tropics zone at the coast; and 3), Mdzihana, a local variety recognized by both maize breeders and farmers for its distinctive traits, also grown at the coast. The Kenyan Coast is a humid, low potential zone.

## Results

*Overview of the data*

Three host varieties (H614, PH4 and Mdzihana) from three agroecological zones (Moist-Transition, Moist Midaltitude and Low Tropics) were selected from a list of the varieties grown (appendix A). The average household size in the H614 zone is 7. 6 compared to 5.6 in the low tropics, where PH4 and Mdzihana are grown. Mean age of household head do not differ much between H614 growers (46) and those in the low tropics (47 years). 80% of household heads in the H614 zone have some years of formal education, with almost the same number 76% in the low tropics. Female-headed households dominate in the low tropics (27%) compared to 23% in the high potential (H614 zone). Over 70% of households in the H614 zone own cattle, 55% access credit, 70% use fertilizer, but they allocate less land (0.95 hectares) to maize. In the low tropics only 33% own cattle, 15% have access to credit, and a mere 12% use fertilizer, yet they have larger areas in maize (4.06 hectares).

*Likelihood of growing Host Varieties*

According the estimation of the first stage of the model, female adult education decreases the probability of growing the local variety (Table 2), while it is insignificant for the two hybrids (H614 and PH4). On the other hand, male adult education negatively influences the probability to grow all the three candidate varieties implying that when men acquire more education their opportunity costs of involvement in maize production increase. In fact, in the high potential area opportunities to grow more remunerative cash crops and work off-farm are substantial, reducing male involvement in maize as compared to female. For the low potential varieties it suggests that male labor is usually drawn out of maize production with increasing education. In the low potential zone there are few alternative cash crops, and deficits in maize production necessitate migration of men to earn cash in the urban centers, leaving women as the main participants in cultivation of maize.

Credit access positively influences the probability to grow H614 but has no significant effect on the low potential varieties (PH4 and Mdzihana). This point at the fact that farmers with credit are able to purchase fresh H614 seeds and attain higher yields. The insignificance of credit on the low potential hybrid (PH4) is likely due to little credit services in this zone. As expected, hiring more labor is negatively associated with growing the local variety, in part this may be because hired labor is associated with commercial orientation of production and secondly because it represents an active local labor market to draw household labor out of maize. Households that grow Mdzihana also have smaller landholdings. Access to input market on the other hand influences probability to grow the high potential H614, implying better access to fresh seeds.

[Table 2]

*Changes in land allocation*

The second step of Heckman's model was applied to the area shares of the varieties. The results (Table 3) show that perceived resistance to stem borer positively influences area shares for both high potential hybrid (H614) and the low potential popular local (Mdzihana). However, it is not significant for PH4.  The magnitude of the effect is particularly large for Mdzihana, implying that insertion of *Bt* resistance in the dominant local variety would increase its cultivation but might have negligible effect on the cultivation of dominant hybrid at the coast, controlling for other factors. Expected yields for the dominant hybrid (H614) are more important in the intensively farmed highlands, a surplus producing region.

Male education does not contribute to greater shares in H614, though female education does—reflecting the role women play in growing the staple food crops. In the low potential zone, educating men contributes positively to growing more PH4, and negatively to growing more of the local variety**.** Livestock wealth on the other hand increases land allocation to H614, but gifts and transfers, extension contacts and access to seed markets make no difference in land allocation. More hired labour reduces the area allocated to H614, indicating a preference for other cash crops, when resources allow.

The higher the proportion of maize area on the farm, the greater the area shares for the low tropics hybrid (PH4) and the smaller the area shares in Mdzihana. Extension contacts are has no important effect on H614, but has an effect on the newly released PH4. It also, unexpectedly, increases the share in mdzihana, the local variety. The insignificance of extension on H614 is likely because the variety was released in 1986, so current extension does not have a major impact, and partly because the adoption rate of H614 zone had already reached a very high level. Greater total value of livestock augments the area share in Mdzihana.

[Table 3]

*Profile of households with high and low probabilities of growing the host variety*

After estimating the regressions, the profile of those households with the highest and lowest 20% predicted probabilities of growing the host varieties was established (Table 4). Holding resistance levels and other explanatory factors constant, profiles indicate which households are most likely clients for the new technology.

Results show that farmers with high-predicted probabilities of growing H614 have more financial, natural and human capital. They have twice the cash gifts and transfers of those with low predicted probabilities, they are nearly five times as wealthy in livestock assets, possess more fertile land and both men and women are more educated. The percentage growing cash crops is higher, but they devote a lower percentage of their land to maize. These households can clearly afford seed, and rely little on extension contact.

Cash income levels are similar for households with low and high predicted probabilities of growing PH4 and Mdzihana, but cash gifts, transfers and credit received are lower for those most likely to grow Mdzihana. The percentage of fertile land is very low for those with high likelihood of growing Mdzihana. Extension contact is clearly important for PH4, as compared to H614. Hassan et al. related the high use of unimproved maize in this zone to lack of seed dealers.

The proportion of households with women decision-makers is larger among households with low probabilities of growing either H614 or PH4, as is often shown in the adoption literature, though gender-linked effects tend to operate through gender-linked access to related inputs or assets (Doss and Morris). All three groups with high-predicted probabilities of growing a variety rank tolerance to stemborer higher.

[Table 4]

## Conclusions

Econometric results show that perceived tolerance to stem borer on the demand for potential host varieties, expressed as the share of maize area, matter for both hybrids and local varieties. The negative effects of men's education on the demand for hybrid maize, compared to the positive effect of women's education, reflect rising opportunity costs for men and the role of women in producing the staple food crop. There is substantial difference between high adopters and low adopters of possible host varieties, with a possible increase in adoption of transgenic hybrids in the high potential zone, with wealthier households and more fertile land and where intensification is high. These farmers no longer need extension contact to grow hybrids, as their adoption rates had long reached optimal levels. However, they need better input markets for fresh seeds.

In the low potential zone, where seed dealers are fewer, extension contact remains significant. Farmers with high-predicted probabilities of growing local variety (Mdzihana) at the coast have less fertile land; they receive less in gifts, transfers, credit and hire less labor. It is likely that Bt may speed the rates of adoption of improved hybrids here (PH4).

## Implications

**Varieties vary in stem borer tolerance and it is important to study all the varieties, before introducing Bt technology to farmers. In addition**, **variety use var**ies **by poverty level, particularly whether the variety is improved or a local**. It is therefore **important** to **package** **Bt maize to fit differential poverty levels among farmers. More so, varieties are adapted to specific areas and Bt introduction to the varieties must take into account specific adaptations.**

Because of yield levels and historical adoption rates, the high potential areas have are relatively suitable candidate sites for promoting maize hybrids with *Bt*-resistance. On the other hand, the adoption rates of farmers in the low potential areas appear more sensitive to stem borer infestation, indicating that *Bt* can increase adoption rates here. The lower susceptibility to stem borer and preference of farmers for their own local varieties, given their chronic maize deficit status, also suggests that these varieties are viable hosts for *Bt* genes. Our findings therefore reveal equity vs. efficiency trade-offs related to the choice of host varieties for insertion of *Bt* resistance.

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Table 1. Hypothesized effect of explanatory variables on share of maize area allocated to potential host varieties by farm households

| Variable | Definition | Hypothesized effect | |
|---|---|---|---|
| | . | Hybrids | Local |
| Farm size (A) | Total Farm size in hectares | (+,-) | (+,-) |
| Exogenous income (Y) | Total annual value of transfers and gifts received (Ksh) | (+) | (+,-) |
| | Total annual value of credit received (Ksh) | (+) | (+,-) |
| Variety traits ($\delta$) | | | |
| Expected Yield | Yield computed from elicited triangular yield distributions | (+) | (+, -) |
| Tolerance to stem borer | Farmer ranking of perceived variety tolerance to stem borer | | |
| Farm characteristics $\Omega_F$ | | | |
| Soil fertility | Percent of farm maize area with excellent soil fertility | (+) | (-) |
| Maize importance | Percent of farm area planted to maize, preceding season | (+, -) | (-) |
| Household characteristics $\Omega_{HH}$ | | | |
| Female adult education | Average number of years, all female in the household | (+) | (-) |
| Male adults education | Average number of years, all male adults in household | (-) | (-) |
| Wealth | Total value of cattle (oxen, dairy, other, in Ksh ) | (+) | (-) |
| Extension contact | Number of extension contacts in the preceding season | (+) | (-) |
| Market characteristics $\Omega_M$ | | | |
| Labour market | Hired labour hours used in the preceding season | (+) | (-) |
| Input Market access | Access to local input market Σ(distance X average speed) | (+) | (-) |

Note: Income was measured for the period 2001-2002, the year preceding the survey, market access was computed as Σ (distance in km x Speed inkm/hour) for input market only, labour used was all hired labour in the farm in man hours.

Table 2. Factors influencing the probability that farm households grow host variety

Dependent variable= If growing variety (1, 0)

| | H614 | PH4 | Mdzihana |
|---|---|---|---|
| ***Household Characteristics*** | | | |
| Female adult education in years | 0.0276 | -0.0075 | -0.4616** |
| Male adult education in years | -0.0925*** | -0.0708*** | -0.9835*** |
| ***Farm Characteristics*** | | | |
| Credit amounts (Ksh) | 0.00021** | 0.0000 | -0.4036 |
| Farm size (ha) | -0.0146 | -0.0385 | -0.2056*** |
| ***Market Characteristics*** | | | |
| Access to local input market index | 0.0006** | 0.0000 | -0.6046 |
| Hired labour in hours | -0.0025 | 0.0001 | -0.4067** |
| Log Likelihood Ratio | -162.816 | -182.765 | -151.274 |
| N | 285 | 329 | 266 |

*= Significant at 0.1, **=significant at 0.05, ***= significant at 0.01. First-stage Probit results of Heckman model. Data source: IRMA baseline survey 2002-2003.

Table 3. Factors influencing land allocation by farm households to host variety

Dependent variable = area shares

| Variable | H614 | PH4 | Mdzihana |
|---|---|---|---|
| ***Variety characteristics*** | | | |
| Tolerance to stem borer | 0.094709** | 0.049759 | 0.196376*** |
| Expected yield | 0.000025* | 0.000003 | -0.000117** |
| ***Household characteristics*** | | | |
| Female adult education | 0.027757** | 0.007368 | 0.015264 |
| Male adult education | -0.024891* | 0.028133* | -0.028075* |
| Wealth | 0.000004** | 0.000001 | 0.000004* |
| Extension contact | -0.010822 | 0.011243* | 0.008584** |
| Gifts and transfers | 0.000001 | 0.000001 | -0.000003 |
| ***Farm characteristics*** | | | |
| Maize importance | -0.000023 | 0.001783* | -0.002150* |
| Soil fertility | 0.001210 | 0.000452 | 0.011390 |
| Extension contact | -0.010822 | 0.011243* | 0.008584** |
| ***Market characteristics*** | | | |
| Hired labour in hours | -0.001686** | 0.000013 | 0.000044 |
| Market access | 0.000157 | 0.000055 | -0.000025 |
| IMR (inverse mills ratio) | 0.445083** | 0.637462** | 0.331356** |
| Log Likelihood Ratio | 7.836000 | -5.075000 | -2.975000 |
| N | 285 | 329 | 329 |
| Selected sample | 71 | 75 | 52 |
| Log Amemiya | -2.720000 | -2.673000 | -2.253000 |
| Akaike | 0.117000 | 0.455000 | 0.576000 |

*= significant at 0.1, **=significant at 0.05, ***= significant at 0.01. Marginal effects reported.

Table 4. Profile of farm households with high and low predicted probabilities of growing potential host varieties for *Bt* insertion

| | H614 | | PH4 | | MDZIHANA | |
|---|---|---|---|---|---|---|
| | High | Low | High | Low | High | Low |
| ***Farm Household Characteristics*** | | | (mean) | | | |
| No. adult household members | 8.14 | 5.46 *** | 6.15 | 7.00 | 5.10 | 8.00 *** |
| Yrs education, adult men | 8.86 | 6.20 *** | 6.87 | 7.55 *** | 6.28 | 7.95 *** |
| Yrs education, adult women | 7.57 | 2.95 *** | 4.93 | 3.78 | 3.24 | 5.57 *** |
| Annual cash expenditure (Ksh) | 78,920 | 78,866 | 90,151 | 95,87.70 | 89,123 | 106,159 |
| Annual gifts and transfers (Ksh) | 18,817 | 8,805 * | 12,557 | 8,414 | 9,667 | 29,850 *** |
| Annual credit received (Ksh) | 2,585 | 1740.17 | 1,178.46 | 2492.42 | 153.80 | 1090.91 |
| Value of cattle (Ksh) | 29,116 | 6,508 *** | 15,672 | 30,764 | 5,964 | 3,686 |
| % Adult males employed off-farm | 64.4 | 60 | 51.2 | 64.2 | 60 | 51.2 |
| % Adult women employed off-farm | 27.4 | 48.1 ** | 13.4 | 24.6 *** | 22 | 24 |
| No. Extension contacts | 0.18 | 1.14 | 7.00 | 1.03 ** | 4.00 | 4.23 |
| **Percent** | | | | | | |
| Female decision-makers | 28.10 | 42.10 *** | 24.40 | 65.20 *** | 23.30 | 37.80 |
| Surplus producers | 60.30 | 54.40 | 75.80 | 71.20 | 64.70 | 64.70 |
| Growing cash crops | 68 | 61.8 *** | 21 | 78 *** | 17 | 27 *** |
| Growing other food crops | 57 | 18.5 *** | 17 | 56 *** | 72 | 19 *** |
| ***Farm characteristics*** | | | | | | |
| Farm size (ha) | 2.83 | 1.85 | 4.00 | 2.50 *** | 4.11 | 2.67 *** |
| Maize area (ha) | 0.34 | 0.80 *** | 2.44 | 2.01 | 3.23 | 2.11 ** |
| % Farm area in maize | 35.4 | 52.5 *** | 67.5 | 87.7** | 75.1 | 80.0 *** |
| % Fertile land | 5.6 | 1.4 ** | 8.8 | 3.0*** | 1.0 | 37.0 *** |
| ***Stemborer tolerance (mean score)*** | 2.8 | 2.0 *** | 2.6 | 2.0 | 2.7 | 1.7 ** |

*= Significant at 0.1, **=significant at 0.05, ***= significant at 0.01 using t-tests for difference of means and Chi-squared tests for proportions.

## Appendix A: Verities grown by zone in the major season in Kenya

| Varieties | Agriecological zone | | | | | Total |
|---|---|---|---|---|---|---|
| | High potential | Moist Mid-Altitude | Dry-Transition | Dry midaltitude | Low Tropics | |
| Amanyala | | 5 | | | | 5 |
| Anzika | | 15 | | | | 15 |
| CG4141 | 5 | | 1 | 1 | | 7 |
| Coast Composite | | | | | 40 | 40 |
| DCL1 | | | | 9 | | 9 |
| DH1 | | | | | 1 | 1 |
| Githigu | 4 | | | | | 4 |
| H511 | 34 | 3 | 4 | 4 | | 45 |
| H512 | 8 | | | | | 8 |
| H513 | 14 | 4 | 2 | | | 20 |
| H614 | 52 | 19 | | | | 71 |
| H622 | | 9 | | | | 9 |
| H625 | 5 | 6 | 1 | | | 12 |
| H627 | | | 1 | | | 1 |
| H628 | | | 1 | | | 1 |
| Kangundo | | | 8 | | | 8 |
| Kanjerenjere | | | | | 26 | 26 |
| Katumani | | 2 | 13 | 20 | 18 | 53 |
| Kikamba | | | 61 | 134 | | 195 |
| Kinyanya | | | 20 | 25 | | 45 |
| Makueni | | | 2 | 8 | | 10 |
| Mdzihana | | | | | 52 | 52 |
| Mengawa | | | | | 47 | 47 |
| Mgiriama | | | | | 1 | 1 |
| Msamaria | | 4 | | | | 4 |
| Mungindo | | | | | 3 | 3 |
| Mwangongo | | | | | 1 | 1 |
| Nyamilambo | | 2 | | | | 2 |
| Nyamula | | 9 | | | | 9 |
| Nyauganda | | 7 | | | | 7 |
| Oking | | 1 | | | | 1 |
| Ongech | | 2 | | | | 2 |
| Opapari | | 1 | | | | 1 |
| Otalii | | 18 | | | | 18 |
| PH1 | | | | | 64 | 64 |
| PH3253 | 23 | 4 | 16 | 6 | | 49 |
| PH4 | | | | | 75 | 75 |
| Rachar | | 18 | | | | 18 |
| Sipindi | | 7 | | | | 7 |
| Zonga | | | | | 1 | 1 |
| no8 | | 4 | | | | 4 |
| Total Hlds (zone) | 145 | 140 | 130 | 207 | 329 | 951 |