

Intensification of Maize Production in Kenya and Uganda*

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1 Introduction

The possibility of an African Green Revolution is once again receiving attention (Otsuka and Kalirajan, 2005). The New Partnership for Africa's Development (NEPAD), for instance, is organizing an African Fertilizer Summit in June 2006 (www.AfricaFertilizerSummit.org). In the past, however, successes in increasing cereal productivity have been short lived in Sub-Saharan Africa. Maize, a major staple crop in Eastern and Southern Africa, experienced rapid increases in productivity in 1960s and 1970s (Eicher 1995; Hassan and Karanja 1997), but earlier successes in Maize Green Revolution did not sustain after 1980s. Previous studies have discussed reasons for failures in realizing a Green Revolution in Africa and pointed out possible explanations such as liquidity constraints, risks in production created by poor infrastructure, unfavorable input-output price ratios. There are, however, some variations even among small-scale African farmers. Two neighboring countries in East Africa provide an interesting comparison: farmers in Kenya apply relatively high amounts of chemical and organic fertilizer on maize, while farmers in Uganda do not apply fertilizer on maize much. As a result, there is a significant difference in maize productivity across the Kenya-Uganda border despite the fact that western parts of Kenya and Eastern parts of Uganda share similar agro-ecological characteristics. There is an earlier study to make such a comparison, but the data from Uganda were not sufficient to conduct a comparative analysis (Nyoro, Kirimi, and Jayne, 2004). To

*Very preliminary. Corresponding author: Takashi Yamano (FASID) Address: GRIPS/FASID Joint Graduate Program, 7-22-1 Roppongi, Minato-ku, Tokyo, 106-8677, Japan. Tel: +81-3-5413-6030; Fax: +81-3-5413-0016; E-mail: yamanota@grips.ac.jp

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achieve the purpose, we use household surveys in Kenya and Uganda conducted under the project, called REPEAT (Research on Poverty, Environment, and Agricultural Technology). Both surveys use similar questionnaire, designed for comparisons across countries. In addition, since these surveys were conducted twice to construct the panel data, we can track the same households over time in most cases in both countries. The surveys in Uganda were conducted in 2003 and 2005. The surveys in Uganda covered 940 households in the first wave and 895 in the second wave. The surveys in Kenya were conducted in 2004 and 2007, which covered 897 households in the first wave and 725 in the second wave, respectively. To identify constraints on fertilizer application and maize production, we examine determinants of maize yield.

The paper is organized as follows: Section 2 describes maize production in Kenya and Uganda by using secondary data. Section 3 explains the household surveys used in this paper. The surveys in both countries were conducted by the same research project and use similar questionnaire. Section 4 and 5 present the descriptive and analytical results on fertilizer application and maize production, respectively, in both countries. Finally, we discuss the policy implications based on the results in Section 6.

2 Maize Production in Kenya and Uganda

Maize production

Maize was first grown in East Africa on the islands of Zanzibar and Pemba in the sixteenth century and was probably introduced to Kenya by Arab traders (Miracle, 1966). Soon, maize production in Kenya expanded in both in quantity and areas by European settlers. Responding to the continued need to increase maize production, the colonial government initiated a comprehensive research program in 1955. After the independence, the program continued releasing high-yielding maize varieties in 1960s and 1970s (Hassan and Karanja, 1997). The success of maize production in Kenya during this period is considered a major success story in African agricultural development (Gabre-Madhin and Haggblade, 2004). In the mid-eighties, however, both maize yield and area, hence production, stopped growing in Kenya, and Kenya has become maize importer in recent years (Groote, Owuor, Doss, Ouma, Muhammad, and Danda, 2005). Figure 1 shows both the total maize production in Kenya and the net maize import to Kenya from 1960 to 2004. The maize production

in Kenya more than doubled from 1 million ton in 1960 to 2.4 million tons in 1978, but since then it remained at about the same level with some fluctuations. Kenya became a net importer of maize twelve times in the last 23 years.

In Uganda, maize was a minor crop in Uganda until early 1990s, but Uganda started expanding its production in the last two decades (Figure 1). Although it is not clear in Figure 1, a significant amount of maize is exported from Uganda to Kenya. FAO data may not capture the accurate information about maize trade between Kenya and Uganda. The increase in maize production in Uganda was achieved by a continuous expansion of maize area, and maize yield has been stagnated or even declined over time (Pender et al. 2001). Maize yield is low in Uganda. Sserunkuuma (2005), for instance, shows that maize yield is about 0.6 tons per ha for local seeds and 1.07 tons per ha for improved seeds.

Fertilizer Application

The most important factor in low maize yield in Uganda could be negligible amounts of chemical fertilizer applied on maize. Figure 2 shows that the chemical fertilizer use, in terms of nitrogen, is very little in Uganda. At the micro level, Sserunkuuma (2005) shows that only four percent of 268 households, who planted improved maize varieties in the long rain season of 2000, applied chemical fertilizer. In contrast, the chemical fertilizer application in Kenya has increased significantly in the past. Figure 2 shows that the nitrogen application has increased from zero in 1960 to just about 60,000 tons in the late 1980s in Kenya. From the late 1980s to the mid 1990s, the nitrogen application stagnated until the late 1990s when it started increasing again.

The stagnation of nitrogen application could be explained partly by confusions in the fertilizer market liberalization by the government of Kenya in the 1980s before its complete withdrawn from the market in 1993. From 1974 to 1984, the government provided a fertilizer monopoly to one firm, the Kenya Farmers Association. However, since the mid 1980s, the government encouraged private firms to enter the market, while maintaining tight controls over the market (Jayne et al., 2003). In 1993, the government finally withdrew itself from the fertilizer market and abandoned price controls. Freeman and Omiti (2003) conclude that market reform has stimulated fertilizer use in Kenya, mainly by improving farmers' access to the input through the expansion of private retail networks. Jayne et al. (2003) calculate that the marketing margins between Mombasa port

and Nakuru have declined about 24 percent, from \$262 per ton in 1990-1995 to \$206 per ton in 1996-2000.

The successful expansion of fertilizer supply networks in Kenya, however, did not expand beyond the Kenya-Uganda border. The fertilizer application in Uganda remains negligible even today. Because of many years of continuous crop cultivations without using chemical or organic fertilizer, there is a growing concern for soil depletion in Uganda, as well as other parts of Africa (Pender et al., 2001; Buresh, Sanchez, and Calhoun, 1997). Although some soil specialists cast doubts about the soil mining scenario because there are some indigenous techniques for maintaining soil fertility (e.g., Mortimore and Harris, 2005), the very little use of fertilizer in Uganda, compared with a neighboring Kenya, raises a question about constraints on fertilizer use. Although the low fertilizer application could be explained partly by the supply side constraints, we focus on the demand side constraints in this paper. If we find the fertilizer use profitable in Uganda, then an expansion of fertilizer supply networks will increase the fertilizer use, hence maize productivity, in Uganda. But if we find it not profitable, then an expansion of fertilizer supply networks will not result in a higher fertilizer use. To find profitability of fertilizer, we will make use of the comparison between western parts of Kenya and eastern parts of Uganda in terms of maize yield and input use because these areas share similar agro-ecological characteristics but their input application levels are very different.

Improved Seed Varieties

The seed industry in Kenya also went through a similar liberalization process. Before the liberalization, parastatals dominated the agricultural and extension sectors in Kenya. New maize varieties were developed by public research institutes, while seed production was in the hands of the Kenya Seed Company (KSC) (Groote et al., 2005). From the late 1960s to the early 1980s, this system was remarkably effective and released many popular varieties (Hassan and Karanja, 1997). The progress in maize production and productivity has stagnated in the 1980s and 1990s, and a consensus emerged that heavy state involvement was responsible for the stagnation. After a short period following the start of the liberalization in the seed industry, domestic and international seed firms slowly entered the seed industry. Currently, improved varieties from major firms, such as KSC, Western Seeds, Pioneer, are available from retail stores throughout the country.

In Uganda, the seed industry has seen the similar process. In the past, the National Agricultural Research System (NARS) has developed and released improved maize varieties. New high-yielding varieties, imported through Kenya, are now available in Uganda. A recent study by Sserunkuma (2005) shows that more 60 percent of sampled households planted “improved maize varieties.” Improved varieties include both purchased (thus new) and recycled high-yielding varieties. Many farmers in Uganda recycle high-yielding varieties. Recycling high yielding varieties cause “genetic depreciation” and loss of desired attributes such as yield potential, pest and diseases resistance (Morris et al., 1999). In the later analysis, we consider the difference in seed types carefully.

In the following sections, we use household surveys from Kenya and Uganda to identify constraints in maize production in the neighboring countries.

3 Data

We use the data from household surveys in Kenya and Uganda as a part of the Research on Poverty and Environment and Agricultural Technology (REPEAT) Project. Both surveys are 2-year panel and employ the similar questionnaire design so as to be comparable each other. Figure 3 shows the survey sites in the REPEAT Project. Each diamond plot represents the survey village. It ranges from Eastern province of Kenya, located in about 100 kilometer east from Nairobi, to South Western region of Uganda along the border with Rwanda. The first wave in Uganda was conducted in 2003 by Makerere University with the financial and technical support from the Foundation for Advanced Studies on International Development (Yamano et al., 2004). It covers 94 Local Council 1 (LC1)s that are located across most regions in Uganda, except North where security problems exist. From each LC1, ten households are randomly selected, resulting in a total of 940 households. The second wave was conducted in 2005. Because of the attrition, it tracked 895 out of 940 households visited in the 1st wave. The surveys in Kenya were conducted in 2004 and 2007. The first wave covered randomly selected 899 households located in 100 sub-locations scattered in central and western regions of Kenya. In the second wave, 7 sub-locations in Eastern province were dropped because of the scale reduction of the survey project. In addition, the attrition also reduced the number of households interviewed. In total, 725 households were revisited for the survey. These two waves of surveys were conducted by Tegemeo Institute, with financial and technical help from National

Graduate Institute for Policy Studies (GRIPS). In this paper, we drop the samples from Eastern province in Kenya for the analysis below since we apply the statistical methods relying on the longitudinal aspects of the data.

Maize Production

We present the basic information on maize production of the sample households in Kenya and Uganda for each of two waves in Table 1. We list survey provinces in Kenya and survey regions in Uganda from east (top) to west (bottom). Nyanza and Western in Kenya and East region in Uganda share the Kenya-Uganda border. Most of sample households produced maize in both waves in Kenya while 76 percent in Wave 1 and 82 percent of sample households in Wave 2 produced maize in Uganda. The average land devoted to maize production per household is slightly smaller in Uganda than Kenya. The average land size for maize production is about 0.5 ha in Kenya.

Although maize yield varies by region as well as with time, it is certain that it is much higher in Kenya than Uganda. The average yield per ha in Kenya is 1,790 kgs in Wave 1 and 2,163 kgs in Wave 2 while it is only 1,080 kgs in Wave 1 and 1392 kgs in Wave 2 in Uganda. Because most of maize fields are not irrigated and the production relies on rainfall for water supply, the yield fluctuates largely from season to season. Nonetheless, there is huge yield gap between Kenya and Uganda consistently. The yield gap per ha is about 50 percent in both waves, which may be explained mainly by the difference in the intensity of input use such as improved seeds¹, chemical fertilizer, and organic fertilizer. Table 2 shows the adoption rate of those inputs and the level of application for each of inputs at the plot level² by region and by wave. Their adoption rates are reported in the odd-numbered columns whereas their quantity applied are reported in the even-numbered columns. For all inputs, their adoption rates are much higher in Kenya than Uganda. Specifically, the difference for chemical and organic fertilizer adoption is enormously large. In Kenya more than 70 percent of households applied at least some chemical fertilizer on maize whereas far less than 5 percent of households applied chemical fertilizer in Uganda. The applied amount is also much

¹The working definition of improved seed is the newly purchased improved seed. Some farmers use the recycled improved seed. Because of genetic depreciation, the maize yield would be reduced to large extent when such a seed is used. Indeed, the yield of the recycled seed seems to be much smaller than that of the newly purchased seed. Figure A1 shows the distribution of maize yield conditioning on the seed types. There are three types of seeds in the figure, namely, local, improved, and recycled seeds.

²A household may have multiple plots. The data provides us the information on input use and output at the plot level.

higher in Kenya than Uganda.

The almost zero application of chemical fertilizer raises many questions about chemical fertilizer in Uganda. Is it not profitable to use chemical fertilizer in Uganda? If it is not profitable, why is it the case? Is the output return to chemical fertilizer not strong enough? Is the price of chemical fertilizer too high or the maize output price too low? In the following analysis, we try to answer these questions by comparing the maize production and output/input prices between Kenya and Uganda.

Input and Output Prices

Table 3 presents the average prices of 100 kgs of maize product, 100 kg of Diammonium Phosphate (DAP), and 100 kgs of the HYV seeds. The DAP is the most commonly used chemical fertilizer on maize production and, hence, the price information is available in the most regions. The prices in local currency are converted into US dollar prices by using the exchange rate at each survey month. It is worth noting that the timings of those surveys in the two countries are different and, hence, the comparison at the absolute level of prices between these two countries may be inappropriate. The relative prices of those two inputs are also given in blankets, which might be more appropriate for the cross-country comparison.

The sales price of maize product is much higher in Kenya than in Uganda. As explained above, however, the gap may not reflect the concurrent price gap due to the difference in the timings of the surveys in the two countries. In order to confirm the price gap, we see the time series data on the wholesale price of maize in Kenya and Uganda from other source, which is given in Figure 3. The figure has 4 lines from 4 cities, namely Nairobi and Kisumu in Kenya and Mbale and Kampala in Uganda. It seems that the significant price gap between two countries always exists and the Kenya price could be double of Uganda price sometime. So the maize price from REPEAT data seems to reflect the real gap between the two countries.

Because the chemical fertilizer sold in Uganda is imported from abroad through Mombasa, the fertilizer price in Uganda necessarily becomes higher than that in Kenya. Therefore, as long as the maize is lower in Uganda than Kenya, the DAP-maize price ratio is always larger in Uganda than in Kenya. Figure 3 tells us the level of the DAP-maize price ratio difference in the two countries. Looking at the average DAP prices in Central and West/South West regions in Uganda are not

even reported because almost no one among our survey respondents reported the purchase price of DAP in these regions. Indeed, no supply network for small scale farmers is available in the regions. Comparing the relative price of DAP in East region in Uganda with that in Kenya, there is a large gap. While the relative price is about 2 to 3 in Kenya, it becomes more than 4 in Uganda. A simple profit maximization theory tells us that the optimal level of fertilizer application is determined at the level where the value of marginal product is equal to the input price. Thus, the gap of the input-output price ratio would largely explain the huge difference in the chemical fertilizer use between two countries. This suggests that the optimal level of fertilizer application in Uganda would be lower than in Kenya.

Lastly, looking at the HYV seed price, it is more or less similar within Kenya while the price in West/South West region seems to be cheaper than other regions in Uganda. The price difference within Uganda may be due to the difference in quality of seed purchased or other reasons such as subsidy program by NGO. We may need to investigate more on this issue. As seen in Table 2, although the rate of the HYV seed adoption in Uganda is one-half as low as that in Kenya, its adoption rate is much higher than that of other inputs Uganda. This is because the HYV seed is not prohibitively expensive unlike the chemical fertilizer in Uganda.

The comparison on the input-output ratio between the two countries roughly tells us the difference in profitability of a certain input under the assumption that the production function that farmers face is similar between the two countries. It does not provide the information on how much profitable a certain input use is. In the next section, we will see the relationship between inputs and yield to measure the profitability of inputs given a certain input-output price ratio.

4 Maize Production

Maize Yield by Seed Type

The average maize yield (kgs per ha) by seed type and by region is reported in Table 4. The yield gain by the adoption of the HYV seed is positive for all the cases except the West/South West region in Uganda in Wave 2 and statistically significant for most cases although the magnitude differs across regions. The regions with larger yield gain by the HYV seed use in Wave 1 do not necessarily have higher gain in Wave 2. It suggests that the magnitude of gain from the HYV

adoption would be weather dependent. Using the HYV seed price and the maize sales price from Table 3 and the average quantity of the HYV seed application among the users from Table 2, we calculate the value of yield gain by the adoption of the HYV seed given in Columns (4) and (8), which is obtained by the yield gain multiplied by the sales price minus the HYV seed cost. The HYV seed is the input-intensive technology which, in general, requires more labor and more fertilizer than the traditional seed to obtain the potentially higher yield. Hence, the “value of yield gain” overestimates the actual profit gain. Despite the fact, the value of yield gain by the adoption of the HYV seed seems to be small or even negative. Since the actual profit gain by the adoption of the HYV seed would be much smaller, it seems that the adoption of the HYV seed does not guarantee the higher profit than the use of local seed.

Maize Yield by Chemical Fertilizer Application Level

The average maize yield (kgs per ha) by chemical fertilizer application level and by region is reported in Table 5. We do not report it for Uganda since very few farmers use chemical fertilizer in Uganda. The application level is divided into four categories as seen in the table. Interestingly, the average yield does not necessarily increase with chemical fertilizer application. The typical pattern seems to be U-shaped. The average yield is relatively high at the zero application level, becomes very low at the low application level, and then gradually increases as the application level rises. This non-monotonic relationship is partly due to the existence of other substitutable inputs and partly due to the soil quality. For instance, organic fertilizer may be used as a substitute for chemical fertilizer. In such a case, high yield would be realized without chemical fertilizer. Also there might be the case that very fertile soil can produce large output without any input. If any, however, such a case has been rarer than before due to the population pressure. Indeed, land has become more and more scarce and is often used without following. Because of the presence of factors that bring the U-shape relationship between the level of chemical fertilizer application and the average maize yield, we would need a careful consideration of substitutable inputs such as organic fertilizer and soil quality in order to measure the returns to chemical fertilizer application.

Maize Yield by Organic Fertilizer Application Level

The relationship between between the organic fertilizer and the average maize yield is presented in Table 6 in turn. The average yield by region is reported for Kenyan samples while one at the aggregate level is reported for Ugandan samples because the number of farmers who apply organic fertilizer in Uganda may not be large enough to construct the average by region. Similarly to the case of chemical fertilizer, the relationship is not monotonic and seems to be U-shaped. It may be true that we are not able to infer the returns to organic fertilizer by looking at the simple correlation with the yield for the same reason as the case of chemical fertilizer.

In Kenya, the level of organic fertilizer application is very high especially in Central province. It is associated with the spread of the adoption of improved cows. Otsuka and Yamano (2005) provide evidence that farmers apply a significant amount of organic fertilizer on maize when they have improved dairy cows. This is because improved dairy cows are often kept in stalls, it is easier to collect manure and apply it on crops. Although there are some dairy farmers in Uganda who keep improved dairy cows in stalls and apply organic fertilizer on crops, the number of them is not as large as in Kenya and organic fertilizer is mainly applied on banana, a main staple crop in Uganda.

Yield Function

As shown in the previous descriptive tables, it is not very clear if maize yield increases as a certain input-use increases when we look at the simple correlation alone. We would need a careful analysis with the consideration of various factors mutually related in order to measure the precise returns to fertilizer applications. We estimate the yield function using 2-year (up to 4-season) panel data containing maize inputs and outputs at the plot level in Kenya and Uganda. We consider a simple yield function of the Cobb-Douglas form. The yield per ha, denoted by Y , from plot p of household i at time t is given as follows:

$$Y_{ipt} = A_i L_{ipt}^{\beta_L} S_{ipt}^{\beta_S} N_{ipt}^{\beta_N} e^{\omega_{ipt}}, \quad (1)$$

where L is the plot size (ha), S is seed quantity planted (kgs/ha), A is the Hicks neutral technology parameter or called a total factor productivity. We assume that A is time-invariant at least for short time period, 2 to 3-year interval as in our data. ω is a productivity shock affected by weather

condition or other idiosyncratic factors. N is a conceptual variable representing soil quality of the plot. Since soil quality is not directly observed and may be affected by various factors, we assume that the quality indicator is a function of three observables, which is given as follows:

$$N_{ipt} = N(E_{ip}, C_{ipt}, O_{ipt}),$$

where E is a basic soil condition (or endowment) assumed to be time-invariant for short time period, C is chemical fertilizer applied (kgs/ha), and O is organic fertilizer applied (kgs/ha). As explained in the previous section, we collected a soil sample from a major maize field from each household only at the first wave of the REPEAT panel surveys. As a soil condition indicator, we use the first principal component obtained by the principal component analysis of soil content variables obtained from soil samples collected.³ Since we collected one sample from a major maize field of a household, we assume that, in the case of households with multiple maize fields, the soil quality is common across their maize plots. If the returns to fertilizer application vary with soil condition as Marenya and Barrett (2007) pointed out, it is important to control for such a variable representing soil condition to identify the causes that some farmers apply no fertilizer even though its average returns seems to be very high.⁴

Taking logs of the yield function [1],

$$y_{ipt} = a_i + \beta_L l_{ipt} + \beta_S s_{ipt} + \beta_N n_{ipt} + \omega_{ipt}, \quad (2)$$

where the variables in lower cases represent the logs of the corresponding to the ones in upper cases. Because n is not directly observed, we use a second-order local approximation for $n = \ln N(\cdot)$ as given by

$$\ln N(E, O, C) = \gamma_0 + \sum_x \gamma_x x + \sum_x \sum_{x'} \gamma_{xx'} xx' \text{ for } x, x' \in \{E, C, O\}.$$

³The details of the soil analysis will be provided on request.

⁴However, there is a drawback of using the soil endowment indicator. This soil endowment variable is available for about 70 percent of sample households because we could not obtain the results of the soil analysis because some soil samples were not in good condition for the analysis or because some samples were lost simply by mistake. Hence, we estimate the model with and without the soil endowment indicator. Another concern is that E could be sensitive to other inputs C and O or output (maize yield) even for a short time period, e.g. 2-3 years. In such a case, the time-invariant assumption of E is not valid. In such a case, we may have to have a more dynamic model to describe the relation between maize yield and soil fertility, instead. This is an issue worth further investigation.

Plugging this into Eq. [2],

$$y_{ipt} = a_i + \beta_L l_{ipt} + \beta_S s_{ipt} + \sum_x \delta_x x_{ipt} + \sum_x \sum_{x'} \delta_{xx'} x_{ipt} x'_{ipt} + \omega_{ipt},$$

where the coefficients δ s are the product of β_N and γ_S , that is, $\delta_v = \beta_N \gamma_v$, $v \in \{E, C, O, EC, EO, CO, EE, CC, OO\}$. The OLS regression of y on the observables with pooled samples may provide biased estimates. First, the unobservable total factor productivity a_i is likely to be correlated with inputs since productive farmers use more inputs as a choice for profit maximization and are likely to obtain more maize yield. Thus, the OLS estimates on the returns to the inputs would be upwardly biased. Fortunately, panel data is available, so the fixed effects estimation resolves or at least mitigates this problem. In that case, the coefficients of time-invariant factors on the right hand side, namely, E_i and E_i^2 , cannot be identified. These terms are dropped and we rewrite the model as follows:

$$y_{ipt} = \alpha_i + \beta_L l_{ipt} + \beta_S s_{ipt} + \sum_{x \neq E} \delta_x x + \sum_{x \neq E} \sum_{x'} \delta_{xx'} x x' + \omega_{ipt}$$

where $\alpha_i = a_i + \delta_E E_i + \delta_{EE} E_i^2$.

Another issue to be considered is on the correlation of the productivity shock with input variables. Specifically, rainfall would be correlated with fertilizer or other input use and with yield simultaneously because the agriculture in our survey regions is mostly rain-fed and farmers determine the level of input use according to the level of rainfall. In this paper, this issue is dealt with by introducing time-region dummies as covariates. By this treatment, other region level time-variant factors can be also controlled. More precisely, we decompose the productivity shock into time-region effects and idiosyncratic factor, i.e., $\omega_{ipt} = \sum_r \sum_{t'} \eta_{rt'} 1\{i \in I_r \& t = t'\} + \varepsilon_{ipt}$, where $1\{\cdot\}$ is the indicator function taking 1 if the argument is true and 0 otherwise and I_r is a set of households living in region r .

For the notational simplicity, we denote z as a vector of the regressors including time-region dummies and ψ as a vector of parameters corresponding to z . Then, we describe the model simply as follows:

$$y_{ipt} = \alpha_i + z'_{ipt} \psi + \varepsilon_{ipt}. \quad (3)$$

Hybrid Seed Use

We may also have to consider the HYV seed adoption on the yield function. As shown in Table 4, the difference in maize yield between HYV and local seed is large and statistically significant in most regions. In addition, it is possible that the returns to fertilizer use differ according to the seed type. This is an important empirical question to identify the causes why some farmers use no fertilizer even though it seems to be profitable at least on average. It would be possible that non-HYV seed adopters do not use fertilizer because of its low response. In order to consider the difference in yield and returns to fertilizer use according to seed type, the extended model is given by

$$y_{ipt} = d_{ipt}y_{ipt}^1 + (1 - d_{ipt})y_{ipt}^0 \quad (4)$$

where d_{ipt} is a binary indicator taking 1 if the HYV seed is planted in plot p of household i at time t and 0 otherwise; y_{ipt}^j ($j \in \{0, 1\}$ or {use, no-use}) is a potential outcome when the HYV adoption status j is exogenously given. Then, the yield y^j is expressed as follows:

$$y_{ipt}^j = \alpha_i^j + z'_{ipt}\psi^j + \varepsilon_{ipt}^j, \quad j \in \{0, 1\}. \quad (5)$$

Notice that we observe only either one of two potential outcomes, that is, $y = y^1$ if the HYV is planted on the plot and $y = y^0$ otherwise. Plugging y^j s into Eq.[4], we obtain

$$y_{ipt} = \alpha_i^0 + d_{ipt}(\alpha_i^1 - \alpha_i^0) + z'_{ipt}\psi^0 + d_{ipt}z'_{ipt}(\psi^1 - \psi^0) + \varepsilon_{ipt}^0 + d_{ipt}(\varepsilon_{ipt}^1 - \varepsilon_{ipt}^0).$$

There are two possible problems in order to obtain consistent estimators of ψ^0 and ψ^1 : the presence of the unobservable effects α_i^j and the potential endogeneity of the regressors specifically on $(d_{ipt}, d_{ipt}z'_{ipt})$, which is caused by their dependence on the selection variable. If the selection issue is not the problem, the first issue will be resolved easily by applying fixed effects estimation. In other words, if the selection of seed type is independent from the potential outcomes conditional on z , which would happen when the selection of seed type is randomly assigned across plots, then we may simply apply fixed effects estimation to obtain the consistent estimates of ψ s.

However, the selection of seed type is not random assignment but choice of farmers who maximize

their expected welfare given various constraints. Therefore, the choice variable d is endogenous and likely to be correlated with the potential outcomes conditional on z . In order to obtain the consistent estimates, we apply the 2-step estimation method for the panel data sample selection model by Kyriazidou (1997). Applying her method, firstly, we have to obtain the consistent estimates of the selection equation with individual effects. In our case, the selection equation will be given by $d_{ipt} = 1\{\eta_i + w'_{ipt}\xi + \nu_{ipt}\}$, where η is time-invariant individual-specific effect, w is a vector of regressors, and ν is unobserved disturbance. Specifically, we use logit estimation to obtain the consistent estimate $\hat{\xi}$. In the second step, using $\hat{\xi}$, the parameters of yield equation, ψ^j , are estimated by

$$\begin{aligned} \psi^j = & \left[\sum_{i=1}^n \frac{1}{M_i(M_i - 1)} \sum_{m \neq m'} \phi_{imm'}(z_{im} - z_{im'})(z_{im} - z_{im'})' d_{im}^j d_{im'}^j \right]^{-1} \\ & \times \left[\sum_{i=1}^n \frac{1}{M_i(M_i - 1)} \sum_{m \neq m'} \phi_{imm'}(z_{im} - z_{im'})(y_{im} - y_{im'}) d_{im}^j d_{im'}^j \right], \end{aligned} \quad (6)$$

where M_i is the number of observations on household i , the subscript m is a substitute for the subscript pt just for notational simplicity, $d^1 = d$ and $d^0 = 1 - d$, and $\phi_{imm'}$ is a kernel weight that becomes large when $w'_{im}\hat{\xi}$ and $w'_{im'}\hat{\xi}$ is close. Namely, $\phi_{imm'} \equiv \frac{1}{h} K\left(\frac{(w_{im} - w_{im'})'\hat{\xi}}{h}\right)$, where $K(\cdot)$ is a kernel function and h is a bandwidth. Intuition behind this estimation method is that by taking the difference in the yield function between two observations within a household when their predicted single indexes $w'\hat{\xi}$ obtained in the first stage regression for the selection model take the same value, not only time-invariant individual fixed-effects, α_i , but also the selection biases disappear. Using the variables transformed by taking the difference in the above manner, we may be able to apply OLS regression and obtain consistent estimators. In practice, there may not be the two observations taking the exact same value of the predicted single indexes within an individual. To handle this issue, the Kyriazidou estimation applies a weighted regression in which heavier weights are assigned to the differences of two samples with closer values on their single indexes.

Regression Results

Determinants of HYV Seed Adoption

We estimate the HYV seed adoption model with Logit with individual (household) effects. Table 7 shows the results of two sets of regressions using all Kenya and Uganda samples, given in Column (1) and (2), or using the samples from the western part of Kenya (covering Western and Nyanza provinces) and the eastern part of Uganda (East region), given in Column (3) and (4). The first model applied is the random-effects Logit estimation and the second model is the fixed-effects Logit estimation. The reason of running the same regression with not only full samples but also sub-samples from restricted areas is that it may not be appropriate to apply the same yield function to all the samples in such a wide area covering large part of these two countries. However, it may be reasonable to think that such an empirical specification can be applied to the area sharing the similar agro-ecological conditions like the areas covering the western part of Kenya and the eastern part of Uganda. Thus, we run the same regression with the sub-samples from those areas, and then compare their results with those obtained using the full samples.

As the basic explanatory variables, we include the household level, the plot level, and the community level variables. In addition, in order to control for the region-specific time-variant effects such as the influence of the climate and also the market conditions, we also incorporate a series of dummies corresponding to region-season combinations as explanatory variables. Because the random-effects method allows us to estimate the coefficients of time-invariant covariates, we also add some household characteristics which do not change much over 2 years such as the level of education of household members.

It is known that the fixed effects estimates are consistent under weaker assumptions than the random effects estimates although the random effects estimates are more efficient when the assumptions are valid. Specifically, the estimates by random-effects model are biased if the individual effects are correlated with the covariates. We conduct the Hausman specification test to verify the appropriateness of the random-effects estimates. More concretely, we test the null hypothesis that the efficient estimates by the random-effects model, which are consistent under the independence assumption of individual effects, are equal to the consistent estimates by the fixed-effects model with respect to the coefficients of common covariates. The test statistics are given in the 3rd row

from the bottom in Table 7. The test rejects the null hypothesis in both cases with the full samples and with the sub-samples, which means that the estimates by the random-effects Logit are biased. Thus, we interpret the results of the fixed-effects model only.

The estimates obtained using full samples are very similar to those obtained using the sub-samples in terms of signs of the coefficients although there seems to be a slight difference in their magnitude. Firstly, the coefficient of the total value physical assets is positive and statistically significant, which implies that the larger asset holders are more likely to adopt the HYV seed. This may suggest that some farmers are credit constrained and, hence, may not be able to purchase the HYV seed. The number of improved cattle owned is positive and significant only in the regression with the sub-samples. Since the improved cattle can be considered as valuable productive assets, the interpretation could be similar to the case of the physical assets. It is not clear, however, why it is significant only in the regression with the sub-samples.

The coefficient of a dummy variable indicating that the maize plot is not owned but rented is positive and significant. This means that the likelihood of the HYV adoption is higher on rented land than owned land. In general, the HYV seed is a technology that requires more inputs than a traditional local seed. It is superior to the local seed in the ability to absorb the nutrient contained in soil. The higher adoption rate of the HYV seed on rented land may reflect the possible action taken by farmers who maximize short-term profit by intensively extracting the soil nutrients rather than preserving soil condition for the future production.

As community level variables, we incorporate prices of inputs. In addition, a dummy variable indicating the absence of the information on the DAP price is included since there are some communities particularly in Uganda where no one reported the DAP price. As explained above, the HYV seed is an input intensive technology and, hence, we expect that the higher price of input brings about the lower adoption of the HYV seed. The coefficient of the DAP price is negative and significant as expected. However, the coefficients of other input prices are not significant in the fixed-effects specifications. It is possibly due to the small within-variation and due to the measurement error on those variables. The coefficient of HYV seed price is positive and significant in the random-effects model probably because the estimate may be influenced by the cross-sectional positive association of the adoption rate with the HYV seed price. As we have seen in Table 3, the relative price of the HYV seed is lower in Uganda than Kenya. On the other hand, the adoption

rate is higher in Kenya than Uganda (Table 2). This cross-sectional association creates the positive coefficient in the random effects regression, which would be biased as the Hausman specification tells. Such a cross-sectional association is eliminated in the fixed-effects estimation. Thus, we apply the fixed effects estimation as the first stage regression for the endogenous switching regression for maize yield production.

Yield Function

We estimate the yield function discussed in the previous section using the first stage estimates of the adoption of the HYV seed reported above. The results of the regressions with full samples are given in Table 8 and ones with sub-samples are given in Table 10. Each table has eight columns, each of which corresponds to a regression for hybrid seed adopters or non-adopters, by the fixed-effects estimation or the semiparametric endogenous switching estimation, and with or without the soil quality variable.

First, let us look at the results of Hausman's specification test. The specification test is conducted to judge the validity of the fixed-effects regression. More precisely, we test the null hypothesis that the efficient estimates obtained by the fixed-effects regression, which would be consistent under the independence assumption of the HYV adoption from the potential outcomes with and without the adoption, are equal to the consistent estimates obtained by the semi parametric endogenous switching regression. The test statistics are give in the fourth row from the bottom in Table 8 and 10. Intuitively, the null hypothesis will be rejected when the coefficients between the fixed-effects regression and the endogenous switching regression are very different. Among the regressions with the full samples (Table 8), there are two cases in which the null hypothesis is rejected, the one for non-hybrid seed users without the soil quality variable and the other for hybrid seed users with the soil quality variable. On the other hand, there is one case in which the null hypothesis is rejected, that is the one for non-hybrid seed users without the soil quality variable among the regressions with the sub-samples. It seems that the self-selection of the HYV seed may not always cause the biases on the estimates. This is probably because the fixed-effects model mitigates the possible biases on the slope coefficients by controlling for the effects of time-invariant household unobservables.

Secondly, let us focus on the effects of each input. Since the cross terms and quadratic terms of inputs are included in the regressions, it might be difficult to figure out the marginal effect of

each input from the tables. Thus, we also report the the marginal effects of chemical and organic fertilizer obtained from the regressions with full samples in Table 9 and with the sub-samples in Table 11. Since the marginal effects may vary with the level of inputs, we evaluate the marginal effects at the three different input levels; at the average for all the samples, for Kenyan samples, or for Ugandan samples. Looking at the marginal effects of chemical fertilizer, they vary from 0.11 to 0.39 according to the combination of the three factors; the seed type adopted, the estimation method, and whether controlling for the soil quality variable or not. Since the unit of chemical fertilizer application variable is 100 kgs per ha and the dependent variable is the log of the maize yield (kgs) per ha, the marginal effects reported in the table multiplied by one hundred can be read as the percentage change in maize yield per ha corresponding to the increase in chemical fertilizer application per ha by 100 kgs. It seems that there is a minor difference in the marginal effects by the regression models between with and without soil condition variable. It may mean that the soil condition variable may not play a crucial role on the regressions.

The marginal effect evaluated at the average input level for the Ugandan samples is higher than that for the Kenyan samples in most cases. This reflects the two factors that, firstly, the estimated marginal effect declines with the level of chemical fertilizer application and, secondly, the application level of chemical fertilizer is lower in Uganda than Kenya. This tendency can be also seen in the regressions with the sub-samples (Table 11) sharing similar agro-ecological conditions. Although the return to chemical fertilizer looks very high, it may not be profitable in Uganda under the actual DAP-maize price ratio. For instance, using the estimated marginal effect by semiparametric regression for non-hybrid seed users (Column 4 in Table 9), the predicted gain by 100 kg increase in chemical fertilizer will be 504 kgs ($= 0.39 \times 1,294$) using the average yield for non-hybrid users in Uganda in Wave 2 (see Column 5 in Table 4). Since the DAP-maize price ratio is 6.1 (see Column 4 in Table 3), the gain is not large enough to pay the cost of chemical fertilizer. For the hybrid-seed adopters, the predicted gain from 100 kg increase in chemical fertilizer will be 310 kgs ($= 0.21 \times 1,460$). Although we obtain different predictions on profitability if using different estimates, it seems to be clear that the chemical fertilizer is not very attractive to farmers in Uganda under such unfavorable input-output price ratio.

In turn, looking at the marginal effect of organic fertilizer application, we see that the increase in organic fertilizer by 1 metric ton per ha raises maize yield per ha by 3.5 per cent to 9.4 per

cent (Table 9). It is worth mentioning that the estimates may suffer the attenuation bias due to the measurement errors on the quantity of organic fertilizer application. The amount of organic fertilizer application reported by farmers is rough approximation of its real weight since farmers do not actually measure the weight of manure or other types of organic fertilizer. Instead, they can estimate its volume based on the size of container or cart which carries organic fertilizer. From the information, the weight of organic fertilizer is retrieved by enumerators using the conversion formula from volume to weight. In addition, the quality of organic fertilizer varies to larger extent relative to chemical fertilizer. Thus, the real amount of organic fertilizer is inevitably contaminated by measurement errors. As one may know, the measurement errors on covariates cause downward bias. Hence, our estimation of the marginal effects may be downwardly biased. The actual effect of organic fertilizer would be larger than our estimates. The amount of organic fertilizer application per ha could be larger than 5 metric tons. For instance, the average amount among adopters is 6.6 tons in Wave 1 and 5.4 tons in Wave 2 in Central, Kenya. Although only few farmers apply organic fertilizer on maize plot in Uganda, if such amount is applied, the total effect on maize yield could be very large. It might be dangerous, however, to derive assertive conclusion from these estimates because they differ to large extent according to the applied estimation method and the samples used. But, it is safe to say that there is a large room for the improvement on maize yield in Uganda through the increase in organic fertilizer application.

5 Conclusions

The need for an African Green Revolution has been cited as a necessary to achieve the Millennium Development Goal on halving poverty. To identify constraints on cereal productivity, we made a comparison between Kenya and Uganda in terms of fertilizer applications and productivity of maize, which is a major staple crop in Eastern and Southern Africa. Characteristics of maize production in these two neighboring countries provide a significant contrast. We use two household surveys collected under the same project to ensure the comparability of the data across two countries.

As expected, we find that the fertilizer–maize price ratio is much lower in Kenya than in Uganda. Because Uganda imports chemical fertilizer from abroad through Mombasa in Kenya, the fertilizer price has to be higher in Uganda than Kenya due to the transportation cost added on the way

from Kenya to Uganda. In addition, the maize price is lower in Uganda because of Kenya's strong domestic demand for maize. As a consequence, chemical fertilizer is much less profitable and, hence, less attractive to farmers in Uganda. To compensate the high fertilizer price and the low maize price, the maize yield response to chemical fertilizer has to be large especially in Uganda. According to our estimation of maize yield function, the marginal effect of chemical fertilizer on the maize yield is higher in Uganda than in Kenya. However, the impact seems not to be large enough for chemical fertilizer to be a profitable input in Uganda due to the high fertilizer price and low maize price. As a consequence, farmers in Uganda apply almost no chemical fertilizer on maize field.

Lack of a supply network of inputs also seems to be a reason for no application of fertilizer in Uganda. Reversely, however, underdevelopment of such a network is the evidence that there is not much demand for inputs, which implies that such inputs are not very profitable and, hence, not very attractive for farmers. Such an input network may be developed also in Uganda as long as chemical fertilizer becomes profitable as seen in Kenya in 1990's. Therefore, in order to increase the maize yield by increase in chemical fertilizer application, the input-output price ratio should be more favorable to farmers. To realize the reduction of input prices, it may be necessary to improve infrastructure for inland transportation and also the efficiency of logistics.

There might be an alternative pathway to increase maize yield rather than relying on the chemical fertilizer. That is the way through organic fertilizer. Our estimation of yield function shows that the returns to organic fertilizer are not so small that the organic fertilizer could have a large impact on the maize production. In addition, especially in Uganda, there is a large room for the improvement on maize yield by utilizing organic fertilizer application. However, further investigation would be needed to show the conclusive evidence.

References

- [1] Buresh, R.J., P.A. Sanchez, and F. Calhoun. (eds.) 1997. *Replenishing Soil Fertility in Africa*, Soil Science Society of America, Madison, Wisconsin.
- [2] Byerlee, D., and C.K. Eicher. 1997. *Africa's Emerging Maize Revolution*, Lynne Rienner Publishers, Colorado.

- [3] Eicher, C.K. 1995. "Zimbabwe's maize-based Green Revolution: Predictions for Replication," *World Development*, vol. 23: 805-818.
- [4] Freeman, H.A., and W. Kaguongo. 2003. "Fertilizer Market Liberalization and Private Retail Trade in Kenya," *Food Policy*, vol. 28: 505-518.
- [5] Groote, H.D., G. Owuor, C. Doss, J. Ouma, L. Muhammad, and K. Danada. 2005. "The Maize," *electronic Journal of Agricultural and Development Economics*, vol. 2: 32-49.
- [6] Hassan, R.M., and D.D. Karanja. 1997. "Increasing Maize Production in Kenya: Technology, Institutions, and Policy," in D. Byerlee and C.K. Eicher (eds.) *Africa's Emerging Maize Revolution*, Lynne Rienner Publishers, Colorado.
- [7] Jayne, T.S., J. Govereh, M. Wanzala, and M. Demeke. 2003. "Fertilizer Market Development: a Comparative Analysis of Ethiopia, Kenya, and Zambia," *Food Policy*, vol. 28: 293-316.
- [8] Kelly, V. 2005. "Farmers' Demand for Fertilizer in Sub-Saharan Africa," mimeo, Michigan State University.
- [9] Kyriazidou, E. 1997. "Estimation of A Panel Data Sample Selection Model," *Econometrica*, vol. 65(6), 1335-1364.
- [10] Mortimore, M., and F. Harris. 2005. "Do Small Farmers' Achievements Contradict the Nutrient Depletion Scenarios for Africa," *Land Use Policy*, vol. 22: 43-56.
- [11] Nyoro, J.K., L. Kirimi, and T.S. Jayne. 2004. "Competitiveness of Kenyan and Ugandan Maize Production: Challenges for the Future," Tegemeo Institute Working Paper.
- [12] Omamo, S.W. 2003. "Fertilizer Trade and Pricing in Uganda," *Agrekon*, vol. 42(4): 310-324.
- [13] Omamo, S.W., and L.O. Mose. 2001. "Fertilizer Trade under Market Liberalization: Preliminary Evidence from Kenya," *Food Policy*, vol. 26: 1-10.
- [14] Otsuka, K., and K.P. Kalirajan. 2005. "An Exploration of a Green Revolution in Sub-Saharan Africa," *electronic Journal of Agricultural and Development Economics*, vol. 2: 1-6.

- [15] Otsuka, K., and T. Yamano. 2005. "The Possibility of a Green Revolution in Sub-Saharan Africa: Evidence from Kenya," *electronic Journal of Agricultural and Development Economics*, vol. 2: 7-19.
- [16] Palm, C.A., R.J.K. Myers, and S.M. Nandwa. 1997. "Combined Use of Organic and Inorganic Fertilizer Maintenance and Replenishment," in R.J. Buresh, P.A. Sanchez, and F. Calhoun (eds.), *Replenishing Soil Fertility in Africa*, Soil Science Society of America, Madison, Wisconsin.
- [17] Pender, J., E. Nkonya, P. Jagger, and D. Sserunkuuma. 2001. "Development Pathways and Land Management in Uganda: Causes and Implementations," Environment and Production Technology Division Discussion Paper, No. 85, International Food Policy Research Institute, Washington D.C.
- [18] Rufino, M.C., E.C. Rowe, R.J. Delve, and K.E. Giller. 2006. "Nitrogen Cycling Efficiencies through Resource-Poor African Crop-Livestock Systems," *Agriculture, Ecosystems and Environment*, vol. 111: 261-282.
- [19] Sserunkuuma, D. "The Adoption and Impact of Improved Maize and Land Management Technologies in Uganda," *electronic Journal of Agricultural and Development Economics*, vol. 2: 67-84.
- [20] Tripp, R., and D. Rohrbach. 2001. "Policies for African Seed Enterprise Development," *Food Policy*, vol. 26: 147-161.

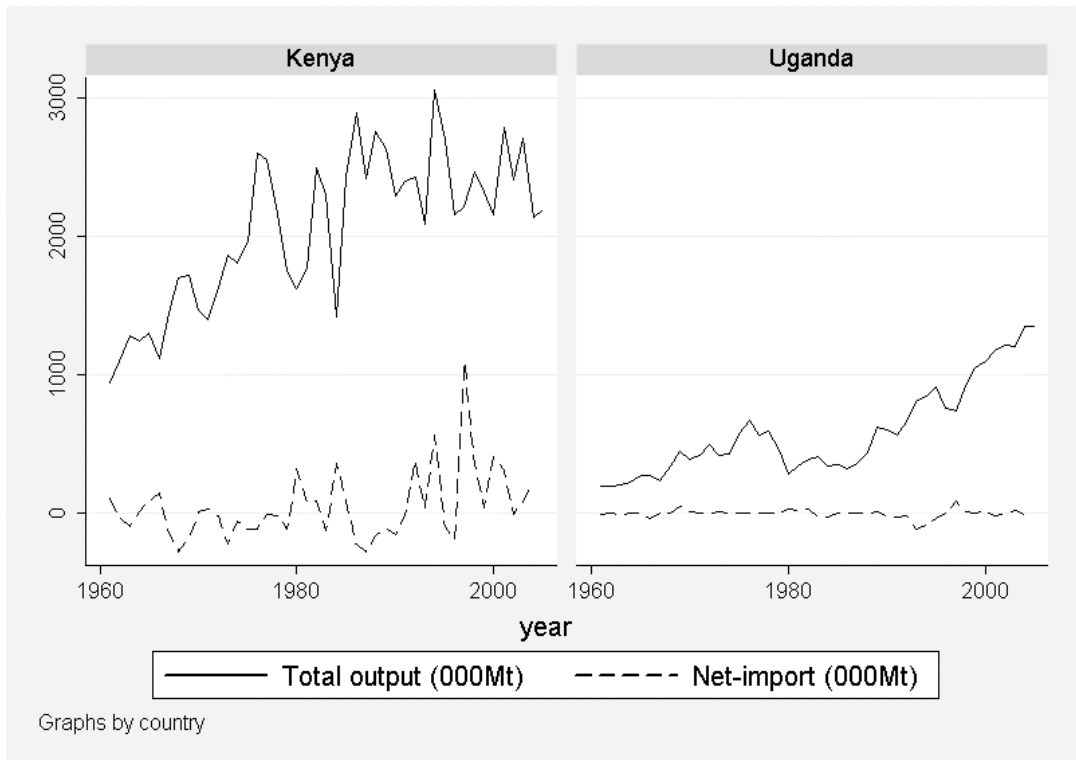


Figure 1. Maize Production and Trade in Kenya and Uganda

Source: FAO Statistical Database (<http://faostat.fao.org>)

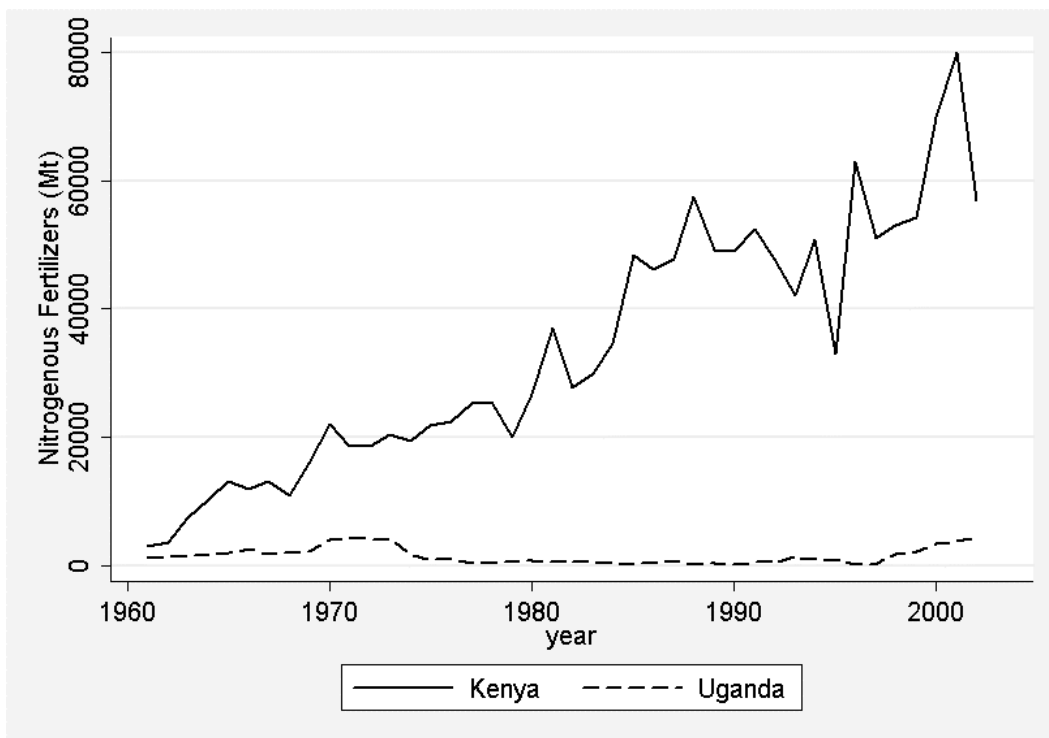


Figure 2. Chemical Fertilizer Consumption in Kenya and Uganda

Source: FAO Statistical Database (<http://faostat.fao.org>).

Note: In Uganda and Rwanda, because chemical fertilizer is imported from Kenya, the fertilizer application in Kenya could include fertilizer application in Uganda and Rwanda.

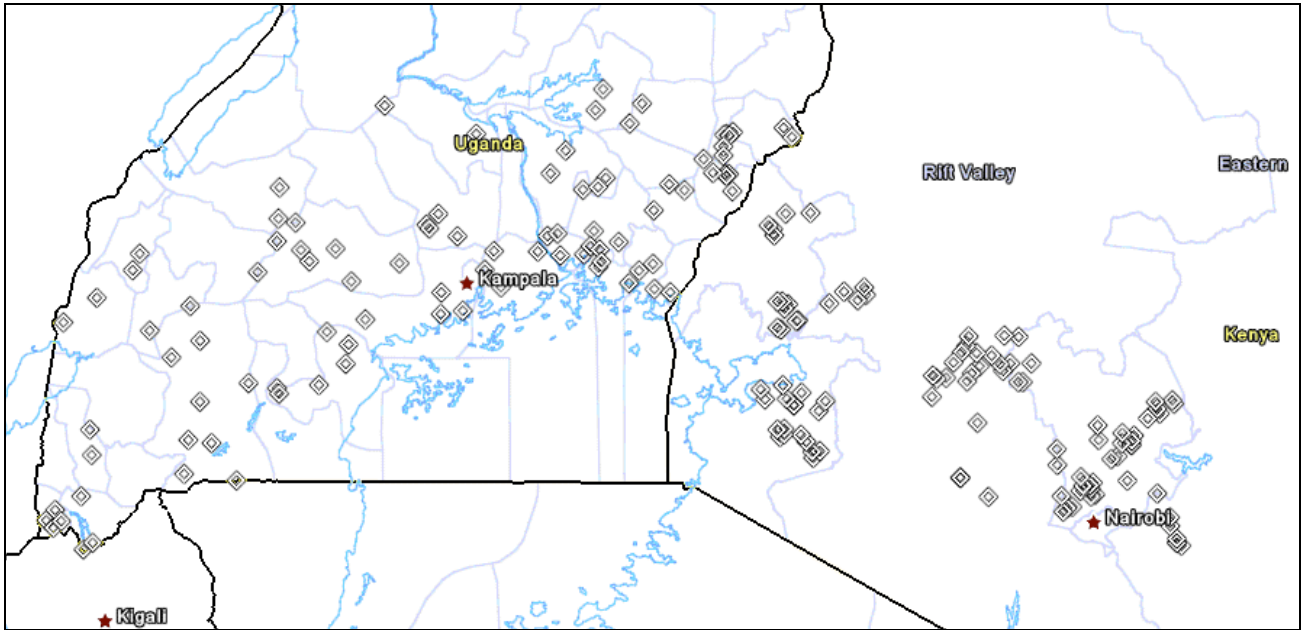


Figure 2. Repeat Survey Sites

Note: Each diamond plot represents a REPEAT survey village.

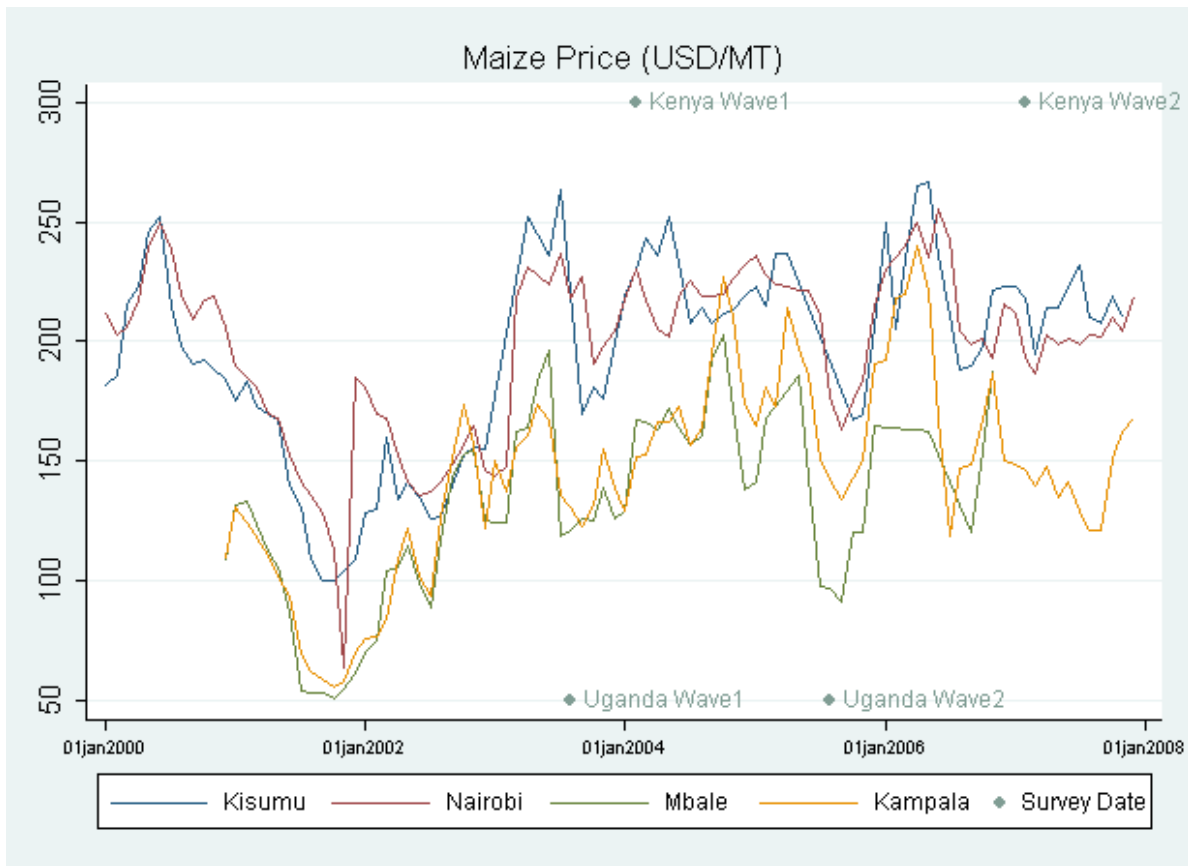


Figure 3. Change in Maize Market Price in Selected Cities

Source: Regional Agricultural Trade Intelligence Network (RATIN) (<http://www.ratin.net/>)

Note: Kisumu is a city in southwestern Kenya (Nyanza province). Mbale is a city in southeastern Uganda.

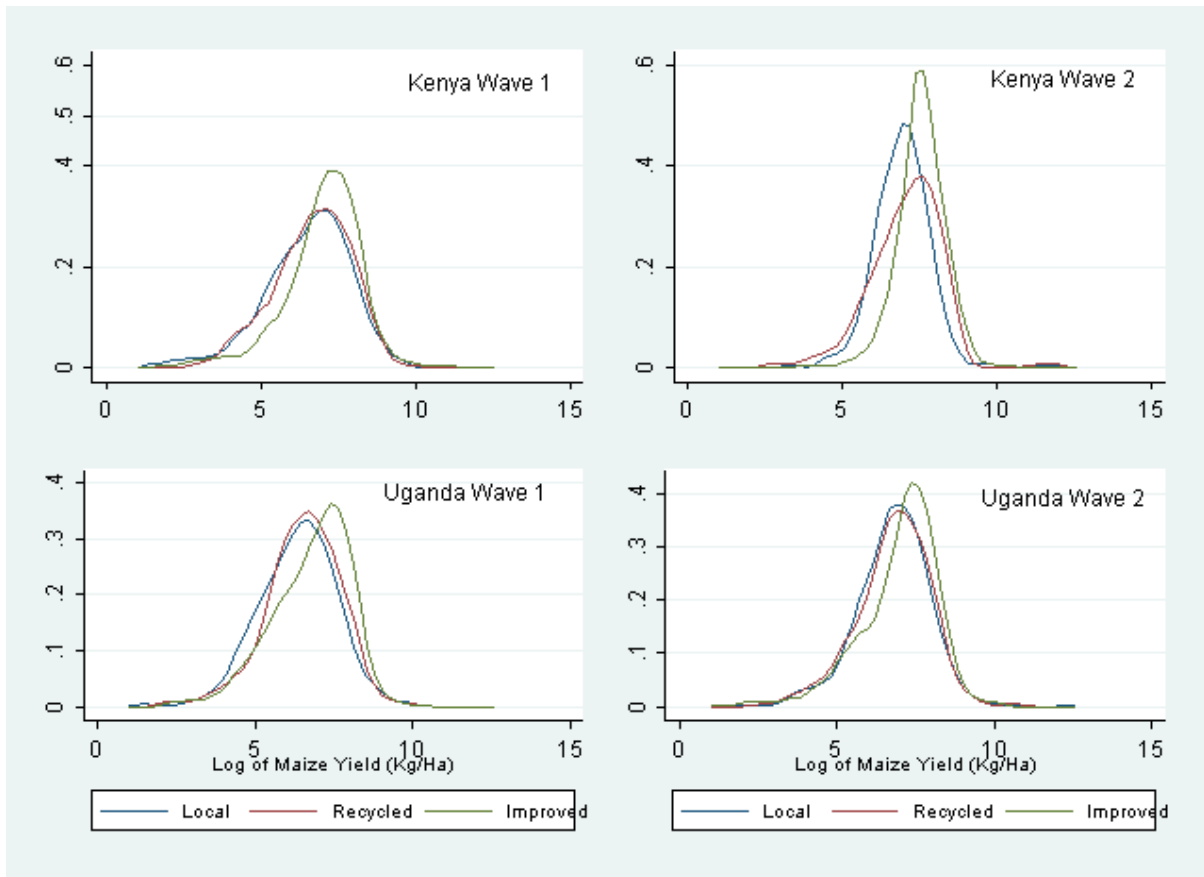


Figure A1. Log of Maize Yield (kgs/ha) by Seed Type

Table 1. Sample Households and Maize Production in Kenya and Uganda

| | Maize Production | | | | | | | |
|---------------|----------------------|---------------|--|---------------|---|---------------|--------------------------------|---------------|
| | Number of Households | | Proportion of households producing maize | | Cultivated areas for maize per household-season (Main season) | | Yield per season (Main season) | |
| | Wave 1 (1) | Wave 2 (2) | Wave 1 (3) | Wave 2 (4) | Wave 1 (5) | Wave 2 (6) | Wave 1 (7) | Wave 2 (8) |
| | <u>Number</u> | | <u>Percent</u> | | <u>Ha</u> | | <u>Kgs/Ha</u> | |
| Kenya | | | | | | | | |
| Central | 315 | 264 | 97.8 | 96.2 | 0.39 | 0.37 | 1,379 | 2,129 |
| Rift Valley | 222 | 198 | 100.0 | 97.5 | 0.71 | 0.68 | 2,548 | 2,669 |
| Western | 112 | 101 | 96.4 | 97.0 | 0.40 | 0.44 | 1,915 | 2,280 |
| Nyanza | 175 | 148 | 98.9 | 97.3 | 0.53 | 0.48 | 1,293 | 1,488 |
| All | 824 | 711 | 98.4 | 96.9 | 0.50 | 0.49 | 1,790 | 2,163 |
| Uganda | | | | | | | | |
| East | 408 | 388 | 78.9 | 89.9 | 0.58 | 0.50 | 1,228 | 1,401 |
| Central | 294 | 269 | 77.9 | 79.9 | 0.36 | 0.34 | 983 | 1,542 |
| West/SW | 230 | 223 | 70.9 | 71.7 | 0.29 | 0.37 | 840 | 1,082 |
| All | 932 | 880 | 76.6 | 82.3 | 0.46 | 0.43 | 1,080 | 1,393 |

Table 2. Technology Adoption on Maize Production by Region

| | HYV seed | | | | Chemical fertilizer | | | | Organic fertilizer | | | |
|-------------|---------------|---------------------------------|---------------|---------------------------------|---------------------|---------------------------------|---------------|---------------------------------|--------------------|---------------------------------|---------------|---------------------------------|
| | Wave 1 | | Wave2 | | Wave 1 | | Wave2 | | Wave 1 | | Wave2 | |
| | Adoption rate | Applied quantity among adopters | Adoption rate | Applied quantity among adopters | Adoption rate | Applied quantity among adopters | Adoption rate | Applied quantity among adopters | Adoption rate | Applied quantity among adopters | Adoption rate | Applied quantity among adopters |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
| | Percent | Kgs/Ha | Percent | Kgs/Ha | Percent | Kgs/Ha | Percent | Kgs/Ha | Percent | Kgs/Ha | Percent | Kgs/Ha |
| Kenya | | | | | | | | | | | | |
| Central | 57.9 | 21.8 | 63.7 | 21.9 | 76.1 | 56.9 | 78.5 | 54.6 | 70.8 | 6,622 | 71.1 | 5,398 |
| Rift Valley | 60.7 | 25.8 | 83.9 | 23.9 | 72.8 | 59.9 | 82.1 | 60.5 | 33.5 | 2,196 | 40.4 | 2,127 |
| Western | 56.1 | 23.1 | 64.1 | 23.1 | 79.7 | 58.7 | 84.4 | 56.9 | 52.0 | 3,950 | 51.6 | 1,873 |
| Nyanza | 50.0 | 21.2 | 53.9 | 20.8 | 66.3 | 48.8 | 64.9 | 54.2 | 30.0 | 2,032 | 31.0 | 1,894 |
| All | 56.6 | 23.0 | 66.9 | 22.5 | 72.8 | 55.6 | 76.9 | 56.3 | 47.2 | 4,715 | 50.4 | 3,665 |
| Uganda | | | | | | | | | | | | |
| East | 35.5 | 18.7 | 35.7 | 23.4 | 4.0 | 41.3 | 11.5 | 49.2 | 3.0 | 1,044 | 6.1 | 866 |
| Central | 21.3 | 21.6 | 16.5 | 20.9 | 1.6 | 11.1 | 1.6 | 33.7 | 3.2 | 3,629 | 2.8 | 2,376 |
| West/SW | 11.9 | 17.7 | 11.9 | 18.9 | 0.0 | n.a | 0.0 | n.a. | 14.1 | 3,010 | 13.5 | 1,439 |
| All | 27.7 | 19.3 | 26.6 | 22.7 | 2.7 | 37.7 | 6.9 | 48.2 | 4.8 | 2,460 | 6.6 | 1,237 |

Table 3. Input and Output Prices on Maize Production by Region.

| Region | Maize Price | | DAP Price | | HYV Seed Price | |
|-------------|------------------|-------------|-------------------|--------------|--------------------|---------------|
| | Wave 1 | Wave 2 | Wave 1 | Wave 2 | Wave 1 | Wave 2 |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| | <u>USD/100kg</u> | | <u>USD/100kg</u> | | <u>USD/100kg</u> | |
| | | | [DAP/Maize price] | | [Seed/Maize price] | |
| Kenya | | | | | | |
| Central | 17.4 | 17.7 | 42.1 | 50.7 | 178.9 | 183.6 |
| | | | [2.4] | [2.9] | [10.3] | [10.4] |
| Rift Valley | 14.3 | 16.3 | 34.8 | 50.9 | 170.8 | 174.4 |
| | | | [2.4] | [3.1] | [11.9] | [10.7] |
| Western | 15.8 | 18.4 | 40.8 | 51.9 | 163.6 | 178.8 |
| | | | [2.6] | [2.8] | [10.4] | [9.7] |
| Nyanza | 19.2 | 19.8 | 42.2 | 53.7 | 155.5 | 193.3 |
| | | | [2.2] | [2.7] | [8.1] | [9.8] |
| All | 16.7 | 17.8 | 40.3 | 51.2 | 167.1 | 182.3 |
| | | | [2.4] | [2.9] | [10.0] | [10.2] |
| Uganda | | | | | | |
| East | 9.4 | 8.8 | 38.2 | 59.4 | 73.0 | 91.9 |
| | | | [4.1] | [6.7] | [7.8] | [10.4] |
| Central | 9.9 | 10.4 | n.a. | n.a. | 49.7 | 64.0 |
| | | | | | [5.0] | [6.1] |
| West/SW | 8.6 | 10.8 | n.a. | n.a. | 35.8 | 30.6 |
| | | | | | [4.2] | [2.8] |
| All | 9.5 | 9.8 | 38.2 | 59.4 | 59.8 | 72.1 |
| | | | [4.0] | [6.1] | [6.3] | [7.4] |

Note: the prices are the region average of the community level prices. The community level prices are the median of prices reported by respondents at the household level.

Table 4. Maize Yield by Seed Type: HYV Seed vs. Local Seed.

| | Wave 1 | | | | Wave 2 | | | |
|---------------|---|------------------------------|--------------------------------------|---|---|------------------------------|--------------------------------------|---|
| | Yield per season with different seed types (Kgs/ha) | | Yield gain by HYV adoption (=2)-(1)) | Value of yield gain ^a (USD/ha) | Yield per season with different seed types (Kgs/ha) | | Yield gain by HYV adoption (=6)-(5)) | Value of yield gain ^a (USD/ha) |
| | Local seed | HYV seed | | | Local seed | HYV seed | | |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Kenya | | | | | | | | |
| Central | 1112 (1205) | 1267 (1208) | 154.5 | -12.0 | 1585 (1140) | 2085 (1088) | 499.7** | 48.3 |
| Rift Valley | 1915 (1281) | 2302 (1204) | 387.2** | 11.3 | 1397 (1095) | 2424 (1258) | 1026.2** | 125.7 |
| Western | 1462 (1270) | 2027 (1225) | 565.7* | 51.5 | 1555 (961) | 2446 (1204) | 890.9** | 122.6 |
| Nyanza | 778 (852) | 1356 (1019) | 578.5** | 78.0 | 1155 (807) | 1722 (958) | 566.4** | 72.1 |
| All | 1278 (1223) | 1702 (1252) | 423.7** | 32.4 | 1407 (1018) | 2161 (1165) | 754.2** | 93.2 |
| Uganda | | | | | | | | |
| East | 1118 (1060) | 1327 (1192) | 208.7 ⁺ | 6.0 | 1320 (1072) | 1512 (1206) | 192.3 ⁺ | -4.6 |
| Central | 761 (808) | 1357 (1145) | 596.1** | 48.3 | 1374 (1258) | 1453 (1272) | 79.3 | -5.2 |
| West/SW | 808 (1009) | 1325 (1300) | 516.8** | 38.1 | 1130 (1129) | 1056 (1194) | -74.6 | -13.8 |
| All | 946 (990) | 1334 (1181) | 388.4** | 25.3 | 1294 (1140) | 1460 (1217) | 165.4⁺ | -0.1 |

Standard deviations in parentheses

Significance levels of test for difference in mean are given by superscripts in the column (3) and (6).

+ significant at 10%; * significant at 5%; ** significant 1%.

^a Value of yield gain = (Difference)*(Maize price) – (HYV seed price)*(Applied quantity among adopters)

Table 5. Maize Yield by Chemical Fertilizer Application Level

| | | <u>Wave 1</u> | | | | <u>Wave 2</u> | | | |
|-------------|----------------------------|--|--------------|--------------|--------------|--|--------------|--------------|--------------|
| | | Chemical Fertilizer Application Kgs/ha | | | | Chemical Fertilizer Application Kgs/ha | | | |
| | | Zero | 0-40 | 40-80 | 80+ | Zero | 0-40 | 40-80 | 80+ |
| | | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Kenya | | | | | | | | | |
| Central | Mean yield (Kgs/ha) | 1,438 | 873 | 839 | 1,305 | 1,768 | 1,637 | 1,730 | 2,159 |
| | [#plots] | [65] | [48] | [42] | [155] | [72] | [64] | [58] | [138] |
| Rift Valley | Mean yield (Kgs/ha) | 2,037 | 1,563 | 1,791 | 2,481 | 2,192 | 1,992 | 1,725 | 2,532 |
| | [#plots] | [83] | [34] | [52] | [135] | [45] | [29] | [50] | [118] |
| Western | Mean yield (Kgs/ha) | 1,470 | 929 | 1,503 | 2,063 | 1,712 | 1,019 | 2,042 | 2,560 |
| | [#plots] | [22] | [13] | [7] | [70] | [19] | [17] | [22] | [62] |
| Nyanza | Mean yield (Kgs/ha) | 648 | 673 | 942 | 1,803 | 1,092 | 1,136 | 1,567 | 2,019 |
| | [#plots] | [92] | [61] | [32] | [90] | [84] | [39] | [50] | [69] |
| All | Mean yield (Kgs/ha) | 1,353 | 950 | 1,271 | 1,875 | 1,587 | 1,500 | 1,721 | 2,312 |
| | [#plots] | [262] | [156] | [133] | [450] | [221] | [150] | [180] | [388] |

Table 6. Maize Yield by Organic Fertilizer Application Level

| | | <u>Wave 1</u> | | | | <u>Wave 2</u> | | | |
|-------------|-----------------------------|--|--------------|-------------|--------------|--|--------------|--------------|--------------|
| | | Organic Fertilizer Application Tons/ha | | | | Organic Fertilizer Application Tons/ha | | | |
| | | Zero | 0-1 | 1-2 | 2+ | Zero | 0-1 | 1-2 | 2+ |
| | | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Kenya | | | | | | | | | |
| Central | Mean yield (Kgs//ha) | 1597 | 839 | 592 | 1198 | 1706 | 1418 | 1718 | 2227 |
| | [#plots] | [91] | [50] | [28] | [141] | [101] | [44] | [41] | [146] |
| Rift Valley | Mean yield (Kgs//ha) | 2128 | 2083 | 1987 | 2540 | 2348 | 1621 | 2444 | 2472 |
| | [#plots] | [201] | [67] | [15] | [21] | [143] | [45] | [29] | [25] |
| Western | Mean yield (Kgs//ha) | 1748 | 1809 | 1653 | 1853 | 2104 | 1683 | 2367 | 2673 |
| | [#plots] | [55] | [19] | [8] | [30] | [57] | [29] | [20] | [14] |
| Nyanza | Mean yield (Kgs//ha) | 1041 | 949 | 1084 | 1670 | 1454 | 1102 | 1301 | 2246 |
| | [#plots] | [192] | [54] | [11] | [18] | [166] | [36] | [18] | [22] |
| All | Mean yield (Kgs//ha) | 1612 | 1406 | 1154 | 1466 | 1861 | 1447 | 1964 | 2282 |
| | [#plots] | [539] | [190] | [62] | [210] | [467] | [155] | [108] | [209] |
| Uganda | | | | | | | | | |
| All | Mean yield (Kgs//ha) | 1041 | 614 | 1188 | 2093 | 1351 | 1008 | 1221 | 1205 |
| | [#plots] | [730] | [18] | [7] | [8] | [839] | [35] | [13] | [9] |

Table 7. Determinants of HYV seed adoption.

| | All samples | | West Kenya and East Uganda samples | |
|---|--------------------------|------------------------------|------------------------------------|--------------------|
| | RE Logit (1) | FE Logit ^a (2) | RE Logit (3) | FE Logit (4) |
| <i>Household level characteristics</i> | | | | |
| ln(Total size of owned land in ha) | 0.0334 (0.36) | 0.0010 (0.01) | -0.0757 (0.57) | 0.2078 (0.86) |
| ln(Value of physical assets in USD) | 0.2733 (3.41)** | 0.2247 (1.76)+ | 0.3752 (3.08)** | 0.2922 (1.70)+ |
| Number of local cattles owned | -0.0139 (0.63) | -0.0353 (0.84) | -0.0008 (0.03) | 0.0051 (0.14) |
| Number of improved cattles owned | 0.0499 (1.24) | 0.0815 (1.20) | 0.3449 (3.22)** | 0.3126 (2.15)* |
| <i>Plot level characteristics</i> | | | | |
| 1 {The maize plot is rented} | 0.6781 (3.21)** | 0.6488 (2.76)** | 1.3297 (4.31)** | 1.0989 (3.27)** |
| Walking time to the plot (mins) | 0.0025 (1.07) | 0.0033 (0.95) | 0.0004 (0.13) | 0.0011 (0.29) |
| <i>Community level characteristics</i> | | | | |
| 1 {No DAP price info. available} | -2.7849 (6.26)** | -1.9363 (2.58)** | -3.0020 (5.31)** | -1.8582 (2.41)* |
| DAP price/ maize price | -0.3749 (4.16)** | -0.2968 (2.30)* | -0.3904 (3.76)** | -0.2737 (2.06)* |
| Male hourly wage/ maize price | -0.1849 (1.08) | 0.1012 (0.36) | -0.1332 (0.49) | 0.5008 (1.33) |
| HYV seed price/ maize price | 0.1076 (4.84)** | 0.0188 (0.65) | 0.0790 (3.01)** | 0.0245 (0.78) |
| <i>Time-invariant household level characteristics</i> | | | | |
| 1 {Female household head} | -0.0963 (0.38) | | 0.3234 (0.84) | |
| Years of schooling of male adult | 0.0644 (2.46)* | | 0.1213 (2.96)** | |
| Years of schooling of female adult | -0.0069 (0.30) | | -0.0506 (1.16) | |
| Number of adult males | 0.1850 (2.54)* | | 0.1105 (1.07) | |
| Number of adult females | 0.2165 (3.12)** | | 0.3096 (3.09)** | |
| Constant | -1.8532 (3.08)** | | -2.3453 (2.94)** | |
| Region * Season * Year dummies | Included | Included | Included | Included |
| Hausman's test for FE vs. RE on coefficients of common covariates | $\chi^2(10)= 27.24^{**}$ | | $\chi^2(10)= 29.34^{**}$ | |
| Observations | 3728 | 1421 | 2083 | 839 |
| Number of households | 1261 | 334 | 576 | 176 |

Absolute value of z statistics in parentheses

+ significant at 10%; * significant at 5%; ** significant at 1%

^a In the fixed-effects Logit estimation, the households who do not alter the state of the HYV seed adoption across plots or seasons are dropped. In addition, the (almost) time-invariant explanatory variables are excluded.

Table 8. Determinants of Log of Maize Yield (Kg/Ha): all samples

| | Model w/o soil condition control | | | | Model w/ soil condition control | | | |
|--|---------------------------------------|----------------------|---|--------------------------------------|---------------------------------|----------------------|--|--------------------------------|
| | Fixed Effects Regression ^a | | Semiparametric Endogenous Switching Regression ^b | | Fixed Effects Regression | | Semiparametric Endogenous Switching Regression | |
| | Hybrid seed (1) | Non-hybrid (2) | Hybrid seed (3) | Non-hybrid (4) | Hybrid seed (5) | Non-hybrid (6) | Hybrid seed (7) | Non-hybrid (8) |
| ln(Maize plot size in ha) | -0.2787 (8.01)** | -0.3261 (12.41)** | -0.2437 (4.61)** | -0.3595 (8.10)** | -0.2851 (6.64)** | -0.3370 (11.09)** | -0.2280 (4.41)** | -0.3652 (6.90)** |
| ln(Seed kgs/ha planted) | 0.4962 (11.79)** | 0.4869 (18.85)** | 0.7043 (9.07)** | 0.4678 (8.10)** | 0.5248 (10.05)** | 0.5191 (17.09)** | 0.6495 (8.84)** | 0.5304 (8.47)** |
| CF: Chemical fertilizer (100 kgs/ha) | 0.2092 (4.49)** | 0.1731 (2.00)* | 0.2191 (3.23)** | 0.4145 (3.17)** | 0.1847 (3.35)** | 0.1419 (1.29) | 0.2953 (4.07)** | 0.3411 (1.89)+ |
| OF: Organic fertilizer (tons/ha) | 0.0404 (3.45)** | 0.0944 (5.24)** | 0.0629 (3.01)** | 0.0951 (3.05)** | 0.0494 (3.68)** | 0.0855 (4.37)** | 0.0565 (2.37)* | 0.0853 (2.21)* |
| CF * OF | -0.0016 (0.79) | -0.0242 (4.44)** | -0.0064 (1.56) | -0.0052 (0.37) | -0.0028 (1.27) | -0.0248 (4.29)** | -0.0084 (1.40) | 0.0006 (0.03) |
| CF ² | -0.0208 (3.07)** | 0.0062 (0.34) | -0.0153 (1.34) | -0.0736 (1.91)+ | -0.0221 (2.90)** | 0.0045 (0.20) | -0.0242 (2.05)* | -0.0492 (1.04) |
| OF ² | -0.0008 (2.69)** | -0.0022 (3.81)** | -0.0017 (2.80)** | -0.0022 (1.54) | -0.0008 (2.55)* | -0.0020 (3.37)** | -0.0014 (1.68)+ | -0.0024 (1.00) |
| CF * PC1 ^c | | | | | 6.6135 (2.90)** | 2.9562 (0.62) | 4.0044 (0.79) | -10.2191 (1.41) |
| OF * PC1 | | | | | -0.8264 (1.86)+ | -0.1854 (0.14) | -0.2684 (0.19) | -2.2900 (0.94) |
| Constant | 5.0994 (43.01)** | 4.5004 (63.54)** | | | 4.9715 (34.39)** | 4.4418 (53.33)** | | |
| Region * Season * Year dummies | Included | Included | Included | Included | Included | Included | Included | Included |
| Hausman's test for Endogenous Switching vs. FE Model | - | - | (3) vs. (1) $\chi^2(7)=11.9$ | (4) vs. (2) $\chi^2(7)=25.8^{**}$ | - | - | (7) vs. (5) $\chi^2(9)=25.8^{**}$ | (8) vs. (6) $\chi^2(9)=8.7$ |
| Number of observations | 2248 | 3364 | 2248 | 3364 | 1633 | 2437 | 1633 | 2437 |
| Number of households | 669 | 894 | 669 | 894 | 499 | 622 | 499 | 622 |
| R-squared | 0.23 | 0.33 | - | - | 0.24 | 0.36 | - | - |

^a Absolute value of t statistics are given in parentheses for the FE regressions.

^b z statistics are given in parentheses for the semiparametric endogenous switching regressions. The standard errors are obtained by bootstrapping with 200 replications. The first stage (selection) regression model is estimated by the fixed effects logit estimation. The result is given in the previous table. The bandwidth used is the number of sample households to the power of -0.2, *i.e.*, $N^{0.2}$.

^c PC1 is a soil quality indicator obtained as the first principal component based on the principal component analysis of soil content indicators collected at the first wave of the REPEAT surveys.

+ significant at 10%; * significant at 5%; ** significant at 1%

Table 9. Marginal Effects of Fertilizer Application: all samples

| Marginal Effects ^a | Model w/o soil condition control | | | | Model w/ soil condition control | | | |
|---|----------------------------------|---------------------|--|---------------------|---------------------------------|---------------------|--|--------------------|
| | Fixed Effects Regression | | Semiparametric Endogenous Switching Regression | | Fixed Effects Regression | | Semiparametric Endogenous Switching Regression | |
| | Hybrid seed (1) | Non-hybrid (2) | Hybrid seed (3) | Non-hybrid (4) | Hybrid seed (5) | Non-hybrid (6) | Hybrid seed (7) | Non-hybrid (8) |
| Chemical Fertilizer: $\partial \ln Y / \partial CF$ | | | | | | | | |
| $E(x_i)$ | 0.169 (0.037) ** | 0.163 (0.081) * | 0.180 (0.056) ** | 0.363 (0.112) ** | 0.166 (0.043) ** | 0.143 (0.098) | 0.233 (0.062) ** | 0.256 (0.147) + |
| $E(x_i i \text{ in } I_{\text{Kenya}})$ | 0.156 (0.034) ** | 0.145 (0.069) * | 0.168 (0.051) ** | 0.310 (0.092) ** | 0.147 (0.040) ** | 0.113 (0.087) | 0.212 (0.056) ** | 0.258 (0.131) * |
| $E(x_i i \text{ in } I_{\text{Uganda}})$ | 0.205 (0.046) ** | 0.172 (0.087) * | 0.212 (0.068) ** | 0.390 (0.124) ** | 0.220 (0.054) ** | 0.159 (0.105) | 0.293 (0.080) ** | 0.253 (0.158) |
| Organic Fertilizer: $\partial \ln Y / \partial OF$ | | | | | | | | |
| $E(x_i)$ | 0.036 (0.011) ** | 0.087 (0.017) ** | 0.043 (0.017) ** | 0.086 (0.031) ** | 0.041 (0.012) ** | 0.078 (0.019) ** | 0.042 (0.019) * | 0.070 (0.036) * |
| $E(x_i i \text{ in } I_{\text{Kenya}})$ | 0.035 (0.010) ** | 0.074 (0.016) ** | 0.041 (0.016) * | 0.079 (0.028) ** | 0.040 (0.011) ** | 0.065 (0.017) ** | 0.039 (0.019) * | 0.078 (0.034) * |
| $E(x_i i \text{ in } I_{\text{Uganda}})$ | 0.040 (0.012) ** | 0.094 (0.018) ** | 0.051 (0.018) ** | 0.090 (0.033) ** | 0.044 (0.013) ** | 0.084 (0.021) ** | 0.050 (0.021) * | 0.066 (0.038) + |

^a Marginal effects are evaluated at the sample means (either total average, Kenya average, or Uganda average).

Standard errors are given in parentheses.

+ significant at 10%; * significant at 5%; ** significant at 1%

Table 10. Determinants of Log of Maize Yield (Kg/Ha): West Kenya and East Uganda samples

| | Model w/o soil condition control | | | | Model w/ soil condition control | | | |
|--|---------------------------------------|----------------------|---|-----------------------------------|---------------------------------|---------------------|--|------------------------------|
| | Fixed Effects Regression ^a | | Semiparametric Endogenous Switching Regression ^b | | Fixed Effects Regression | | Semiparametric Endogenous Switching Regression | |
| | Hybrid seed (1) | Non-hybrid (2) | Hybrid seed (3) | Non-hybrid (4) | Hybrid seed (5) | Non-hybrid (6) | Hybrid seed (7) | Non-hybrid (8) |
| ln(Maize plot size in ha) | -0.2845 (6.70)** | -0.3536 (10.02)** | -0.2172 (3.56)** | -0.3265 (5.93)** | -0.2610 (5.28)** | -0.3408 (8.99)** | -0.2304 (3.57)** | -0.3114 (4.48)** |
| ln(Seed kgs/ha planted) | 0.4957 (10.75)** | 0.5039 (13.90)** | 0.7321 (7.81)** | 0.5135 (7.87)** | 0.5160 (9.67)** | 0.5479 (13.92)** | 0.6170 (8.33)** | 0.6026 (8.67)** |
| CF: Chemical fertilizer (100 kgs/ha) | 0.1774 (2.74)** | 0.3481 (2.19)* | 0.1478 (1.51) | 0.5879 (2.35)* | 0.1288 (1.66)+ | 0.5675 (2.79)** | 0.1917 (1.45) | 0.9095 (3.07)** |
| OF: Organic fertilizer (tons/ha) | -0.0153 (2.34)* | -0.0058 (0.24) | -0.0137 (1.07) | 0.0061 (0.08) | -0.0137 (2.11)* | 0.0087 (0.27) | 0.0065 (0.44) | 0.1347 (1.71)+ |
| CF * OF | -0.0177 (1.98)* | -0.0388 (0.70) | -0.0101 (0.52) | -0.1504 (1.30) | -0.0126 (1.21) | -0.0590 (0.74) | -0.0129 (0.43) | -0.4332 (2.95)** |
| CF ² | 0.0651 (2.11)* | 0.1373 (2.89)** | 0.1035 (1.97)* | -0.0656 (0.75) | 0.0493 (1.25) | 0.1274 (2.60)** | -0.0109 (0.17) | 0.0538 (0.55) |
| OF ² | -0.0015 (1.42) | -0.0072 (1.55) | -0.0035 (1.43) | 0.0080 (0.71) | -0.0014 (1.21) | -0.0080 (1.63) | -0.0018 (0.49) | -0.0180 (1.40) |
| CF * PC1 ^c | | | | | 0.4140 (0.11) | -13.8066 (1.03) | -1.1638 (0.09) | 2.3299 (0.13) |
| OF * PC1 | | | | | 1.1507 (0.86) | 0.9794 (0.48) | 2.2493 (1.03) | 0.2173 (0.07) |
| Constant | 5.1493 (39.42)** | 4.5302 (45.68)** | | | 5.1525 (33.79)** | 4.4655 (40.99)** | | |
| Region * Season * Year dummies | Included | Included | Included | Included | Included | Included | Included | Included |
| Hausman's test for Endogenous Switching vs. FE Model | - | - | (3) vs. (1) $\chi^2(7)=6.5$ | (4) vs. (2) $\chi^2(7)=16.1^*$ | - | - | (7) vs. (5) $\chi^2(9)=4.2$ | (8) vs. (6) $\chi^2(9)=.$ |
| Number of observations | 1078 | 1621 | 1078 | 1621 | 707 | 1307 | 707 | 1307 |
| Number of households | 282 | 393 | 282 | 393 | 206 | 303 | 206 | 303 |
| R-squared | 0.31 | 0.38 | - | - | 0.36 | 0.42 | - | - |

^a Absolute value of t statistics are given in parentheses for the FE regressions.

^b z statistics are given in parentheses for the semiparametric endogenous switching regressions. The standard errors are obtained by bootstrapping with 200 replications. The first stage (selection) regression model is estimated by the fixed effects logit estimation. The result is given in the previous table. The bandwidth used is the number of sample households to the power of -0.2, *i.e.*, $N^{0.2}$.

^c PC1 is a soil quality indicator obtained as the first principal component based on the principal component analysis of soil content indicators collected at the first wave of the REPEAT surveys.

+ significant at 10%; * significant at 5%; ** significant at 1%

Table 11. Marginal Effects of Fertilizer Application: West Kenya and East Uganda samples

| Marginal Effects ^a | Model w/o soil condition control | | | | Model w/ soil condition control | | | | |
|---|----------------------------------|---------------------|--|--------------------|---------------------------------|---------------------|--|--------------------|--|
| | Fixed Effects Regression | | Semiparametric Endogenous Switching Regression | | Fixed Effects Regression | | Semiparametric Endogenous Switching Regression | | |
| | Hybrid seed (1) | Non-hybrid (2) | Hybrid seed (3) | Non-hybrid (4) | Hybrid seed (5) | Non-hybrid (6) | Hybrid seed (7) | Non-hybrid (8) | |
| Chemical Fertilizer: $\partial \ln Y / \partial CF$ | | | | | | | | | |
| $E(x_i)$ | 0.141 (0.052) ** | 0.335 (0.146) * | 0.108 (0.074) | 0.371 (0.200) + | 0.103 (0.062) + | 0.485 (0.182) ** | 0.180 (0.094) + | 0.434 (0.244) + | |
| $E(x_i i \text{ in } I_{\text{Kenya}})$ | 0.119 (0.045) ** | 0.311 (0.125) * | 0.099 (0.061) | 0.330 (0.169) + | 0.087 (0.054) | 0.525 (0.179) ** | 0.165 (0.080) * | 0.300 (0.191) | |
| $E(x_i i \text{ in } I_{\text{Uganda}})$ | 0.173 (0.063) ** | 0.348 (0.158) * | 0.123 (0.095) | 0.393 (0.219) + | 0.127 (0.075) + | 0.465 (0.202) * | 0.201 (0.122) | 0.505 (0.294) + | |
| Organic Fertilizer: $\partial \ln Y / \partial OF$ | | | | | | | | | |
| $E(x_i)$ | 0.051 (0.028) + | 0.132 (0.045) ** | 0.074 (0.040) + | -0.023 (0.081) | 0.043 (0.034) | 0.129 (0.047) ** | 0.012 (0.054) | 0.041 (0.108) | |
| $E(x_i i \text{ in } I_{\text{Kenya}})$ | 0.043 (0.026) + | 0.124 (0.042) ** | 0.068 (0.037) + | -0.025 (0.074) | 0.036 (0.031) | 0.119 (0.045) ** | 0.013 (0.048) | 0.056 (0.087) | |
| $E(x_i i \text{ in } I_{\text{Uganda}})$ | 0.063 (0.030) * | 0.137 (0.047) ** | 0.083 (0.044) + | -0.022 (0.087) | 0.053 (0.037) | 0.134 (0.050) ** | 0.011 (0.064) | 0.033 (0.123) | |

^a Marginal effects are evaluated at the sample means (either total average, Kenya average, or Uganda average).

Standard errors are given in parentheses.

+ significant at 10%; * significant at 5%; ** significant at 1%