# IMPROVED SEEDS, FERTILIZER OR NATURAL RESOURCE MANAGEMENT? EVIDENCE FROM KENYA'S SMALLHOLDER MAIZE FARMERS

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**Paper prepared for presentation at the EAAE 2014 Congress**
**'Agri-Food and Rural Innovations for Healthier Societies'**

August 26 to 29, 2014
Ljubljana, Slovenia

**Abstract**

There is consensus that adoption of technological improvements is crucial to increasing agricultural productivity and reducing poverty, while sustaining the agro-ecosystems. There is however disagreement as to which type of technologies are well suited in developing countries; external input intensive technologies or low external input/ natural resource management (NRM) technologies. This paper uses plot level survey data collected from all maize growing areas in Kenya and employs a multivariate probit to assess conditions under which different technologies are adopted. We find that indeed the technologies that farmers adopt vary with different conditions ranging from plot level to climatic conditions.

(Keywords; Technologies, adoption, Multivariate probit)

## 1 Introduction

Empirical studies show that agricultural technologies can help reduce poverty directly, by raising incomes of farm households, and indirectly, by raising employment and wage rates of functionally landless labourers, and by lowering the price of food staples (Winters et al., 1998; Evenson and Gollin, 2003; Minten and Barrett, 2007; Moyo et al., 2007; Diagne et. al., 2009; Becerril and Abdulai, 2010). Adoption of technological improvements is thus crucial to increasing agricultural productivity and reducing poverty, while sustaining the agro-ecosystems that support livelihoods. There is however some disagreement about which type of technologies is most appropriate or most promising and how priorities should be set. While some consider low-external input strategies as more suitable for African smallholders (IAASTD, 2009), others suggest models of input intensification and commercialization with a stronger role of the private sector (Pingali, 2007). In practice the suitability of technologies and their impacts depend on many situation- specific conditions. More research is required to show comparative evidence of what really works under which conditions. This is especially true against the background of changing global environments, which may render previously suitable technologies and approaches inappropriate in some cases.

Generally, there are two broad recommendations of technologies aimed at increasing productivity 1) the external input intensive technologies which include use of improved maize varieties and chemical fertilizers and 2) the low external input, natural resource management (NRM) technologies which consist of conservation agriculture, soil & water management practices and use of organic manure. Studies have been done on adoption of each of these technologies in different countries using different methodologies. Studies such as (Nkonya et al., 1997; Becerril and Abdulai, 2009; Kassie et al., 2011) have studied adoption of improved seed varieties. Other studies such as Nkonya et al. (1997) and Cavane and Donovan (2011) have studied adoption of chemical fertilizers. Still other studies have studied adoption of conservation agriculture and organic manure (Kassie et al., 2009;) and further still studies such as Gebremedhin and Swinton (2003) have studied adoption of soil and water management practices (terraces and soil bunds). However, existing literature cannot provide comparative results across countries and technologies since the data and methodology used in each of these studies are quite different. Additionally, most of these studies have analyzed adoption of technologies at household level. Considering plot level characteristics such as soil fertility, topography of the land, ownership and tenure to have influence on farming decision and land management, farmers may adopt different technologies in different plots.

This paper also acknowledges the fact that farmers do not make adoption decisions of the various technologies independently but that they make such decisions simultaneously. Farmers are faced with technology alternatives that may be adopted simultaneously as complements or substitutes to deal with their overlapping constraints such as weeds, pest and disease infestations, and low soil fertility and crop productivity (Dorfman, 1996). By focusing on single technologies most previous studies ignore the possibility that the choice of technologies to be adopted may be partly dependent on earlier technology choices and thereby underestimate or overestimate the influence of various factors on adoption. (Wu and Babock, 1998). Modeling technology adoption in a multiple technology choice framework is therefore important to capture useful economic information contained in interdependent and simultaneous adoption decisions (Dorfman, 1996).

To provide a better understanding of available technologies under different farming conditions, this paper seeks to compare factors determining adoption of high external input intensive technologies and the NRM technologies at plot level using a single data set and a harmonized methodological approach. In addition, this paper seeks to find out complementarities and substitutability between technology options and whether farmers are likely to adopt the external input intensive and NRM technologies in separation or combination. The focus of this technology adoption study is on maize farming in Kenya as the most important staple food with average consumption of 125 kg per capita providing more than one third of daily caloric supply (FAO, 2011). Maize is grown in almost all agro-ecological zones, including marginal areas, and approximately 80% of maize produced in Kenya is grown under small holder production systems (Owour, 2010).

## 2 Description of the technologies

External input intensive technologies are mainly improved seeds and chemical fertilizers. Improved maize varieties include hybrids and open pollinated varieties (OPVs) whose traits have been improved for selected characteristics such as drought tolerance, disease resistance, short maturity rate, increased yield per unit of land, and quality protein (Byerlee, 1994). In sub-Saharan Africa, poor soil fertility is one of the major causes of low agricultural productivity therefore chemical fertilizers are usually aimed at improving soil fertility.

NRM strategies are mainly developed to deal with environmental distress. One of the major environmental problems of developing countries is land degradation in the form of soil erosion and nutrient depletion, both of which undermine land productivity. Soil and water management practices such as constructing terraces and soil/stone bunds are usually recommended to curb the problem of soil erosion. These alternative soil and water management practices contrasts in length of investment and effectiveness of erosion abatement. Stone terraces are constructed walls that retain embankments of soil. Their construction involves preparing a base for the wall, transporting construction rocks, and carefully layering the stones. Stone terraces are more effective than soil bunds in preventing soil erosion on steep slopes prone to heavy runoff. Soil bunds on the other hand are embankments made by ridging soil on the lower side of a ditch along a slope contour. They can be constructed by hand digging or plowing and are usually cheaper and easier to establish than stone terraces.

Conservation agriculture is another NRM strategy and it involves decreased disturbance to the structure of the uppermost soil layers. This is achieved through combination adoption of three essential farm practices: a reduced tillage method of seedbed preparation (zero/minimum tillage), permanent soil cover through crop residue management (mulching) and crop rotation (Hobbs et al., 2008). In this paper zero tillage and mulching (crop residues retention as soil cover) will be analyzed separately as two different technologies to find out the level of interdependence between these two practices. Mulching has other beneficial effects such as reducing soil evaporation, improving water infiltration, reducing maximum temperatures in the soil surface layers, increasing aggregate stability and soil porosity and so on. Finally, use of animal manure as another NRM technology has great potential as a principal source of nutrients for soil fertility maintenance and crop production in developing countries. This is mainly because low rural incomes, poor infrastructures, thin markets and inappropriate public policies hinder the widespread use of chemical fertilizers. At the same time, high population growth has led to rapid expansion of cultivated land and caused a breakdown in the traditional bush fallow system used for the maintaining soil fertility.

## 3 Data and Descriptive statistics

### *3.1 Data*

The data includes 4035 plots among 1344 households distributed across all the maize growing areas in Kenya distributed under six maize Agro Ecological Zones (AEZs) as defined by Hassan (1998). Households to be surveyed were selected using stratified two stage sampling technique. The stratas were the six maize AEZs in Kenya. The sub-locations (Kenya's smallest administrative units) as determined in the 2009 Kenya national bureau of statistics (KNBS, 2010), census were the primary sampling units (PSU), and the households were secondary sampling units (SSU). Based on (De Groote, 1996), the required number of PSUs was calculated at 120 sub-locations, spread over the different zones. For each sub-location, 12 households were selected by random sampling except for the coastal lowlands where six households were selected per sub-location due to budgetary constraints. The survey was conducted between December 2012 and February 2013 with a reference period of 2012 cropping year. Data was collected on socio economic characteristics of the household members, general risk preferences, maize plot level characteristics and asset ownership among others.

### *3.2 Descriptive Statistics and hypothesized explanatory variables*

Table 1 presents a brief description of the dependent and hypothesized explanatory variables and their descriptive statistics.

**Table 1 Descriptive statistics of the dependent and the explanatory variables (n=4035)**

| ***Variable name*** | ***Description of the variable*** | ***Mean*** | ***Std Dev*** |
|---|---|---|---|
| *Dependent variables* | | | |
| Improved seeds | =1if seeds are improved varieties, 0 otherwise | 0.72 | 0.45 |
| Fertilizer | =1 if farmer applied chemical fertilizers, 0 otherwise | 0.54 | 0.50 |
| Terraces | =1if farmers practiced terracing on the plot, 0 otherwise | 0.52 | 0.50 |
| Soil bunds | =1 if the farmer had soil bunds on the plot, 0 otherwise | 0.17 | 0.37 |
| Crop residues | =1if farmer left any crop residues on the plot, 0 otherwise | 0.54 | 0.50 |
| Zero tillage | =1if farmer practiced zero tillage on the plot, 0 otherwise | 0.11 | 0.32 |
| Manure | =1 if the farmer used animal manure, 0 otherwise | 0.52 | 0.50 |
| *Plot level characteristics* | | | |
| Plot size | Size of the plot in acres. | 1.23 | 1.54 |
| Plot ownership | =1 if owns the plot, 0 if it is rented /borrowed in | 0.88 | 0.33 |
| Medium soil fertility[a] | =1 if the soil fertility of plot was rated medium 0 otherwise | 0.51 | 0.50 |

| | | | |
|---|---|---|---|
| Good soil fertility[a] | =1 if the soil fertility was rated good 0 otherwise | 0.37 | 0.48 |
| Gentle slope[b] | =1 if the slope of the plot is gentle 0 otherwise | 0.43 | 0.50 |
| Medium slope[b] | =1 if the slope of the plot was rated medium 0 otherwise | 0.20 | 0.40 |
| Steep slope[b] | =1 if the slope of the plot is steep 0 otherwise | 0.05 | 0.22 |
| *Socio economic characteristics* | | | |
| Age of farmer | Age of the farmer in years | 50.00 | 14.53 |
| Male | = 1 if the farmer is male, 0 otherwise | 0.57 | 0.50 |
| Education farmer | Years of formal education of the farmer | 7.54 | 3.89 |
| HH size | Number of HH members. | 6.5 | 2.6 |
| Land size | Total land owned by the household in acres. | 5.59 | 9.11 |
| TLU | Total livestock units | 5.85 | 7.88 |
| Risk taking | Risk attitude of the farmer (discrete scale between 1 and 5) 1 is high risk averse and 5 is a risk loving. | 3.20 | 1.45 |
| *Institutional variables* | | | |
| Credit access | =1if the HH has access to credit and 0 if not | 0.20 | 0.40 |
| Group membership | =1 if participates in any group and 0 otherwise. | 0.87 | 0.33 |
| Distance market | Distance in walking hours to the nearest main market | 1.62 | 1.57 |
| *Climatic shocks* | | | |
| Drought | Frequency of drought experienced between 2003 – 2012 | 2.21 | 2.07 |
| Flooding | Frequency of flooding experienced between 2003 – 2012 | 0.56 | 1.73 |
| *AEZ dummies*[c] | | | |
| Dry Mid altitude | =1 if a HH is located in the dry mid attitude, 0 otherwise. | 0.16 | 0.37 |
| Dry Transitional | =1 if located in the dry transitional zone, 0 otherwise | 0.15 | 0.36 |
| Moist Transitional | =1 if located in the moist transitional zone, 0 otherwise | 0.26 | 0.44 |
| High Tropics | =1 if a HH is located in the high tropics, 0 otherwise | 0.18 | 0.38 |
| Moist Mid altitude | =1 if located in the moist mid attitude, 0 otherwise. | 0.18 | 0.38 |

**a)** For the fertility of the soil, poor soil fertility is defined as the base dummy variable[b)] For the slope, flat slope is defined as the base dummy variable. [c)] For the AEZ, the lowland tropics is defined as the base dummy variable

General risk preference of the farmer was determined by posing a simple gambling game to the farmers. The farmer was presented with five payoffs and was to choose only one (Table 2). For each choice the amount the farmer would win was randomly determined by drawing a stone from a blinded bag. In the bag there are 5 blues stones and 5 yellow stones so the farmers had an equal chance of drawing either colour.

**Table 2. Risk Preferences of the farmers**

| Choice | Payoff (Ksh) | | Risk scale | Risk preference |
|---|---|---|---|---|
| | Blue stone (prob= 50%) | Yellow stone (prob=50%) | | |
| 1 | 50 | 50 | 1 | High risk averse |
| 2 | 80 | 30 | 2 | Moderate risk averse |
| 3 | 100 | 20 | 3 | Low risk averse |
| 4 | 120 | 10 | 4 | Risk neutral |
| 5 | 150 | -20 | 5 | Risk loving |

10 Kenyan Shilling (Ksh) = 0.11 US Dollars as of June 2014

The expected payoff increased from choice 1 to choice 5 and so did the standard deviation (risk) of the amount. It would be expected that high risk averse farmers would settle for choice 1 where though the expected amount is less, they are certain of winning equal amount either way while the risk loving farmers would go for choice 5 where they had a chance of earning high amounts though it was also uncertain and may even lead to them loosing**.**

Climatic shocks variables include the number of times the farmer reported to have experienced shocks due to drought or flooding during the ten years prior to the survey (2003-2012). We considered the last ten years since it is long enough for a farmer to make land management decisions based on the climatic events and the fact that most farmers could not recall the climatic events beyond 10 years. Lastly the AEZs include the highland topics, moist mid altitude, moist transitional, dry mid altitude, dry transitional and the lowland tropics. These AEZs differ in various attributes -annual rainfall, elevation, temperature, total area under maize, potential and actual maize yield and contribution to total maize produced in the country (Hassan 1998; Jaetzold et al., 2006). The highlands tropics, the moist transitional and the moist mid altitude receive comparatively higher levels of rainfall and they also contribute more to the total maize produced in the country compared to the other zones. They are also located on the relatively higher altitudes compared to the other AEZs. The highland tropic AEZ in particular has the highest potential yield and is also the highest contributor to the total maize production in the country. Of all the agro ecological zones, the lowland tropic records the lowest amount of annual rainfall, the highest temperature and it is also the smallest contributor to the total maize produced in the country.

## 4 Technology Adoption Determinants

### *4.1 Modeling Approach*

As the adoption of each technology is not independent from other technological choices on the same farm (and may overlap), the paper employs a multivariate probit model that accounts for error term correlation (Marenya and Barrett, 2007). The multivariate probit (MVP) econometric technique simultaneously models the influence of the set of explanatory variables on each of the different practices, while allowing the unobserved and unmeasured factors (error terms) to be freely correlated (Lin et al. 2005). Such correlations may be due to complementarities (positive correlation) or substitutabilities (negative correlation) between different technologies. Positive correlation also arises if there are unobservable farmer specific characteristics that affect several decisions but that are not easily captured by measurable proxies. The multivariate probit model takes these correlations into account. If correlation exists, the estimates of separate (probit) equations of the farmers' choices are biased and inefficient.

Our model consist of 7 binary choice equations; use of improved maize varieties, chemical fertilizers terracing, soil bunds, zero tillage, crop residues and use of animal manure. We therefore have seven dependent binary variables ($y_{i}$).

$$y_{im} = \beta_m X_m + \varepsilon_{im}, \quad m=1,2.....7 \qquad \text{..........} \qquad (1)$$

$$y_{im} = 1 \; if \; y_{im} > 0 \; and \; 0 \; otherwise \qquad \text{.............} \qquad (2)$$

$\varepsilon_{im}, \; m=1,2.....7$ are the error terms distributed as multivariate normal each with a mean 0 and a variance covariance matrix V, where V has 1 on the leading diagonal and correlations $p_{jk} = p_{kj}$ as off diagonal elements. $X_m$ represents a vector of plot level characteristics, socio economic variables, institutional variables, climatic shocks and agro ecological variables and the $\beta_m$ is a vector of the corresponding coefficients.

Table 3 presents the results of the multivariate probit showing plot level, socio economic, institutional, climatic and agro ecological variables affecting adoption of the various technologies. The likelihood ratio test rho is highly significant (p-value=0.000) implies that the null hypothesis that the covariance of the error terms across equations are not correlated is rejected thus justifying the use of the MVP. The p-value of the Wald test statistic for the overall significance of the model is 0.000, indicating that the multivariate probit regression is highly significant overall and that the model specification fits the data well. Land tenure (plot ownership) positively affects adoption of soil and water conservation practices (both terracing and soil bunds) and use of manure but negatively influences adoption of zero tillage, improved seeds and use of chemical fertilizers. Land tenure on a plot can affect land management practices, if there is tenure insecurity, there will be little incentive to invest in land improvement (Feder et al., 1988). Soil and water conservation practices and use of manure are more long term in that it takes a longer time to derive the benefits of these technologies and this explains why they are more likely to be practiced in owned plots than in borrowed in or rented in plots.

The fertility level of the plots also influences the type of technology practiced; good soil fertility positively influences adoption of improved seed varieties and terracing but negatively influences the practice of minimum/zero tillage and making of soil bunds. Use of improved seed is a high investment technology thus farmers are more likely practice it in more fertile plots so as to ensure maximum returns on their investment compared to zero tillage and soil bunds which are low input investment technologies. The slope of the plots also influences the adoption of all the technologies. Use of chemical fertilizers, zero tillage and terracing are more likely to be practiced in areas with a steep slope. Steep sloped areas are generally more prone to soil erosion and therefore farmers are more likely to put up soil and water management practices such as terracing so as to control for soil erosion. Additionally, due to soil erosion the fertility of these soils has to be restored and as such farmers are more likely to use chemical fertilizers in these areas so as to nourish the soils. Similar to these findings, Marenya and Barret (2007) also find that farmers farming on a steep terrain are more likely to adopt zero-tillage.

Male farmers are more likely to use improved seeds compared to the female farmers. Use of improved seeds is a high input technology and owing to the fact most of the female farmers are less endowed with resources they may not have the capacity to afford these improved seeds. Similarly, education level of the farmers is positively associated with adoption of improved seeds and chemical fertilizers. This may be due to the higher labour opportunity costs of more educated farmers leading them to invest in those practices with higher returns. However, contrary to our expectation larger families (higher endowment of family labour) are less likely to use animal manure (labour intensive technology) but they practice zero tillage and leaving crop residue on the farm (less labour intensive technologies). This may however be explained by Amaza et al., (2007) that it is likely that farmer with larger families attach greater importance to nonfarm activities compared to smaller households thus they allocate less labour to their own farms leading them to adopting less labour intensive technologies.

More land acreage is positively associated with adoption of improved seeds. Similarly, more land size is positively associated with zero tillage and leaving crop residues on the farm, both of which are components of conservation agriculture. Access to credit is also positively associated with adoption of the external input intensive technologies (both improved seeds and chemical fertilizers) and conservation agriculture (zero tillage and mulching). Land ownership is a measure of wealth in SSA, thus households with more land size and those that access to credit can afford the input intensive technologies and are as well able to raise the initial investment capital required to purchase zero tillage implements like direct seeders as well as herbicides for controlling weeds. Plot size and farm size on the other hand is negatively associated with use of animal manure and making of soil bunds indicating that these practices are associated with smaller farms.

The probability of adopting these technologies is also determined by the total livestock units (TLUs) owned by the households. High level of TLUs is positively associated with use of animal manure. Use of manure is more supply driven than demand driven owing to the fact that animal manure is bulky which makes it less transportable. As such households with more animals will also have more manure and will in turn be more likely to use animal manure in their farms. However, higher level of TLUs is negatively associated with adoption of chemical fertilizers; this is mainly due to the substitutability between animal manure and chemical fertilizers since both aim at improving soil fertility. In addition, a large number of livestock is positively associated with adoption of zero tillage. A plausible explanation is that since livestock is a more secure form of investment or store of value cash needs, the more the livestock units, the more the labour and capital requirements for management purposes and hence the need to explore labor saving technologies (such as zero tillage) in their farming activities. Similarly, a high number of TLUs is positively associated with adoption of improved seeds: livestock ownership in SSA is a form of investment and as such farmers with more livestock units are well able to afford the improved seeds. Conversely, a high number of livestock units discourage leaving crop residues in the farm. This is mainly due to the competing uses of crop residues which is very common in SSA; as livestock fodder and as crop residues, and in most cases use as fodder takes precedence given the important roles played by livestock in the region.

Climatic shocks and the agro ecological zones also influence the technology these farmers adopt. Farmers who experienced drought more frequently over the years are more likely to leave crop residues on the farms (mulching). This is probably due to the fact that one of the roles of mulching is to conserve water by preventing evaporation and as such farmers leave crop residues as a coping strategy in response to the frequent droughts. On the other hand, farmers who experienced droughts more frequently were less likely to use improved seeds and chemical fertilizers. This is because these technologies require more investment and farmers would expect high returns from their investments. With frequent droughts, farmers are less certain of the returns due to the high possibility of failed rains and owing to the fact that in SSA most small scale agriculture is rain fed. As expected those areas that experiences floods more frequently are more likely to adopt terracing but are less likely use soil bunds. This is because terraces are more long term and permanent soil and water conservation practice compared to the soil bunds thus in flood prone areas terraces are a more durable solution.

Closely related to these climatic factors are AEZs, the lowland tropics zone, which is defined as the base is the area that receives the lowest amount of rainfall than all the other AEZs.

For the same reason as above, use of improved seeds and chemical fertilizers is associated with the areas which receive high rainfall amounts that is the high tropics, moist transitional and the dry transitional. This is true in all the AEZs expect for the moist mid altitude zones which in spite of the fact it receives substantially high amount of rainfall has significantly lower adoption of improved seeds in comparison with the lowland tropics. This is however in line with the finding of Ransom and Osoro (1999), that farmers in the moist mid altitude zone, especially those double-cropping maize, planted Lake Region local maize varieties that take relatively longer to mature than the hybrids recommended for the area. According to the study, the local varieties are preferred for qualities other than time to maturity; in fact, better tolerance to low soil fertility levels and biotic stresses (such as *Striga* spp., a parasitic weed) may be more important to maize farmers in this region than early maturity.

**Table 3 Results of the Multivariate Probit**

| | Improved seeds | | | Fertilizer | | | Terraces | | | Soil bunds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Coefficient | Std Error | Marginal effects | Coefficient | Std Error | Marginal effects | Coefficient | Std Error | Marginal effects | Coefficient | Std Error | Marginal effects |
| ***Plot level characteristics*** | | | | | | | | | | | | |
| Plot size | 0.032 | 0.020 | 0.009 | -0.022 | 0.017 | -0.006 | 0.043*** | 0.016 | 0.014 | -0.039** | 0.019 | -0.009 |
| Plot ownership | -0.127* | 0.076 | -0.036 | -0.289*** | 0.073 | -0.085 | 0.285*** | 0.067 | 0.094 | 0.167** | 0.076 | 0.040 |
| Medium soil fertility | 0.194*** | 0.070 | 0.056 | 0.017 | 0.072 | 0.005 | 0.174** | 0.069 | 0.057 | -0.043 | 0.076 | -0.010 |
| Good soil fertility | 0.367*** | 0.075 | 0.105 | -0.168** | 0.075 | -0.050 | 0.149** | 0.072 | 0.049 | -0.272*** | 0.081 | -0.065 |
| Gentle slope | 0.036 | 0.054 | 0.010 | 0.082 | 0.053 | 0.024 | 0.549*** | 0.05 | 0.181 | -0.135** | 0.057 | -0.032 |
| Medium slope | 0.088 | 0.067 | 0.025 | 0.341*** | 0.065 | 0.100 | 0.899*** | 0.063 | 0.296 | -0.066 | 0.069 | -0.016 |
| Steep slope | 0.12 | 0.116 | 0.034 | 0.662*** | 0.117 | 0.196 | 1.083*** | 0.119 | 0.356 | 0.1 | 0.116 | 0.023 |
| ***socio economic characteristics*** | | | | | | | | | | | | |
| Male | 0.114** | 0.05 | 0.033 | -0.126** | 0.049 | -0.037 | 0.067 | 0.047 | 0.022 | 0.150*** | 0.053 | 0.036 |
| Age of farmer | 0.019** | 0.01 | 0.005 | -0.003 | 0.010 | -0.001 | 0.003 | 0.009 | 0.000 | 0.006 | 0.011 | 0.001 |
| Age of farmer SQ | 0.000 | 0.000 | -3.8e-5 | 1.12e-4 | 0.000 | 3.3e-5 | 3.6e-5 | 0.000 | 1e-05 | -4.42e-05 | 0.000 | -1.1e-5 |
| Education farmer | 0.043*** | 0.007 | 0.012 | 0.070*** | 0.007 | 0.021 | 0.011 | 0.006 | 0.003 | 0.014* | 0.007 | 0.003 |
| Land size | 0.009** | 0.004 | 0.003 | 0.002 | 0.003 | 0.000 | -0.001 | 0.003 | -0.000 | -0.010** | 0.004 | -0.002 |
| TLU | 0.011*** | 0.004 | 0.003 | -0.012*** | 0.003 | -0.003 | -0.002 | 0.003 | -0.001 | 0.001 | 0.004 | 0.000 |
| Risk taking | -0.043*** | 0.016 | -0.012 | -0.006 | 0.016 | -0.002 | -0.071*** | 0.016 | -0.023 | 0.036** | 0.018 | 0.009 |
| HH size | -0.015 | 0.013 | -0.004 | -0.024** | 0.012 | -0.007 | -0.022* | 0.012 | -0.007 | -0.003 | 0.014 | -0.001 |
| ***Institutional variables*** | | | | | | | | | | | | |
| Group membership | 0.077 | 0.072 | 0.022 | 0.076 | 0.074 | 0.023 | 0.214*** | 0.069 | 0.070 | 0.158** | 0.080 | 0.038 |
| Distance market | -0.038*** | 0.014 | -0.011 | -0.025* | 0.014 | -0.007 | 0.022 | 0.014 | 0.007 | -0.008 | 0.016 | -0.002 |
| Credit | 0.175*** | 0.059 | 0.05 | 0.276*** | 0.057 | 0.082 | -0.015 | 0.053 | -0.005 | 0.142** | 0.059 | 0.034 |
| ***Climatic shocks*** | | | | | | | | | | | | |
| Drought | -0.028** | 0.011 | -0.008 | -0.091*** | 0.012 | -0.026 | 0.019* | 0.011 | 0.006 | -0.027** | 0.013 | -0.006 |
| Flooding | -0.015 | 0.013 | -0.004 | 0.016 | 0.013 | 0.005 | 0.039*** | 0.012 | 0.013 | -0.056*** | 0.016 | -0.013 |
| ***AEZ*** | | | | | | | | | | | | |
| Dry Mid altitude | -0.166* | 0.097 | -0.048 | -0.053 | 0.109 | -0.016 | 1.157*** | 0.101 | 0.380 | 0.044 | 0.115 | 0.010 |
| Dry transitional | 0.248** | 0.099 | 0.071 | 0.905*** | 0.107 | 0.268 | 1.174*** | 0.103 | 0.385 | -0.118 | 0.118 | -0.028 |
| Moist transitional | 0.823*** | 0.105 | 0.236 | 1.431*** | 0.109 | 0.423 | 0.416*** | 0.102 | 0.137 | 0.143 | 0.115 | 0.034 |
| High tropics | 0.882*** | 0.122 | 0.253 | 1.670*** | 0.122 | 0.494 | -0.026 | 0.112 | -0.008 | 0.496*** | 0.123 | 0.119 |
| Moist mid altitude | -0.361*** | 0.099 | -0.103 | 0.363*** | 0.107 | 0.107 | 0.373*** | 0.103 | 0.123 | -0.179 | 0.119 | -0.043 |
| Constant | -0.615** | 0.262 | | -0.793*** | 0.272 | | -1.662*** | 0.262 | | -1.428*** | 0.298 | |

| | Crop residues | | | Zerotillage | | | Manure | | |
|---|---|---|---|---|---|---|---|---|---|
| | Coefficient | Std Error | Marginal effects | Coefficient | Std Error | Marginal effects | Coefficient | Std Error | Marginal effects |
| ***Plot level characteristics*** | | | | | | | | | |
| Plot size | 0.083*** | 0.018 | 0.026 | 0.045*** | 0.017 | 0.008 | -0.060*** | 0.016 | -0.022 |
| Plot ownership | -0.079 | 0.069 | -0.024 | -0.157* | 0.081 | -0.028 | 0.274*** | 0.065 | 0.101 |
| Medium soil fertility | 0.073 | 0.074 | 0.022 | -0.376*** | 0.082 | -0.066 | 0.062 | 0.067 | 0.023 |
| Good soil fertility | 0.086 | 0.076 | 0.026 | -0.251*** | 0.085 | -0.044 | -0.067 | 0.069 | -0.025 |
| Gentle slope | 0.104** | 0.053 | 0.032 | -0.053 | 0.065 | -0.009 | 0.119** | 0.049 | 0.043 |
| Medium slope | 0.106* | 0.064 | 0.032 | -0.044 | 0.082 | -0.008 | 0.091 | 0.060 | 0.034 |
| Steep slope | 0.018 | 0.109 | 0.005 | 0.686*** | 0.118 | 0.120 | -0.061 | 0.101 | -0.022 |
| ***Socio economic characteristics*** | | | | | | | | | |
| Male | -0.037 | 0.048 | -0.011 | -0.034 | 0.060 | -0.006 | -0.028 | 0.045 | -0.010 |
| Age of farmer | 0.028*** | 0.010 | 0.008 | -0.001 | 0.012 | 0.000 | 0.021** | 0.009 | 0.008 |
| Age of farmer SQ | -3.8e-4*** | 0.000 | -1.2e-4 | -3.5e-5 | 0.000 | -6.1e-6 | -0.001 | 0.000 | -3.8e-5 |
| Education farmer | -0.0126* | 0.007 | -0.004 | -0.017** | 0.008 | 0.000 | -0.003 | 0.006 | -0.001 |
| Land size | 0.011*** | 0.003 | 0.003 | 0.010*** | 0.003 | 0.002 | -0.012*** | 0.003 | -0.004 |
| TLU | -0.010*** | 0.003 | -0.003 | 0.009*** | 0.003 | 0.002 | 0.017*** | 0.003 | 0.006 |
| Risk taking | -0.044*** | 0.016 | -0.014 | 0.003 | 0.02 | 0.000 | 0.02 | 0.015 | 0.007 |
| HH size | 0.004 | 0.012 | 0.001 | 0.007 | 0.015 | 0.001 | -0.038 | 0.011 | -0.014 |
| ***Institutional variables*** | | | | | | | | | |
| Group membership | 0.037 | 0.071 | 0.011 | 0.016 | 0.086 | 0.003 | 0.286*** | 0.066 | 0.106 |
| Distance market | 0.030** | 0.015 | 0.009 | -0.007 | 0.017 | -0.001 | -0.035*** | 0.014 | -0.013 |
| Credit | 0.164*** | 0.055 | 0.050 | 0.157** | 0.068 | 0.028 | -0.123** | 0.051 | -0.046 |
| ***Climatic shocks*** | | | | | | | | | |
| Drought | 0.036*** | 0.011 | 0.011 | 0.008 | 0.014 | 0.001 | -0.017 | 0.011 | -0.006 |
| Flooding | 0.015 | 0.014 | 0.011 | 0.002 | 0.015 | 0.000 | -0.017 | 0.012 | -0.006 |
| ***AEZ*** | | | | | | | | | |
| Dry Mid altitude | -1.917*** | 0.122 | -0.590 | -0.478*** | 0.113 | -0.084 | 0.674*** | 0.096 | 0.250 |
| Dry transitional | -1.965*** | 0.124 | -0.604 | -0.809*** | 0.125 | -0.142 | 0.576*** | 0.097 | 0.214 |
| Moist transitional | -0.883*** | 0.123 | -0.272 | -0.279** | 0.113 | -0.049 | 0.073 | 0.098 | 0.026 |
| High tropics | -0.920*** | 0.131 | -0.283 | -0.254** | 0.124 | -0.045 | 0.027 | 0.107 | 0.010 |
| Moist mid altitude | -0.127 | 0.127 | -0.039 | -0.473*** | 0.116 | -0.083 | 0.220** | 0.098 | 0.081 |
| Constant | 0.737*** | 0.278 | | -0.414 | 0.325 | | -1.269*** | 0.249 | |

N=4035; Log likelihood= -11772.70; Wald $chi^2$ = 4169.45; P value= 0.0000 and likelihood ratio test of rho $chi^2$ (21) = 662.488 p value = 0.0000
***, ** and * indicates significance level at 1%, 5% and 10%, respectively

## 5 Joint decision making on adoption of different technologies

We also estimate univariate probit models for each of the technologies including all the other technologies as explanatory variables to show the relationships and also the strength of the relationships between the technologies but not causality. From the results, farmers adopt individual approaches of external input technologies together and the NRM technologies together but they hardly adopt a combination of the two together. There is a strong positive relationship indicated by the positive and significant marginal effect between the following technologies; improved seeds & fertilizers, zero tillage & crop residues, terraces & manure and crop bunds & manure. Still, some technologies show strong negative relationships and they include: fertilizers & manure, crop residue & manure, terracing & soil bunds. This is mainly because these technologies are mostly substitutes. Still terracing is negatively associated with conservation agriculture (that is both use of crop residues and zero tillage) though these technologies are not substitutes. It may be that due to the fact that the conditions that favour adoption of each of these technologies are different; terracing is mostly practiced in those areas with high rainfall amounts whereas conservation agriculture is practiced in areas with low rainfall amounts.

**Table 4. Results of the univariate Probit showing relationships between the technologies**

| | Improved seeds | Fertilizers | Terraces | Soil bunds | Crop residues | Zero tillage | Manure |
|---|---|---|---|---|---|---|---|
| Improved seeds | | 0.351*** | 0.010 | 0.021* | -0.009 | -0.003 | 0.030 |
| | | (0.016) | (0.019) | (0.012) | (0.019) | (0.012) | (0.019) |
| Fertilizers | 0.284*** | | 0.040** | 0.024** | -0.030* | 0.006 | -0.086*** |
| | (0.014) | | (0.017) | (0.012) | (0.017) | (0.010) | (0.017) |
| Terraces | 0.007 | 0.040** | | -0.225*** | -0.162*** | -0.020* | 0.109*** |
| | (0.015) | (0.017) | | (0.012) | (0.017) | (0.010) | (0.017) |
| Soil bunds | 0.029 | 0.048** | -0.402*** | | -0.011 | 0.019 | 0.111*** |
| | (0.019) | (0.023) | (0.017) | | (0.023) | (0.014) | (0.022) |
| Crop residue | -0.006 | -0.030* | -0.159*** | -0.003 | | 0.051*** | -0.142*** |
| | (0.015) | (0.017) | (0.016) | (0.011) | | (0.010) | (0.016) |
| Zero tillage | -0.004 | 0.015 | -0.054** | 0.029 | 0.131*** | | -0.032 |
| | (0.023) | (0.026) | (0.027) | (0.019) | (0.024) | | (0.026) |
| Manure | 0.023 | -0.084*** | 0.107*** | 0.057*** | -0.141*** | -0.012 | |
| | (0.015) | (0.017) | (0.017) | (0.011) | (0.016) | (0.010) | |

N= 4035,. ***, ** and * indicates significance level at 1%, 5% and 10%, respectively. The results are the marginal effects and the figures in parenthesis are the standard errors

## 6 Summary and Conclusion

Research and adoption of technologies are crucial in increasing agricultural productivity and lowering the poverty levels in developing countries. However, there are some disagreements about which type of technologies are most appropriate for the developing countries. In reality there is no single approach that will work in each situation and the suitability of these technologies varies with different conditions. This study seeks to determine conditions under which each of these technologies are adopted using data collected from all the maize growing areas in Kenya with the focus being on small holder farmers. In addition, the paper seeks to find out what the combination of technologies farmers mostly adopt. Seven technologies are under consideration in this paper and are classified in to two; the external input intensive technologies (improved seeds and chemical fertilizers) and the NRM strategies (zero tillage, leaving crop residues, use of animal manure, terracing and making of soil bunds). We use the MVP to jointly analyze the adoption of these technologies and univariate probit models of each of the technology on all the other technologies to assess the interdependence between the technologies. Different conditions ranging from plot level attributed to AEZs influence the type of technology adopted by the farmers. Therefore, these factors should be considered when planning, implementing and evaluating extension programs for dissemination of each of these technologies. We also found that farmers mainly adopt either a combination of input intensive technologies or the NRM strategies but rarely a mix of the input intensive and NRM technologies. This may be attributed to the fact that farmers get information on the different agricultural technologies from different information sources. Some of these sources promote the input intensive technologies while others promote the NRM technologies.

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