On the Possibility of a Maize Green Revolution in the Highlands of Kenya: An Assessment of Emerging Intensive Farming Systems

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Abstract As population pressure on land grows rapidly in Kenya, rural farmers have started to intensify land use, which has led to the emergence of a new maize farming system. The new system is characterized by the adoption of high-yielding maize varieties, the application of chemical fertilizer and manure produced by stall-fed improved dairy cows, and intercropping, especially the combination of maize and legumes. This study aims to explore the determinants of the new maize farming system and its impact on land productivity. We examine not only the impacts of new technologies and production practices but also the impact of the entire new maize farming system by generating an agricultural intensification index based on a principal component analysis. The estimation results show that a decrease in the land-labor ratio accelerates farming intensification, and that the adoption of each new technology and production practice has positive and significant impacts on land productivity. These findings are further supported by the significantly positive impacts of the agriculture intensification index on land productivity.

Keywords Farming system・Agricultural intensification・Population pressure・Maize・Green Revolution・Kenya

7.1 Introduction

The improvement of agricultural productivity is imperative for poverty reduction in developing countries in general, and in sub-Saharan Africa (SSA), in particular, considering its high rate of population growth, increasingly limited availability of cultivatable lands, and the rise of food prices in the international market (David and Otsuka 1994; Otsuka, Estudillo, and Sawada 2008; Barret, Carter and Timmer 2010). Asia experienced a rapid rise of agricultural productivity, known as the "Green Revolution," characterized by the adoption of chemical fertilizer and fertilizer-responsive high-yielding varieties in the 1970s and 1980s, along with the expansion of irrigation infrastructure (Kikuchi and Hayami 1978; David and Otsuka 1994; Evenson and Gollin 2003c; Hayami and Godo 2005; Otsuka and Larson 2013b). In contrast, Africa is the only continent experiencing the stagnation of agriculture productivity. Researchers, therefore, continue to look for ways to enhance agriculture productivity in Africa. However, it is widely believed that underdeveloped infrastructure and markets lead to high transaction costs for the purchase of chemical fertilizer and seeds of high-yielding varieties and to poor access to irrigation, and, hence, it is not possible for small farmers to achieve rapid growth in agricultural productivity (Jayne et al. 2003; Kydd et al. 2004; Reardon et al. 1999; Gregory and Bumb 2006).

Yet, under these circumstances, some farmers have begun adopting a new farming system of maize production in the highlands of Kenya characterized by the application of organic fertilizer, i.e., manure produced from improved dairy cattle in addition to the use of hybrid seeds, chemical fertilizer, intercropping with legumes, and crop rotation (Otsuka and Yamano 2005). A typical farmer in this system grows Napier grass, which is a common feed crop for cattle that can also repel pests, feeds it to improved cattle that are raised in stalls, collects manure from the stalls, and applies it on the maize plots, where the intercropping of hybrid maize with nitrogen-fixing legumes is practiced. This farming system is similar not only to the Green Revolution in Asia in the 1970s and 1980s whose essence is the application of high-yielding varieties and chemical fertilizer, but also to the agricultural revolution in U.K. in the 18th century, which is based on the application of manure produced from stall-fed cattle as well as the production of feeds on crop fields. It may not be unrealistic to assume that this new farming system, which embodies the essence of the two preceding revolutions in agricultural history, will bring about "revolutionary" changes in farm productivity in SSA.

To our knowledge, however, no study has statistically examined the determinants of the adoption and productivity impacts of this emerging farming system in SSA. Therefore, this study aims to identify the determinants of the adoption of this new farming system and to estimate its impact on the productivity of maize, the major staple crop in Kenya, through regression analyses. In addition to estimating the effects of each element of the new farming system on production and productivity, this study attempts to measure the impact of the entire system by creating a single agriculture intensification index that captures this multidimensional input intensification. Our approach will provide insights into the effects of the new farming system on the productivity and profitability of maize farming, which should assist policy makers in constructing new, effective strategies for agricultural productivity improvement in SSA.

The remainder of the chapter is structured as follows. Section 7.2 outlines the background of this study, while Section 7.3 describes the data collection method and provides descriptive statistics. Section 7.4 explains how the maize farming system index is constructed, Section 7.5 describes our identification strategies, and Section 7.6

presents the estimation results. Finally, Section 7.7 discusses the conclusions and policy implications of this study.

7.2 Background

In the 18th century, the agricultural revolution was realized due to the introduction of the turnip as a feed crop, the stall-feeding of cattle, and the ample application of manure to crop fields (Timmer 1969). This new farming system was based on crop rotation, feed production, stall-fed cattle, and the application of manure, which enhanced crop yields. In contrast to cattle grazing under a three-field system which requires large areas of land but does not require intensive labor use, stall-feeding of cattle is labor intensive as it requres feed crops or feeding grass. The collection of manure from stalls and its application to crop fields is also labor intensive. In addition, the stall-feeding of cattle makes it possible to fully collect manure. Therefore, a farming system based on the stall-feeding of cattle is a more labor-using and yield-enhancing technology than the traditional three-field farming system based on grazing. This method seems to fit with densely populated areas in SSA, which have been experiencing rapid population growth, the shrinkage of cultivatable lands per capita, and declining soil fertility.

Asia has experienced rapid productivity growth mainly in rice and wheat since the late 1960s (David and Otsuka 1994; Hayami and Godo 2005), which is called the Green Revolution. This high growth in agricultural productivity was realized by the application of chemical fertilizer, the adoption of high-yielding modern rice varieties, and the development of irrigation. Farmers used the modern varieties and chemical fertilizer simultaneously because the provision of soil nutrients is necessary to realize the high yield potential of the modern varieties. Therefore, the important lesson from the Green Revolution in Asia is that both the adoption of high-yielding varieties and the application of chemical fertilizer are necessary to increase crop yields significantly (Hayami and Ruttan 1985; David and Otsuka 1994).

However, in a country where infrastructure is underdeveloped, it is difficult for poor farmers in rural area to have access to chemical fertilizer due to its high transaction cost. Moreover, unlike lowland rice farming, which is most sustainable, upland farming requires the maintenance of soil fertility by applying organic fertilizer in addition to chemical fertilizer. Hence, many farmers in the highlands of Kenya apply organic fertilizer which is made from enteruria collected from stall-fed cows as depicted in Figure 7.1. Farmers grow feed grass such as Napier grass, which repels pests, and feed it to improved cows in the stalls. Then, farmers collect the cows' enteruria and create manure from it. Many of them plant a hybrid maize variety and apply both manure and chemical fertilizer on the plot. Moreover, they often intercrop maize with legumes that fix nitrogen from the atmosphere, which improves soil fertility. It is important to emphasize that this system combines the technological advantages from two agricultural revolutions, one that occurred in England in the 18th century and another that was achieved in Asia in the 20th century. We hypothesize that the emerging farming system has the potential to boost maize productivity significantly in SSA.

7.3 Descriptive Analysis

7.3.1 Data

In order to analyze the determinants of the adoption of the new maize farming system and its impact on maize and entire crop yields, including the yield of leguminous crops, and milk production, household and plot-level data are taken from a survey called

RePEAT. This data set was jointly collected by the National Graduate Institute for Policy Studies (GRIPS), the World Agroforestry Center, and Tegemeo Institute of Agricultural Policy and Development in Kenya. The RePEAT survey is originally based on a survey conducted by the Smallholder Diary Project (SDP) that collected data from more than 3,300 households randomly selected from communities in the Central, Rift Valley, Nyanza, and Western, and Eastern provinces in Kenya by the International Livestock Research Institute, Nairobi. In 2004, the RePEAT survey randomly selected 99 sub-locations, which is the smallest community unit and is equivalent to a village, and up to 10 households from each of the selected sub-locations, which results in a sample of 899 households.

The second round of the RePEAT survey was conducted in 2012, which revisited 751 households that were interviewed in 2004. Thus, the attrition rate is 16.5%.[1] We drop households that did not provide complete answers for the survey and that did not grow maize because our focus is on maize production. To address extreme values or outliers, we drop the households if their outcome variables including the maize yield per hectare, total value of crop harvest per hectare, crop income per hectare, the sum of crop and milk revenue per hectare, and crop and milk income per hectare are more than the 99th percentile of each variable. Eventually, our final sample size consisted of 663 households in 97 sub-locations and 1,750 maize plots. The RePEAT survey includes detailed household information on agricultural activities, land use, demographics, education, assets, nonfarm income, agricultural expenditure, consumption.

Table 7.1 shows the socioeconomic characteristics of the sample households.

[1] Attrition weights are adopted to control for attrition issues in the estimation.

According to this table, the proportion of female headed households has increased from 22% to 30%, and the typical household head has become older by 5 years from 2004 to 2012. Although the household size has not changed much over time, the composition of a typical household has changed as the number of household working age (15-64 years) members increased by 0.2, and the number of dependents has decreased by 0.4 over time. The size of owned land was small already in 2004, i.e., 1.8 hectares, indicating that the population pressure was severe in the highlands of Kenya. Farm size has shrunk to 1.5 hectares over the eight-year period, which clearly leads to a decrease in the land-labor ratio over time. It is clear that in order to increase maize production, maize yield must be increased. The transportation infrastructure has improved over time in Kenya as evidenced by the shortened time distance to the nearest market by car, which indicates that the accessibility to agricultural inputs and output markets and information could have improved over time.

7.3.2 Maize Production in Kenya

Figure 7.2 traces the change in the quantity of maize production, maize harvested area, and land productivity of maize from 1962 to 2010 in Kenya. All of them are indexed in which all values are converted into 100 in 1962. Although there are upward trends in the quantity of maize production and area harvested, the rate of growth in the land productivity of maize has been negligible over time. It raises a red flag regarding food security in Kenya whose annual population growth rate was still 2.7% in 2012 and whose potential for area expansion is limited. Therefore, how to boost the maize yield is an urgent issue in this country.

Table 7.2 provides production data in Kenya based on our survey data in 2004 and 2012. The size of the maize plot has shrunk over time, which is consistent with the declining trend in the owned land size. The adoption rate of hybrid maize, however, has increased from 50% to 78%, and expenditures for chemical inputs other than chemical fertilizer, which include herbicides, pesticides, and fungicides, have risen from 109 Kenyan Shieling (KSh) per hectare to 211 KSh per hectare from 2004 and 2012.[2] In contrast, the ratio of intercropping with legumes and the proportion of area planted to Napier grass slightly declined over time. Both the adoption rate of manure and the quantity of manure applied per hectare have risen significantly over time, which resulted from raising stall-fed improved cows and the production of Napier grass. It is also remarkable to observe that the adoption rate of chemical fertilizer significantly increased over time, even thoguh its applied quantity, which is converted into the total weight (in kg per hectare) of primary nutrients in terms of nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O_5) contained in fertilizers (hereafter, NPK), slightly and insignificantly decreased over time. While the maize yield has increased by about 21%, the value of the harvest from maize and all other intercropped crops of the maize plots has increased by as much as 26%. Similarly, sample households experienced a growth in their crop income, defined as the total value of harvested crops minus the paid-out costs of chemical and organic fertilizer, other chemical inputs, seeds, and hired labor, by 24% over time. This indicates that the yield is increasing not only for maize but also for other crops planted in the intercropping system. Since intercropping with maize and other crops, such as legumes, is a common farming practice in Kenya, we may underestimate maize productivity if we look at only maize on the intercropped maize

[2] Throughout this chapter, all prices are converted to the real price setting 2009 as a base year. The consumer price index for 2004 is 66.03 and that for 2012 is 103.53.

plots. A possible hypothesis about the stagnant maize productivity in Kenya as a whole is that while “effective” maize productivity increased, measured maize productivity is stagnant due to the increasing practice of intercropping.

Table 7.3 shows the amount of fertilizer application and land productivity by the types of maize seeds. The adoption of hybrid maize seeds is associated with a higher yield and value of harvest than that of local seeds by about 55% and 44%, respectively. Consistently, the proportion of plots with chemical fertilizer application is higher for hybrid seeds than for local seeds by 32%, and the quantity of chemical fertilizer applied per hectare is also greater for the hybrid seed parcels than for the local seed by 31 kg per hectare. In contrast to chemical fertilizer use, the proportion of manure used is slightly higher for local seed parcels than for hybrid parcels. However, when we look at the quantity of manure applied per hectare, it is greater for hybrid seeds than forlocal seeds. This indicates that rural farmers in Kenya know the importance of applying both chemical and organic fertilizer to realize the yield potential of the hybrid seeds.

Overall, it is clear that maize farmers in the highlands of Kenya spontaneously began exerting efforts to intensify land use under the increasing population pressure on the limited land resources.

7.3.3 Milk Production in Kenya

It is a mistake to examine only maize fields if we are interested in the impacts of new maize-based farming system because keeping improved dairy cows is an integral part of this farming system. Figure 7.3 depicts the trends in milk production, the number of milking cows, and milk production per cow from 1962 to 2010 in Kenya. All of them are indexed by converting into 100 in 1962. The number of cows and milk production per cow have increased rapidly and concomitantly from 1980 to 1987 and 2000 to 2005. However, the number of cows suddenly dropped since 2006. This is mainly due to an outbreak of Rift Valley fever, a viral disease communicable to animals such as cows, sheep, and goats, in Kenya. It is interesting to observe that milk production per cow has started to slowly rise since 1998, thereby resulting in the increase in total milk production. This is most likely due to the widespread adoption of dairy cows, which are more productive than local cows.

Consistent with the decrease in the number of cows shown in Figure 7.3, Table 7.4 displays the decline in the number of both local and improved cows from 2004 to 2012 in the RePEAT data, though these changes are not statistically significant. However, the quantity of milk produced per cow by local, improved, and both local and improved cows all increased over time. It is also clear that milk production per improved dairy cow is about four times greater than that of a local cow, which demonstrates the much higher productivity of improved cows over local cows. The use of improved dairy cows is reminiscent of the White Revolution realized in India a few decades ago (Kajisa and Palanichamy 2013).

7.4 The Agriculture Intensification Index

It is difficult to measure the overall effect of the farming system, which consists of multiple changes in input uses and production practices, by simply looking at individual elements of the new farming system separately because their effects on agriculture production could be interactive. In fact, many changes are expected to be complementary. In such a case, if we analyze the impacts of each change on the outcome variables by estimating the production function by using each input and technology separately as an explanatory variable, we could miss the interacting effects of multiple changes. Although it is theoretically possible to specify the general form of production function, such as translog, it is empirically difficult to estimate such a function due to the limited degree of freedom and high correlation among various elements of the new farming system. Therefore, it will be useful to construct a single index that represents the degree of adoption of the new maize farming system. This single index should incorporate the important multiple indicators from each dimension of agriculture intensification in the system.

This study uses principal component analysis (PCA) to construct an index of agricultural intensification. PCA is a variable reduction procedure which decomposes variations in the variables included in the analysis into components (Darnell 1994). A component is a linear combination of weighted explanatory variables, in such a way that the component accounts for a maximal amount of variance in the explanatory variables (Cavatassi, Davis, and Lipper 2004). Since the first component captures the greatest proportion of total variation, it will be used as an agricultural intensification index in our analysis. The component is constructed based on the factor scores which are used as weights for each explanatory variable to calculate an index which represents the degree of agricultural intensification. The agricultural intensification index is computed by the following formula (Filmer and Prichett 1998):

$$AI_{ip} = \sum_{ip=1}^{N} F_k \left[\frac{(x_{ipk} - X_k)}{s_k}\right] \quad ,$$

(1)

where AI_{ip} is the agricultural intensification index of household i on maize plot *p* which follows a normal distribution with a mean of 0, F_k is the factor score for the variables k in the PCA model, x_{ipk} is the variable k of household i on the maize plot p, and X_k and S_k are the mean and standard deviation of the variable k. As AI_{ip} becomes greater, farming is supposed to be more intensified. Dummy variables for hybrid maize seed adoption, the quantity of intercropped legume seeds with maize, the quantity of manure per hectare, and the quantity of chemical fertilizer converted in NPK per hectare are included in the PCA model as these input variables represent agricultural intensification of the new maize farming system. Since the data used for the analysis consist of two rounds of household panel data, it is necessary to create an index which can be compared over time. Therefore, the pooled data from the two rounds of household panel data are used to estimate the intensification index.

Table 7.5 shows the factor loadings of the individual elements accounting for the agricultural intensification index. The principal component explains 34% of the variance in the 4 variables. Factor loading, which provides the direction and weight for each variable, shows that hybrid seed adoption and the quantity of chemical fertilizer applied per hectare account for a large part of the agricultural intensification. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy takes a value between 0 and 1, and higher KMO values indicate that the correlation between pairs of the explanatory variables could be explained by the other explanatory variable (Kaiser 1974). The KMO of our analysis is 0.55, and it is usually considered that PCA is acceptable if the value of KMO is more than 0.5. The factor loadings obtained from the pooled samples of the 2004 and 2012 surveys display similar patterns, which indicates that it is acceptable to use an index created from pooled data. The result shows that the agricultural intensification index has increased from -0.226 to 0.249 from 2004 to 2012, indicating that agricultural intensification has advanced even in the short period of 8 years.

Table 7.6 provides evidence that the agricultural intensification index captures the degree of intensification of each input quite well by looking at the crop production on the maize plots in the main season by quartile in 2012. As shown in the table, there are upward trends in almost all individual input uses as well as in the adoption of new production practices, as the quartile of the agricultural index goes up. Consistently, outcome variables such as maize yields, revenue from all crops, and net revenue increase as the degree of agricultural intensification deepens. These findings indicate that the farmers' effort of agricultural intensification is likely to pay off in rural Kenya. Furthermore, it is interesting to note that households that belong to the greatest quartile of the index have the smallest operated maize plot size, which is consistent with the negative correlation between farm size and agricultural intensification widely observed in SSA in recent years (Larson et al. 2014).

7.5 Estimation Strategy

7.5.1 Determinants of the New Maize Farming System Adoption

Following the literature on agricultural intensification, this study focuses on population pressure as the driving force that accelerates agricultural intensification. Boserup (1965) argues that a rise in population density will change the relative prices of land and labor, which increases the demand for new inputs such as fertilizer, irrigation water, improved seeds, and herbicide in order to intensify land use. This leads to an increase in input use per unit of area, which is regarded as agricultural intensification. In this way, population pressure accelerates the intensive use of labor and other non-land inputs, which facilitates the shift of farming system from extensive, such as slash and burn farming, to intensive, such as sedentary multi-cropping farming with higher agricultural productivity (Otsuka and Place 2001). Similarly, Hayami and Ruttan (1985) argue that changes in relative input scarcities would bring about changes in farmers' behaviors and institutions to adapt to new conditions, which is called the "induced innovation hypothesis." In their hypothesis, it is hypothesized, as in the Boserupian view, that population pressure decreases the wage rate relative to land price, which increases the demand for labor and non-land input use, thereby enhancing land productivity. Empirical evidence shows that population pressure is associated with smaller land size and higher agricultural intensification (Josephson, Ricker-Gillbert, and Florax 2014; Muyanga and Jayne 2014; Ricker-Gillbert, Jumbe, and Chamberlin 2014). Following the existing literature, this study employs the ratio of a household's owned land to family labor as a proxy for population pressure on the land in order to explore its impact on agriculture intensification.

To assess the effect of the land-labor ratio and other household characteristics to explain agricultural intensification, we consider the estimation of the following reduced form equation:

$$I_{lkjit} = \alpha_{lkji} + \beta_1 L_{lkjit} + \beta_2 R_{lt} + \beta_3 X_{lkjt} + \beta_4 P_l + \beta_5 D_t + \beta_6 P_l * D_t + \varepsilon_{lkjit} \quad , (2)$$

where I_{mlkjit} is the agricultural intensification index or one of the four agriculture input or practice variables of interest, i.e., manure applied per hectare, the amount of chemical fertilizer converted into the NPK applied per hectare, adoption of hybrid maize seed, and the amount of intercropping legume seed planted. All variables pertain to the main crop season for maize plot *i* of household *j* in district *k* in province *l* in time *t*. L_{lkjit} is a ratio of owned land size to the number of working age (15-64) household members. R_{lkt} is a coefficient of variation of rainfall. X_{lkjt} is a vector of household control variables including the number of working age (15-64) household members, a dummy variable for female head, the household head's age, a dummy variable for head with primary education, the value of non-land assets, the time distance to the nearest market by a motor vehicle, and the soil carbon content of the main maize plot which represents soil fertility. Some soil samples were lost or spoiled in the laboratory and thus a dummy variable for no soil information is created and included in the regressors in order to avoid the loss of the observations without soil sample information. P_l and D_t are province and time dummies. α_{lkji} is a household fixed effect that intends to capture farmer management ability, household risk preferences, unmeasured household wealth, and other time-invariant household level factors, that could be correlated with the land-labor ratio and input use simultaneously. The existence of α_{lkji} would cause OLS estimates to be biased. To purge α_{lkji}, we take advantage of the household panel data and estimate equation (2) using a household level fixed-effects estimation approach. Our main interest is the estimated parameters of β_1.

7.5.2 Impact of the New Maize Farming System on Agricultural Production

To examine the impact of the new maize farming system on agricultural productivity, the impact of each individual element of the new farming system is estimated separately. The following model is used to examine the individual effects:

$$Q_{lkjit} = \gamma_{lkj} + \delta_1 I_{lkjit} + \delta_2 L_{lkjit} + \delta_3 R_{lkt} + \delta_4 X_{lkjt} + \delta_5 P_l + \delta_6 D_t + \delta_7 P_l * D_t + \epsilon_{lkjit}, \quad (4)$$

where Q_{lkjit} is one of the three output variables of interest, which are the physical maize yield per hectare, the value of harvest of all crops, and the income from the production of all crops, which is defined as the value of the harvest from all crops minus the paid-out costs of chemical and organic fertilizer, other chemical inputs, seed, and hired labor on the maize plot in the main crop season.

In order to measure the impact of the entire farming system, the following equation is employed:

$$Q_{lkjit} = \theta_{lkji} + \pi_1 AI_{lkjit} + \pi_2 L_{lkjit} + \pi_3 R_{lkt} + \pi_4 X_{lkjt} + \pi_5 P_m + \pi_6 D_t + \pi_7 P_m * D_t + \mu_{lkjit}, \quad (5)$$

where AI_{lkjit} is the agricultural intensification index for household *i* in district *j* in time *t*.

Outputs from a new maize farming system accrue not only from crop production but also from milk production. Therefore, the following models are also employed in order to capture the effect of the maize-based farming system on the total value of crop harvested and milk production and income from the crop and milk production:

$$Y_{lkjt} = \vartheta_{lkji} + \rho_1 AI_{lkjt} + \rho_2 L_{lkjt} + \rho_3 R_{lt} + \rho_4 X_{lkjt} + \rho_5 P_l + \rho_6 D_t + \rho_7 P_l * D_t + \varphi_{lkjit}, \quad (6)$$

where Y_{lkjt} is alternately the crop harvested and milk production or income from crop and milk production defined as the revenue from the crop harvest and milk production minus the paid-out costs, including the costs of livestock services and feeds for the main crop season.

With the same reasoning as in the determinants of the adoption model, the unobservable fixed effects (γ_{lkj}, θ_{lkji}, or ϑ_{lkj}) would cause bias and inconsistent estimates. Thus, the household fixed-effects model approach is used for the estimation of equations (4), (5) and (6) in this study.[3]

7.6 Estimation Results

7.6.1 Determinants of the Adoption of New Maize Farming System

Table 7.7 shows the estimation results of the new maize-based farming system adoption model. In columns (1) to (5), the specifications explaining the quantity of manure per hectare, the quantity of NPK equivalent chemical fertilizer use per hectare, the adoption of hybrid maize seed dummy, the quantity of intercropped legume seeds planted per hectare, and the agriculture intensification index on the maize plot in the main crop season are estimated by the household level fixed-effects. The most important finding is that the land-labor ratio has negative and significant effects on chemical fertilizer use and the agriculture intensification index, which supports our hypothesis that population pressure encourages input use intensification. Households located close to markets and with younger heads are more likely to adopt hybrid maize seeds.

7.6.2 Impact of the New Maize Farming System on Agricultural Production

Table 7.8 shows the impact of individual input use and intercropping on land productivity alternatively measured by (1) maize yield per hectare, (2) value of harvest from all crops per hectare, and (3) crop income per hectare on the maize plot in the main crop season, which are estimated by the household fixed-effect model. The adoption of hybrid maize is found to contribute to a 25% and 13% increase in the maize yield and the value of harvest from all crops, respectively. Interestingly, the

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[3] Ideally we should endogenize the technology adoption variables. However, we have failed to find appropriate instrumental variables so far.

intercropping with legume dummy is shown to decrease maize yield by 11%, but this negative effect is more than compensated for by the additional value of harvest and income from other crops, judging from its positive effect on the value of harvest from all crops. This means that although intercropping with legumes on the maize plots decreases the maize yield, farmers can obtain higher revenue and income from the intercropped production of legumes. In addition, as legumes contribute to the improvement of soil nutrients by fixing nitrogen from the atmosphere, intercropping with legumes could contribute to a gain in the total crop revenue in the longer run. The additional application of organic fertilizer by 1 ton per hectare is expected to increase the maize yield, the value of harvest from all crops, and the income from all crops by about 4.1%, 4.2%, and 4.8%, respectively. Similarly, the additional application of chemical fertilizer by 10 kg per hectare is expected to increase the maize yield, the value of harvest from all crops, and the income from all crops by about 3.3%, 3.1% and 1.3%, respectively.

It may not be possible to capture the whole impact of the new maize farming system only by estimating the impact of an individual effect on agriculture production. Therefore, Table 7.9 attempts to examine the effect of the entire new maize farming system by using the agricultural intensification index as an explanatory variable while using the household fixed-effect model. Estimation results show the positive and consistently positive effects of the agricultural intensification index on all outcome variables. The magnitudes of the impact on the index are smaller for income than for value of the harvest, which could reflect the fact that agricultural intensification is a costly practice to conduct, and thus the magnitude of the coefficients of the index are smaller for the net outcomes than for the gross outcome. However, even though agricultural intensification is costly, it remains true that crop income would increase significantly with increases in agricultural intensification.

Since the new maize farming system aims to increase output not only from crop production but also from milk production, Table 7.10 illustrates the impacts of agricultural intensification on (1) the total value of all crops harvested and milk production and (2) the sum of crop and milk income. Consistent with the findings in Table 7.9, the effects of the agriculture intensification are positive and significant on both outcome variables. Similar to the results shown in Table 7.9, the coefficient is smaller in the income regression. An inverse relationship between owned land size and outcome variables is observed in Table 7.10: Doubling owned land size per working age member would reduce the value from all crops and milk and the crop and milk income by 9.8% and 11%, respectively. This finding indicates that the maize-based farming system is conducive to both production efficiency and the equity of income distribution.

7.7 Conclusions and Policy Implications

As population pressure grows rapidly in Kenya, rural farmers have started to intensify farming systems by adopting new inputs and production practices, including the adoption of high-yielding maize varieties, the application of organic fertilizer produced by improved dairy cows, and intercropping especially of maize with legumes that could fix nitrogen. Since the phenomenon of the new farming system has failed to receive a lot of attention from researchers, our knowledge of the driving forces and impacts of this system is limited. Hence, this study aims to quantify the determinants of the new maize farming system and its impact on agriculture productivity. To gauge the impact of the new farming system, this study examines the impacts of individual inputs as well as the impact of the new maize farming system by using an agricultural intensification index constructed by PCA.

The estimation results show that the decrease in the land-labor ratio increases chemical fertilizer application and the extent of agricultural intensification. These findings indicate that population pressure accelerates farming intensification, consistent with the Boserupian and induced innovation hypotheses. Furthermore, it is found that the adoption of hybrid maize seed, intercropping legumes with maize, manure application, and chemical fertilizer application have positive and significant impacts on land productivity. These impacts are confirmed and reinforced by the consistent and significantly positive impacts of the agriculture intensification index on land productivity in terms of the value of production and income per hectare.

Therefore, we conclude that the new farming system has already improved the productivity of small-scale farmers in the highlands of Kenya. It is worth emphasizing that the substantial yield gain has already been achieved by this farming system without strong support from the Kenyan government and aid donors. Moreover, to our knowledge, no agricultural research center has undertaken research on the “optimum” farming systems. In all likelihood, this is a serious omission as this farming system is consistent with the British Agricultural Revolution and the Asian Green Revolution as well as the Indian White Revolution. Thus, it can be expected that much more significant increase in the productivity of farming could be achieved if appropriate research is carried out and appropriate technical support and extension services regarding this new maize farming system are provided for small-scale maize farmers in Kenya.

Table 7.1 Sample household characteristics in Kenya

	2004	2012	Testing

	Mean(b)	S.D.	Mean(c)	S.D.	difference in means[a]
Number of households	663		663		
Female headed HH (%)	22	(41)	30	(46)	***
Age of the head (years)	56	(14)	61	(14)	***
Head completed primary education (%)	39	(49)	0.42	(49)	
Years of schooling of HH head (years)	6.5	(4.4)	6.8	(4.3)	
HH size	7.0	(3.1)	7.0	(3.2)	
HH members between 15 & 64	4.2	(2.2)	4.4	(2.4)	
Number of dependents	2.9	(2.)	2.5	(1.8)	***
Owned land size (ha)	1.8	(2.8)	1.5	(2.1)	**
Owned land size per HH members between 15 & 64 (ha)	0.6	(0.9)	0.4	(0.7)	***
Value of asset (KSh)	88,068	(238,179)	79,902	(353,745)	
Time to the nearest market by car (min)	21	(20)	15	(12)	***

*** and ** indicate significance at 1 and 5%, respectively

[a] Significance testing of the difference between columns (b) and (c)

Table 7.2 Crop production of the maize plots in the main crop season in Kenya

	2004		2012		Testing difference in means[a]
	Mean(b)	S.D.	Mean(c)	S.D.	
Number of plots	846		904		
Maize plot size (ha)	0.41	(0.40)	0.37	(0.36)	*
Hybrid maize seeds (%)	50	(50)	78	(41)	***
Intercrop with legumes (%)	76	(43)	72	(45)	*
Area planted to Napier grass (ha)	0.05	(0.18)	0.03	(0.14)	
Manure applied (%)	38	(49)	51	(50)	***
Ratio of chemical fertilizer applied (%)	68	(46)	76	(43)	***
Quantity of manure (kg/ha)	971	(2,873)	1,578	(3,079)	***
Quantity of chemical fertilizer (kg/ha)[b]	49	(64)	47	(48)	
Cost of other chemical inputs (KSh/ha)[c]	109	(478)	211	(555)	***
Quantity of maize yield (kg/ha)	1,766	(1,595)	2,142	(1,522)	***
Value of harvest from all crops (KSh/ha)	47,520	(43,069)	60,011	(47,465)	***
Crop income from all crops (KSh/ha)[d]	37,869	(39,983)	46,786	(44,362)	***

*** and * indicate significance at 1 and 10%, respectively

[a] Significance testing of the difference between columns (b) and (c)

[b] Quantity of chemical fertilizer is measured in NPK equivalent

[c] This includes herbicides, pesticides, fungicides, and other chemical input

[d] Crop income is defined as the value of harvest minus the paid costs of chemical and organic fertilizer, other chemical inputs, seed, and hired labor

Table 7.3 Yield and fertilizer application by seed type in the maize plots in the main crop season in Kenya in 2012

	Type of maize seeds			Testing difference in means[a]
	Local seeds (b)	Hybrid seeds (c)	All	
Number of maize parcels	199	705	904	
Maize yield (kg/ha)	1,496	2,325	2,142	***
Value of harvest from all crop (KSh/ha)	44,723	64,326	60,011	***
Manure				
Manure applied (%)	57	50	51	*
Quantity Applied (kg/ha)	1,332	1,648	1,578	
Chemical fertilizer				
Chemical fertilizer applied (%)	51	83	76	***
Quantity Applied (kg/ha)	23	54	47	***

*** and * indicate significance at 1 and 10%, respectively
[a] Significance testing of the difference between columns (b) and (c)

Table 7.4 Milk production per household in Kenya in 2004 and 2012

	2004		2012		Testing difference in means[a]
	Mean (b)	S.D.	Mean (c)	S.D.	
Number of households	663		663		
Number of local cows	1.5	(6.1)	1.3	(4.7)	
Number of improved cows	2.0	(2.9)	1.9	(2.5)	
Number of total cows	3.5	(6.4)	3.2	(4.8)	
HH with improved cows (%)	58	(49)	58	(49)	
Quantity of milk produced per cow for HH owning only local cows (liter/cow)	159	(251)	178	(204)	
Quantity of milk produced per cow for HH owning only improved cows (liter/cow)	705	(608)	855	(671)	***
Quantity of milk produced per cow for HH owning local & improved cows (liter/cow)	326	(275)	369	(261)	
Quantity of milk produced per cow for all HH (liter/cow)	528	(570)	647	(640)	***
Value of milk produced (KSh/cow)	30,658	(36,015)	29,722	(37,419)	
Milk income (KSh/cow)[b]	21,477	(29,280)	23,606	(32,192)	

*** indicates significance at 1%

[a] Significance testing of the difference between columns (b) and (c)

[b] Milk income is defines as the value of milk produced milk minus all the paid costs of services and feed

Table 7.5 Factor loading for maize production intensification index of the maize plots in the main crop season in Kenya in 2004 and 2012

	Pooled years	2004	2012
Individual elements	**Factor loadings**		
Hybrid maize seeds (=1)	0.59	0.59	0.60
Quantity of intercropped legume seed (kg/ha)	0.39	0.36	0.37
Quantity of manure (kg/ha)	0.31	0.19	0.35
Quantity of chemical fertilizer (kg/ha) [a]	0.63	0.70	0.62
KMO	0.55	0.49	0.55
Proportion variation explained	0.34	0.34	0.34
Mean of agriculture intensification index generated from pooled data	0.00	-0.226	0.249

[a] Quantity of chemical fertilizer is measured in NPK equivalence

Table 7.6 Crop production by quartile of the agriculture intensification index in the maize plots in the main crop season in Kenya in 2012

	Quartile of agriculture intensification index			
	1st	2nd	3rd	4th
Hybrid maize seeds (%)	22	93	99	99
Intercrop with legumes (%)	55	65	78	88
Adoption of organic fertilizer (%)	50	51	44	61
Adoption of chemical fertilizer (%)	42	76	90	96
Quantity of manure (kg/ha)	886	1,031	931	3,465
Quantity of chemical fertilizer (kg/ha) [a]	13	25	56	95
Cost of other chemical inputs (KSh/ha) [b]	93	175	227	350
Quantity of maize yield (kg/ha)	1,552	1,948	2,222	2,849
Value of harvest from all crops (KSh/ha)	40,954	50,145	58,205	90,773
Crop income from all crops (KSh/ha) [c]	35,384	39,875	43,329	68,570
Maize plot size (ha)	0.34	0.42	0.44	0.30

[a] Quantity of chemical fertilizer is measured in NPK equivalence

[b] This includes herbicides, pesticides, fungicides, and other chemical inputs

[c] Crop income is defined as the value of harvest minus the paid costs of chemical and organic fertilizer, other chemical inputs, seed, and hired labor

Table 7.7 Estimation results of the determinants of input intensification in the main crop season in Kenya (household fixed-effect model, plot level data)[a]

	Manure (t/ha)	Chemical fertilizer (10kg/ha) [b]	Hybrid maize seeds (=1)	Intercropped legume seeds (kg/ha)	Intensification index
Explanatory variables	(1)	(2)	(3)	(4)	(5)
Log of owned land size per working age member (ha)	-0.000172	-0.484***	0.00197	-0.0614	-0.0597**
	(0.0911)	(0.145)	(0.0118)	(0.0789)	(0.0282)
Log of time to the nearest market by car (min)	-0.333	-0.00773	-0.0808*	0.134	-0.113
	(0.280)	(0.520)	(0.0474)	(0.253)	(0.0988)
Coefficient of variation of rainfall	0.301	3.057	-0.0818	2.063*	0.573
	(1.359)	(2.349)	(0.175)	(1.056)	(0.420)
Female headed (=1)	-0.121	-0.913	0.0480	0.0154	-0.0498
	(0.258)	(0.655)	(0.0588)	(0.285)	(0.129)
Log of head's age	-0.0330	-0.259	-0.212***	0.654	-0.196
	(0.469)	(1.140)	(0.0753)	(0.493)	(0.216)
Head completed primary education (=1)	0.197	0.900	-0.0266	-0.0643	0.0747
	(0.356)	(0.604)	(0.0494)	(0.243)	(0.114)
Log of value of assets (KSh)	0.00688	0.359	0.0278	-0.0774	0.0628
	(0.135)	(0.256)	(0.0195)	(0.111)	(0.0459)
Log of carbon	-0.245	0.430	-0.0224	0.489	0.0694
	(0.466)	(0.697)	(0.0768)	(0.402)	(0.159)
Constant	1.809	-0.209	1.311***	-1.439	-0.256
	(2.622)	(4.985)	(0.413)	(2.298)	(1.043)
Observations	1,750	1,750	1,750	1,750	1,750
R-squared	0.033	0.073	0.236	0.040	0.136
Number of households	663	663	663	663	663

The numbers in parentheses are robust standard errors

***, **, and * indicate significance at 1, 5, and 10%, respectively

[a] Interaction terms between year 2012 and provinces, and between year 2012, provinces, and no carbon information dummies are included in all regressions

[b] Quantity of chemical fertilizer is measured in NPK equivalence

Table 7.8 Estimation results of the effects of input intensification on crop production in the main crop season in Kenya (household fixed-effect model, plot level data)[a]

	Log of maize yield (kg/ha)	Log of value of harvest from all crops (KSh/ha)	Log of crop income[c] (KSh/ha)
Explanatory variables	(1)	(2)	(3)
Hybrid maize seeds (=1)	0.247***	0.130*	0.0330
	(0.0703)	(0.0732)	(0.0900)
Intercrop with legumes (=1)	-0.107*	0.179***	0.0435
	(0.0590)	(0.0667)	(0.0832)
Organic fertilizer (t/ha)	0.0413***	0.0421***	0.0478***
	(0.00967)	(0.0102)	(0.0120)
Chemical fertilizer (10kg/ha) [b]	0.0331***	0.0295***	0.0128*
	(0.00490)	(0.00537)	(0.00673)
Log of owned land size per working age member (ha)	0.0236	0.0244	0.0208
	(0.0269)	(0.0277)	(0.0357)
Log of time to the nearest market by car (min)	0.177*	0.0607	0.0465
	(0.0993)	(0.0980)	(0.123)
Coefficient of variation of rainfall	-0.318	-0.418	-0.173
	(0.367)	(0.382)	(0.450)
Female headed (=1)	-0.0235	-0.0919	-0.119
	(0.114)	(0.122)	(0.138)
Log of head's age	0.00164	-0.00342	-0.00667
	(0.00374)	(0.00379)	(0.00479)
Head completed primary education (=1)	0.0301	-0.0183	0.0972
	(0.104)	(0.108)	(0.119)
Log of value of assets (KSh)	-0.0107	-0.0176	-0.0290
	(0.0467)	(0.0466)	(0.0535)
Log of carbon	0.00332	-0.0430	0.149
	(0.184)	(0.163)	(0.182)
Constant	6.432***	10.45***	10.41***
	(0.606)	(0.597)	(0.713)
Observations	1,750	1,750	1,750
R-squared	0.206	0.151	0.598
Number of households	663	663	663

The numbers in parentheses are robust standard errors

***, **, and * indicate significance at 1, 5, and 10%, respectively

[a] Interaction terms between year 2012 and provinces, and between year 2012, provinces, and no carbon information dummies are included in all regressions

[b] Quantity of chemical fertilizer is measured in NPK equivalence

[c] Crop income is defines as the value of harvest minus the paid costs of chemical and organic fertilizer, other chemical inputs, seed, and hired labor

Table 7.9 Estimation results of the effects of the intensification index on crop production in the main crop season in Kenya (household fixed-effect model, plot level data)[a]

Explanatory variables	Log of maize yield (kg/ha) (1)	Log of value of harvest from all crops (KSh/ha) (2)	Log of crop income[b] (KSh/ha) (3)
Intensification index	0.266***	0.254***	0.175***
	(0.0273)	(0.0273)	(0.0352)
Log of owned land size per working age member (ha)	0.0173	0.0314	0.0244
	(0.0271)	(0.0271)	(0.0358)
Log of time to the nearest market by car (min)	0.162	0.0620	0.0397
	(0.0993)	(0.0969)	(0.120)
Coefficient of variation of rainfall	-0.480	-0.488	-0.291
	(0.365)	(0.382)	(0.449)
Female headed (=1)	-0.0484	-0.0779	-0.119
	(0.114)	(0.124)	(0.143)
Log of head's age	0.000692	-0.00348	-0.00689
	(0.00372)	(0.00369)	(0.00468)
Head completed primary education (=1)	0.0309	-0.0127	0.0943
	(0.105)	(0.109)	(0.120)
Log of value of assets (KSh)	-0.0134	-0.0207	-0.0379
	(0.0465)	(0.0469)	(0.0537)
Log of carbon	0.0186	-0.0383	0.164
	(0.184)	(0.163)	(0.182)
Constant	6.945***	10.99***	10.81***
	(0.604)	(0.598)	(0.713)
Observations	1,750	1,750	1,750
R-squared	0.210	0.153	0.597
Number of households	663	663	663

The numbers in parentheses are robust standard errors

***, **, and * indicate significance at 1, 5, and 10%, respectively

[a] Interaction terms between year 2012 and provinces, and between year 2012, provinces, and no carbon information dummies are included in all regressions

[b] Crop income is defines as the value of harvest minus the paid costs of chemical and organic fertilizer, other chemical inputs, seed, and hired labor. A negative income dummy is included in (3)

Table 7.10 Estimation results of the effects of the intensification index on agriculture production in the main season in Kenya (location fixed-effect model, HH level data)[a]

	Log of value from all crops & milk (KSh/ha)	Log of crop & milk income[b] (KSh/ha)
Explanatory variables	(1)	(2)
Intensification index	0.197***	0.129***
	(0.0314)	(0.0426)
Log of owned land size per working age member (ha)	-0.0979**	-0.108**
	(0.0436)	(0.0522)
Log of time to the nearest market by car (min)	0.0622	-0.0508
	(0.100)	(0.138)
Coefficient of variation of rainfall	-0.331	-0.143
	(0.356)	(0.490)
Female headed (=1)	-0.124	-0.244
	(0.112)	(0.166)
Log of head's age	-0.00306	-0.00637
	(0.00378)	(0.00537)
Head completed primary education (=1)	-0.0281	-0.0146
	(0.102)	(0.150)
Log of value of assets (KSh)	0.0298	0.0262
	(0.0493)	(0.0658)
Log of carbon	0.126	0.0928
	(0.158)	(0.215)
Constant	10.77***	10.67***
	(0.617)	(0.780)
Observations	1,326	1,326
R-squared	0.123	0.839
Number of households	663	663

The numbers in parentheses are robust standard errors

***, **, and * indicate significance at 1, 5, and 10%, respectively

[a]Interaction terms between year 2012 and provinces, and between year 2012, provinces, and no carbon information dummies are included in all regressions, and a negative income dummy is included in (2)

[b] Income form crop and milk defined as the revenue from the crop harvest and milk production minus the paid costs of chemical, organic fertilizer, other chemical inputs, seed, hired labor, livestock services & feeds

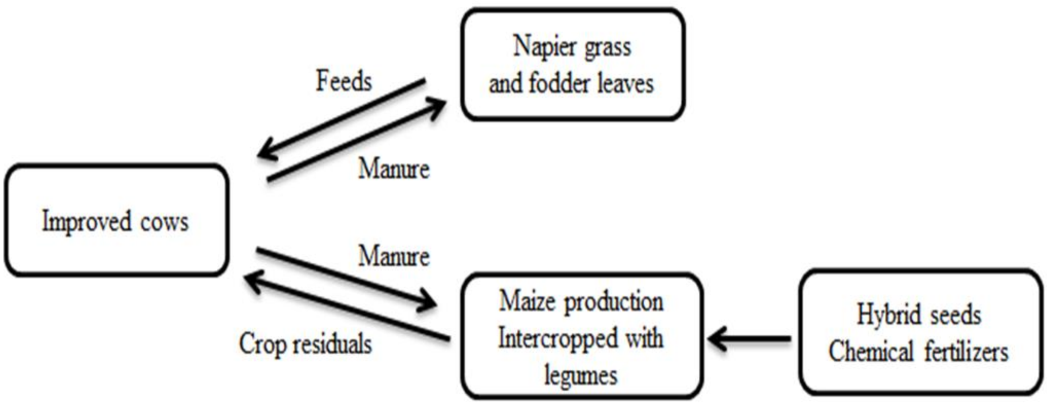

Fig. 7.1 Organic green revolution in East Africa (Source: Revised figure 4 from Otsuka and Yamano 2005)

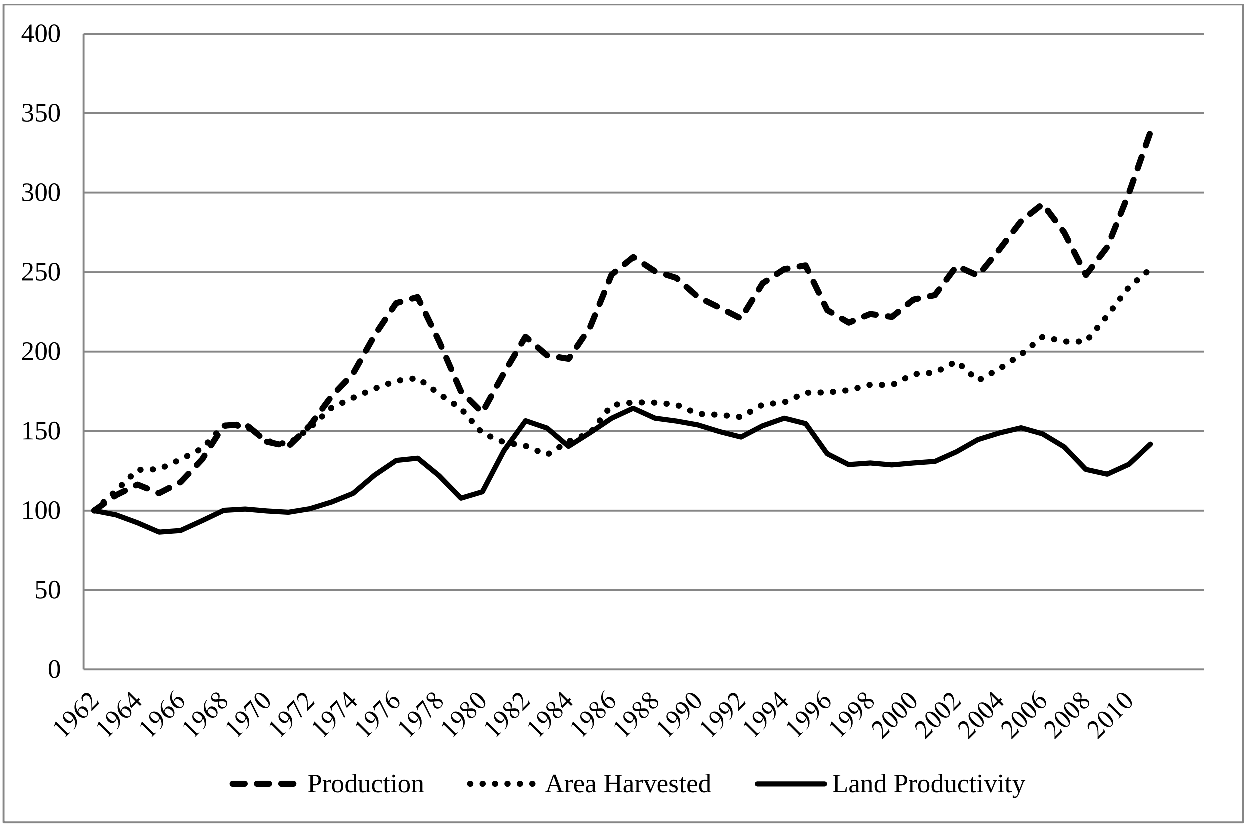

Fig. 7.2 Maize production in Kenya, index (1962= 100) (Source: FAOSTAT Online Database)

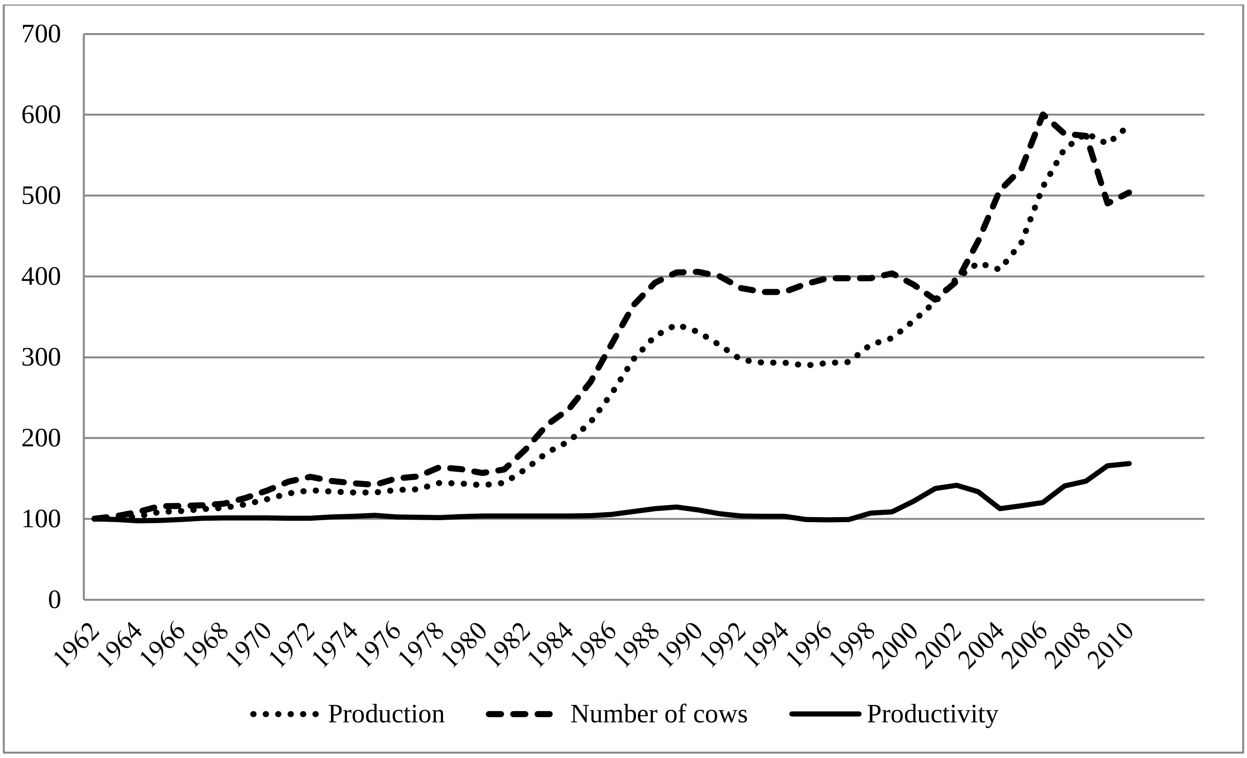

Fig. 7.3 Milk production in Kenya, index (1962= 100) (Source: FAOSTAT Online Database)