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The Possibility of a Green Revolution in Sub-Saharan Africa: Evidence from Kenya

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Abstract

It is widely believed that a Green Revolution similar to the one achieved in Asia is impossible in Sub-Saharan Africa. Although grain yields have been stagnant in this region, there are some signs of the intensification of farming systems in the face of growing population pressure on limited land resources. In this paper we focus on the new farming system based on the use of manure produced by dairy cows, which may be termed an "Organic Green Revolution." Using the farm household data collected from Kenya, this paper demonstrates that the Organic Green Revolution has a potential of doubling maize yields in highlands of Kenya.

Keywords: *Green Revolution, Agricultural Revolution, Organic Green Revolution, dairy cows, manure, chemical fertilizer, maize yield*

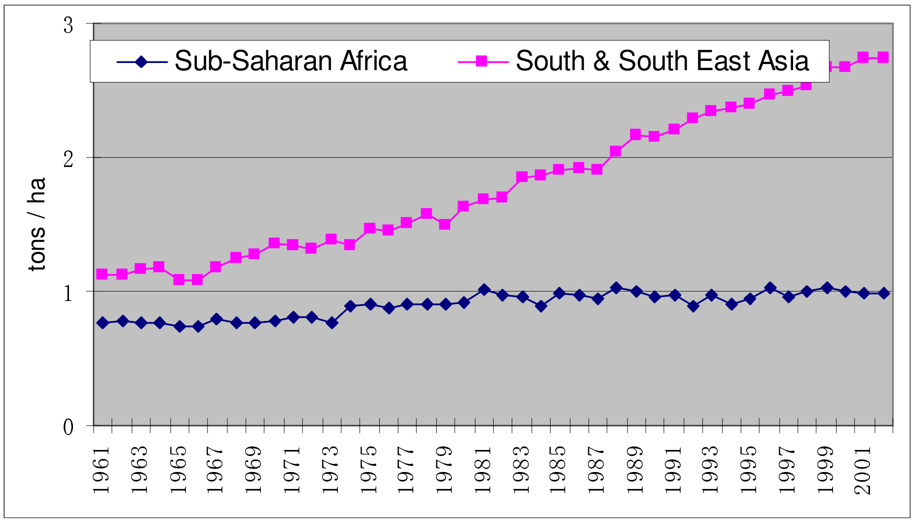
1. Introduction

There is a widely held assumption among many specialists in African agriculture that a Green Revolution – similar to the one achieved in Asia in the 1960s and 1970s - is an impossible dream and, hence, such production improvements are far beyond the reach of poor farmers in Sub-Saharan Africa. While clearly there has been little previous success in sparking a Green Revolution in this beleaguered region, does this mean that it is really an impossible dream for Sub-Saharan Africa?

Given its rapidly growing population and the increasingly limited availability of uncultivated land in many areas, the people of Sub-Saharan Africa may face more famines unless dramatic improvements in crop yields are achieved.[1]

Alarmingly, cereal production per hectare has been largely stagnant in Sub-Saharan Africa, in contrast to Asia where the Green Revolution has significantly contributed to the improvement of the cereal crop yields for the last several decades (see Figure 1).

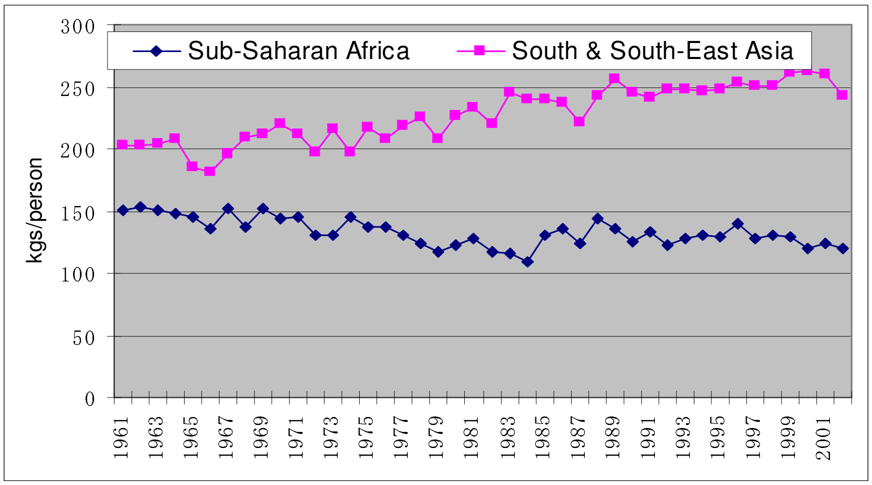
Figure 1. Changes in Cereal Yield (ton per ha) in Sub-Saharan Africa and South/South-East Asia



As result, food production per capita is already declining in the region, in distinct contrast to Asia where the Green Revolution has significantly contributed to the improvement of the food-population balance for the last several decades (Figure 2).[2]

[1] Food aid can mitigate food shortages, at least in the short run.
[2] Note that larger quantity of root crops is produced and consumed in Sub-Saharan Africa than in Asia.

Figure 2. Cereal Production per person (Total Population) in Sub-Saharan Africa and South/South-East Asia



There are, however, some signs of the intensification of farming systems in the Sub-Saharan region, which are often being led by farmers' initiatives (Gabre-Madhin and Haggblade, 2004). In this paper, we focus on one farming system that can potentially transform the agricultural system in some parts of Africa into an intensified farming system. This new farming system, which may be dubbed an "Organic Green Revolution (OGR)," is based on the use of manure produced by improved dairy cows (i.e., cross breeds of European and local cattle). A typical farmer who employs this farming system cultivates Napier grass (a popular feed crop) on the farm, feed Napier grass to improved cattle in stalls, obtain manure from the stalls, and apply the manure or compost on crops (such as maize or banana). Farmers spend cash income from milk and crops to maintain and intensify the farming system. The OGR combines the most desirable yield-enhancing features of the Agricultural Revolution in the 18th century England and the Green Revolution in tropical areas of Asia realized since the late 1960s, the two precedent revolutions in the world agricultural history. The OGR is suitable in many parts of Sub-Saharan Africa because it does not rely on irrigation systems and chemical fertilizer, which is more expensive in Africa and risky without irrigations systems.

In order to examine the OGR technology, we use the data from Kenya. The data were collected by the Foundation for Advanced Studies on International Development (FASID) in collaboration with the World Agroforestry Centre, the International Livestock Research Institute (ILRI), and the Tegemeo Instutute. The data cover more than 90 communities and about 900 households. The data contain detailed farm production information including detailed dairy production systems and organic fertilizer application in 2004.

The outline of the paper is as follows: Section 2 draws lessons from two agricultural revolutions. Section 3 introduces a new farming system that is becoming popular in highlands in Kenya. Section 4 describes the data used in the paper and reports the estimation results of manure application, chemical fertilizer application, high-yielding (HYV) maize adoption, and maize yield functions.[3] The conclusions are discussed in Section 5.

2. Lessons from previous Agricultural Revolutions

Agricultural Revolution in the 18th century England

Livestock grazing requires large areas of land and, hence, is most appropriate in areas where land is abundant (Hayami and Ruttan 1985). However, manure produced by cattle cannot be fully collected and utilized as fertilizer for any crops, unless they are stall-fed. Because feed crops must be cultivated on fields and fed to cows in stalls, stall-feeding is labor intensive. In addition, the application of manure on crop fields requires extra labor. Thus, a farming system based on feed production, the stall-feeding of cattle, and the application of manure is a highly labor-intensive and land-saving system.

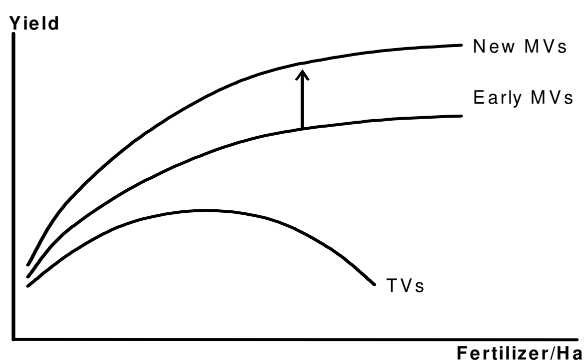
The Agricultural Revolution in the 18th century England was realized precisely because of the introduction of the turnip as a feed crop together with the stall-feeding of cattle (e.g., Timmer 1969). This new farming system - called the Norfolk crop rotation - replaced the open-three-field system that was dependent on the grazing of cattle in open fields, and contributed to the large application of manure and, consequently, high crop yields. The main lesson that Sub-Saharan Africa can learn from the English Agricultural Revolution is that the stall-feeding of cattle fed by cultivated feeds is an effective way to enhance soil nutrients of crop fields.

The Green Revolution in Asia

The high price of chemical fertilizer is the main barrier holding back a Green Revolution in Africa. FASID's research found chemical fertilizer prices in Sub-Saharan Africa to be generally two to three times higher than in Asia, due mainly to high transport costs. Hence, unlike Asian farmers who rely heavily on chemical fertilizer, African farmers seldom apply it, unless it is subsidized, as is the case in Ethiopia.[4]

This is despite the fact that it is essential to apply more soil nutrients if we want to increase crop yield per unit of cultivated land. The increased application of fertilizer alone, however, is not sufficient: Traditional crop varieties (TVs) are usually tall and thin and when a large amount of fertilizer is applied, they tend to lodge. Thus, they are low-yielding and their yield curves can be described by the inverted U-shaped curve shown in Figure 3.

Figure 3. Yield Curves of Traditional Varieties (TVs) and Modern Varieties (MVs)



[3] HYV maize varieties refer primarily to newly purchased hybrid varieties.
[4] In highlands of Kenya, where land is particularly scarce, chemical fertilizers are widely applied, as will be shown later in this study.

In the rice Green Revolution in Asia, modern varieties (MVs) with short, strong, and stiff stalks were developed so they would not easily lodge and would be more yield responsive to increased fertilizer application. The first rice MV (IR8) was developed by the Philippines-based International Rice Research Institute (IRRI) by crossing a semi-dwarf, high-yielding variety from Taiwan (Dee-gec-woo-gan) and a local Indonesia variety (Peta). It was released in 1966, with the latter being used for environmental adaptation (Baker and Herdt 1985). Again, it is important to emphasize that the yield potential of MVs can be fully realized only when a large amount of fertilizer is used.

In the case of rice MVs, the new varieties that were developed to be suitable to local conditions further shifted the yield curve upward (David and Otsuka 1994). As a result of the Green Revolution in rice farming in Asia, rice yields doubled, rice production tripled, and real rice prices have declined to one-third of their level in the late 1960s (Pingali, Hossain, and Gerpacio 1997).[5] The Green Revolution in wheat in Asia is a similar success story, with a Japanese variety developed before the war being used to introduce high-yielding, semi-dwarf genes to MVs (Dalrymple 1978).

The most important lessons for Sub-Saharan Africa to learn from Asia's Green Revolution is that the increased application of fertilizer and the development and wide adoption of improved varieties are essential strategies for increasing crop yields. However, because chemical fertilizer prices are prohibitively high in Sub-Saharan Africa, there is obviously a need for a slightly different approach in relation to fertilizers.

Since limited irrigation is another major constraint in Sub-Saharan Africa, it is, in general, appropriate to choose crops that do not need as much water as rice. Such crops include maize, sorghum, and millet.[6] As far as maize is concerned, improved varieties that are mildly fertilizer-responsive have been developed by national agricultural research institutions and private seed companies, and are available in many African countries, including Sub-Saharan nations.

3. The Organic Green Revolution in East Africa

Like the Agricultural Revolution in the 18th century England, the OGR in East Africa, e.g., Kenya, Uganda, and Ethiopia, will depend on the stall-feeding of cattle using cultivated feed (e.g., Napier grass and oats, as shown in Figure 4). However, unlike the Asian Green Revolution, the OGR must rely on organic fertilizer, i.e., manure and compost produced by stall-fed cattle (McIntire et al., 1992).[7] The cattle involved are the cross-bred cattle between highly productive European cows and disease- and pest-resistant local cows, which – in some ways - is reminiscent of the cross between the Taiwanese and Indonesian rice varieties that helped spark the Green Revolution.[8] As with the Asian Green Revolution, African farmers must use improved crop varieties, which are more responsive to fertilizer than TVs. We suspect, however, that these varieties are not as high-yielding as the MVs developed for Asia, because there has been comparatively little adaptive breeding research undertaken by international agricultural research organizations for the agro-ecological conditions of Sub-Saharan Africa (Evenson and Gollin 2003).

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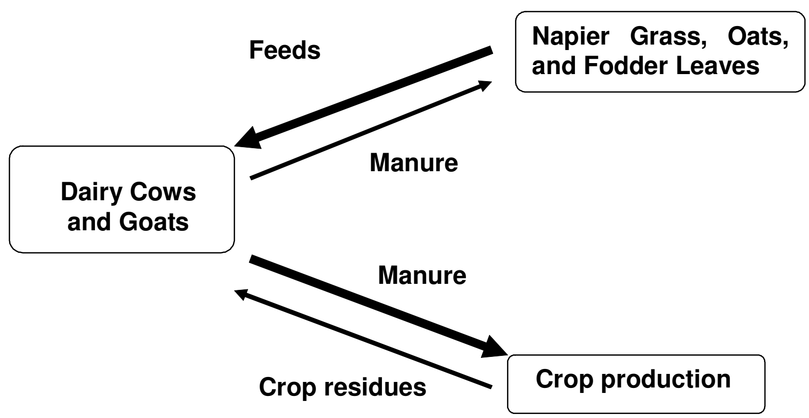
[5] Rice production increased faster than rice yield because of the increased cropping intensity of rice made possible by the early maturity and non-photoperiod sensitive natures of MVs.

[6] This does not deny, however, the increasing importance of rice production in lowland areas of Sub-Saharan Africa.

[7] For simplicity, henceforth we will not distinguish between manure and compost. Also note that organic fertilizers refer to both manure and compost, as well as nutrients from agroforestry trees which have capacity to fix nitrogen.

[8] Because of the prevalence of a chronic disease, trypanosomaiasis, it is economical to keep dairy goats in some areas.

Figure 4. "Organic Green Revolution" in East Africa



Note that stall-feeding of cattle with cultivated feeds does not enhance the total amount of soil nutrients in the entire farming system. In fact, the total amount of nutrients will likely decline because of the export of nutrients from the plant-soil-animal system through harvested products and milk. Such a system, however, enhances the internal cycling of nutrients and the ability to extract and relocate soil nutrients to crop fields (Buresh 1999). The long-term sustainability of such a system will depend on the inherent amount of soil nutrients available to be extracted, i.e., native soil fertility, and the rate at which nutrients are replenished by exogenous sources, such as nitrogen fixed by agroforestry trees and legume crops.

In short, the OGR seeks the best possible combination of the most desirable yield-enhancing features of the world's two, already recognized successful revolutions in agriculture. Additionally, the use of manure is particularly appropriate for the fragile soils found in Sub-Saharan Africa, which have been depleted in the past by their intensive use without the adequate replenishment of nutrients.

4. Data and Results

4.1 Data and Descriptive Analysis

In order to assess the impacts of the OGR technology, we use our own survey data collected from Kenya in 2004. The surveys covered 90 sub-locations and 894 households in central and western parts of Kenya, where dairy production is active. In Table 1, we present livestock production systems by region. It is clear that the improved dairy production system is widely adopted in Kenya: about 56 percent of sampled households have at least one improved cattle, whereas bout 47 percent of the households keep at least one cattle in semi- or zero-grazing feeding system.[9] Somewhat unexpectedly, not only organic fertilizers but also are also widely applied: About 80 percent and 75 percent of households apply chemical and organic fertilizers, respectively. Such widespread use of both organic and chemical fertilizers would reflect the growing scarcity of land, which stimulates the increased intensification of land use by means of fertilizer application.

[9] Note that semi-grazing refers to the mixed grazing and stall-feeding system.

Table 1. REPEAT Sample Households in Kenya

Province	Sample households	Livestock Production System		Fertilizer Application	
		Improved Cattle	Semi- or Zero-grazing	Chemical fertilizer	Animal Manure
		- % -	- % -	- % -	- % -
Nyanza	175	37.7	31.0	71.4	70.3
Western	112	33.0	21.4	83.0	69.6
Rift Valley	226	64.2	26.1	82.0	67.6
Central	310	75.8	55.5	88.4	84.8
Eastern	71	28.1	46.5	57.7	81.7
Total	**894**	**56.3**	**47.2**	**80.3**	**75.5**

Does the intensified dairy-crop production system really increase organic fertilizer application as the conceptual framework of the OGR technology suggests? To answer this question, we stratify the sample households by type of cattle (Table 2). Among households in Kenya that have at least one improved cattle, about 86 percent apply manure on crops, while about 63 percent of households that do not have improved cattle apply manure on crops. In terms of quantity of manure application, households with improved cattle apply far greater amount of organic fertilizer than households without them. More specifically, the households with improved cattle applied 2,105 kilograms of organic fertilizer per hectare of crop fields, while the households without them apply only 542 kilograms per hectare. The difference, 1,563 kilograms, is statistically significant. The difference remains large when we compare the quantity of organic fertilizer application per cattle between households with and without improved cattle. Such difference reflects the difference in manure production per cattle between improved and local cows. We find a similar pattern when we stratify households by the type of feeding systems. Zero-grazing households apply significantly more manure on crop fields than grazing households.

Table 2. Livestock Production System and Manure Use on Crops in Kenya

Livestock Production System	Number of households	Percentage of households using manure	Quantity of Manure applied on farm	
			Per Hectare	Per Cattle
	- no. (%) -	- % -	kg/ha	kg/cattle
Local Cattle Only	391 (44)	62.7	542	220
Improved Cattle	503 (56)	86.1	2,105	744
Difference		23.4**	1,563**	524**
Grazing	333 (37)	61.4	617	512
Semi-grazing	219 (25)	74.4	1,512	402
Zero-Grazing	342 (38)	89.8	2,185	782

One may wonder on which crops is organic fertilizer applied? In Kenya, about half of the total quantity is applied on maize, about 19 percent on Napier grass, 12 percent on coffee, and 6 percent on bananas. Thus, households apply organic fertilizer primarily on maize fields. Since maize is the most important staple crop in Kenya, it is obviously worth investigating the impacts of organic fertilizer use on maize yield.

In Table 3, we present maize yield (kilograms per hectare) by the seed type. As expected, maize HYVs have higher yield than local varieties: the average yield is 2,129 kg/ha for HYVs and 1,412 kg/ha for local varieties. Organic fertilizer is applied on about 38 percent of maize plots and the average application amounts to 1,264 kg/ha. If we consider only maize plots with positive amount of organic fertilizer application, we find that the average application is as much as 3,362 kg/ha. It is also found that more organic fertilizer is applied on local varieties than HYVs: it is applied on 41 percent of local maize plots and 35 percent of HYV maize plots. In terms of quantity, the average amount of organic fertilizer application is about 1,381 kg/ha on local maize plots, while it is 1,171 kg/ha on HYV maize plots. On the other hand, chemical fertilizer is applied in 72 percent of maize plots and the average amount of chemical fertilizer applied is 102 kg/ha. As may be expected, larger amount of chemical fertilizer is applied on maize fields planted to HYVs, because they are highly responsive to chemical fertilizer application.

Table 3. Maize Yield and Fertilizer Application by Seed Type in Kenya

	Number of Maize Plots	Yield	Organic Fertilizer		Chemical Fertilizer	
			% of plots applied	Quantity applied	% of plots applied	Quantity applied
	Number	Kg/ha	Percent	Kg/ha	Percent	Kg/ha
Local Seeds	490	1,412	41.4	1,381	58.8	64
		(1,834)	(49.3)	(2,722)	(49.3)	(101)
HYV Seeds	618	2,129	34.6	1,171	82.7	132
		(2,124)	(47.6)	(2,595)	(37.9)	(144)
All	1,108	1,812	37.6	1,264	72.1	102
		(2,032)	(48.5)	(2,653)	(44.9)	(131)

Note: Numbers in parentheses are standard deviations. The amount of chemical fertilizer is measured in terms of the quantity of nutrients, i.e., the sum of N, P, and K.

4.2. Regression Results

Input Application on Maize Plots

First, we estimate three input applications models on manure, chemical fertilizer, and HYV seed uses. The dependent variables are the quantity of manure applied on maize plots in kg/ha, the quantity of chemical fertilizer applied on maze plots in kg/ha, and the HYV adoption rate measured by the proportion of HYV maize seeds. Because the first two dependent variables are censored at the lower bound and the last dependent variable is censored at both lower and upper bounds, we use Tobit models to estimate these models. The results are presented in Table 4.

Table 4. Input Applications on Maize Plots (Tobit)

	Manure 1,000 kg/ha	Chemical Fertilizer 1,000 kg/ha	Proportion of HYV seeds
	(A)	(B)	(C)
Instrumental Variables			
Number of Improved cattle per ha	0.338	0.008	0.006
	(5.96)**	(3.84)**	(1.01)
Number of local cattle per ha	0.223	-0.005	-0.044
	(2.98)**	(1.68)*	(4.91)**
DAP Price	0.004	-0.003	0.003
	(0.08)	(1.89)*	(0.61)
Transportation Cost of Fertilizer (Kshs/kg)	0.632	-0.037	0.051
	(1.82)*	(2.86)**	(1.45)
Dairy Association Available (=1)	0.709	0.001	0.096
	(2.26)**	(0.10)	(3.04)**
Farmer Group Available (=1)	0.108	0.051	0.039
	(0.20)	(2.63)**	(0.71)
Plot Characteristics			
Intercropped with Beans	1.035	0.044	0.065
	(2.67)**	(3.38)**	(1.74)*
Intercropped with non-bean crops	0.304	0.006	-0.030
	(0.58)	(0.31)	(0.58)
Fallowed in a season before	-1.673	-0.007	-0.061
	(2.40)**	(0.29)	(0.90)
Own title (=1)	0.614	0.045	0.020
	(1.60)	(3.31)**	(0.53)
Rent-in Land	-2.955	0.057	0.061
	(4.22)**	(2.93)**	(1.08)
Steep (=1)	-0.349	-0.006	-0.026
	(1.02)	(0.55)	(0.78)
Farm Size in ha	-0.055	-0.001	0.009
	(1.20)	(0.28)	(2.14)**
Farm Size Squared	0.001	-0.000	-0.000
	(0.65)	(0.94)	(0.55)
Damaged: Rainfall Shortage	0.641	-0.022	-0.069
	(1.80)*	(1.74)*	(1.90)*
Damaged: Other idiosyncratic Damages	0.578	0.026	-0.056
	(1.67)*	(2.20)**	(1.66)*
Household Characteristics			
Female Headed	-0.446	-0.004	-0.039
	(1.30)	(0.34)	(1.12)
Education Men	0.002	0.003	-0.001
	(0.04)	(1.78)*	(0.19)
Education Women	0.019	0.003	0.010
	(0.42)	(2.00)**	(2.18)**
Number of Men in the HH	0.085	0.007	0.004
	(0.65)	(1.58)	(0.33)
Number of Women in the HH	0.209	0.004	0.001
	(1.60)	(0.92)	(0.07)
Community Level			
Input Credit Available (=1)	0.518	0.063	0.189
	(1.63)	(5.75)**	(5.93)**
Constant	-5.987	-0.052	-0.165
	(3.75)**	(0.94)	(1.05)
Observations	1,088	1,088	1,088

Numbers in parentheses are t-ratios. ** indicates significance at 5% level; * at 5 %level.

We find that the number of improved cattle is a significant factor positively affecting the manure application. The estimated coefficient indicates that one additional improved cattle per hectare increases the manure application by 140 kg/ha, which is about a 11 percent increase in the manure application. Although the number of local cattle also increases the manure application, its impact is smaller than that of improved cattle. The availability of marketing services by dairy association in the community increases the manure application, because the association promotes milk marketing, thereby stimulating the careful management of milk cows. These findings support our earlier argument that the farming system is intensified via the use of manure among dairy farmers.

The estimation results on manure application also suggest that the manure application is a part of the strategy to manage soil fertility. For instance, less manure is applied on maize plots that were fallowed in the previous crop season, presumably because fallowed plots are more fertile. Also more manure is applied on maize plots intercropped with beans, which are grown to restore soil fertility. These findings indicate that manure application and fallowing are substitute, whereas manure application and the intercropping of maize are complement. It may be interesting to note that less manure is applied on rented-in plots. In Kenya, tenants rent-in land only for a short period, i.e., about 4 years on average in contrast to about 24 years of cultivation of owned land. Thus, it is likely that tenant farmers apply less manure, which is expected to nourish land for at least a few years. In contrast, more manure is applied on maize plots that suffered from shortage of rainfall. It appears that farmers have tried to compensate for the lack of moisture by the application of manure, which helps preserve soil moisture.[10]

It is important to note that the number of improved cattle is positively associated with chemical fertilizer application, suggesting that manure and chemical fertilizer applications are used together to intensify the farming system. The estimated coefficient indicates that one percent increase in the number of improved cattle leads to a 5 percent increase in the chemical fertilizer application. In contrast, the number of local cattle has negative effects not only on the chemical fertilizer use but also on the HYV seed adoption, suggesting that households with more local cattle are engaged in less intensive farming practices. Both the DAP price and the transportation costs of chemical fertilizer have negative impacts on the chemical fertilizer application, as expected. Other results on chemical fertilizer application and HYV seed adoption are consistent with our prior expectations.

Maize Yield Models

Next, we estimate the maize yield models with two-stage least squares methods, treating the three input variables as endogenous (Table 5). The six instrumental variables are identified in Table 4. We estimate two models with and without the ratio of HYV maize seeds, because we find it difficult to identify separate effects of HYV maize and chemical fertilizer application in view of the close association between the two. We assume that when the ratio of HYV maize seeds is excluded, the estimated coefficients of manure and chemical fertilizer applications would reflect the yield effects of maize seeds.

[10] Although it is found that more manure is also applied on maize plots, which suffer from other crop damages, the reasons are not clear as there are a large number of causes for crop damages.

Table 5. Maize Yield: *ln*(Maize Output in kgs/ha)

	2SLS (A)	2SLS (B)
Manure Application (1,000 kgs/ha) [A]	0.169	0.169
	(2.08)**	(2.09)**
Chemical Fertilizer (1,000 kgs/ha) [A]	3.342	3.222
	(1.73)*	(1.60)
Ratio of HYV Maize Seeds [A]		0.150
		(0.20)
Plot Characteristics		
Intercropped with Beans	-0.342	-0.344
	(2.99)**	(3.01)**
Intercropped with non-bean crops	-0.067	-0.065
	(0.49)	(0.48)
Fallowed in a season before	0.485	0.490
	(2.56)**	(2.57)**
Own title (=1)	0.011	0.012
	(0.10)	(0.11)
Rent-in Land	0.011	0.008
	(0.07)	(0.05)
Steep (=1)	-0.034	-0.034
	(0.36)	(0.36)
Farm Size in ha	-0.025	-0.026
	(2.01)**	(1.85)*
Farm Size Squared	0.000	0.000
	(1.71)*	(1.73)*
Damaged: Rainfall Shortage	-0.572	-0.565
	(5.41)**	(5.10)**
Damaged: Other idiosyncratic Damages	-0.260	-0.251
	(2.66)**	(2.32)*
Household Characteristics		
Female Headed	-0.090	-0.088
	(0.95)	(0.93)
Education Men	-0.023	-0.023
	(2.04)**	(2.05)**
Education Women	0.017	0.016
	(1.26)	(1.14)
Number of Men in the HH	0.027	0.028
	(0.74)	(0.76)
Number of Women in the HH	-0.033	-0.031
	(0.91)	(0.86)
Community Level		
Input Credit Available (=1)	-0.278	-0.293
	(2.33)**	(2.12)**
Constant	7.056	7.028
	(33.9)**	(28.4)**
Observations	1088	1088
R-squared	0.21	0.22

Note: [A] Endogenous variables. Instrumental variables are identified in Table 4.
Numbers in parentheses are t-ratios. ** indicates significance at 5% level; * at 10 %level.

According to the results reported in Table 5, the manure application has a strong impact on maize yield. For instance, if the manure application increases from zero to the average application level, i.e., 1,264 kg/ha, then the maize yield increases by 24 percent. The chemical fertilizer application also has a positive impact of maize yield: the maize yield increases by 34 percent when the chemical fertilizer use increased from zero to the average application of 102 kg/ha. Thus, if both manure and chemical fertilizer are applied at their average amounts, the maize yield increases by 55 percent. These results are robust to the inclusion of the HYV variable.

Note that these results tend to understate the impact of manure and chemical fertilizer application on maize yields. First, since the manure application has impacts on yields for more than a few seasons, its total impact is underestimated in the calculation above, which considers only the yield effect within a season. Second, if we compare zero users of both types of fertilizers with full users, the estimated increase in yield would be close to 100 percent.

he maize yield increases by 49 percent if maize is planed to fallowed plots. The size of this impact is comparable to the impacts of average manure and chemical fertilizer applications combined, which suggests the importance of fallowing in restoring soil fertility. However, it is becoming more difficult to fallow land in Kenya because of the increasing population pressure on limited cultivated areas. Indeed, our data show that only six percent of all plots were fallowed in the previous season. Thus, the fertilizer applications have to increase to maintain or improve soil fertility. Finally, it may be noted that the farm size is negatively associated with maize yield, suggesting inefficiency in land market, which prevents transfer of land from large farmers, who are less efficient, to small farmers, who are more efficient.

5. Conclusion

It is important to emphasize that substantial yield gains have already been achieved via the use of cow manure, as well as chemical fertilizer in the East African highlands and *without* strong support from research institutions, governments, and international organizations. Therefore, it appears likely that far greater increases in crop production can be achieved, if appropriate support is provided to research programs for the technological improvements of the new farming system based on crop-livestock-feed interactions, as well as to extension programs.

In Asia, the Green Revolution was technology-driven, where MVs developed by IRRI and the Mexico-based International Maize and Wheat Improvement Center (CIMMYT) led to subsequent changes in the research, extension, marketing, and irrigation policies of the government and international donor communities to facilitate and strengthen the overall impact (Hayami and Kikuchi 1982). In other words, the development and use of MVs was a real breakthrough, which, in turn, induced a series of institutional innovations conducive to the realization of the Green Revolution. This suggests that there is a large role to be played by crop-breeding research to develop higher-yielding varieties appropriate for Sub-Saharan Africa. Also needed is farming systems research to identify the optimum mix of crop varieties, feed production, and dairy cows.

As was mentioned earlier, dairy cows are expensive.[11] In order to disseminate the OGR technology, it will also be essential to initiate appropriate credit programs to promote the adoption of dairy cows. Equally as important is the need to improve the efficiency of fresh milk marketing, because the profitability of the entire new farming system proposed depends not only on the profitability of crop production, but also - critically - on that of milk production. Presumably more important is the provision of veterinary services, as dairy cows are not resistant to diseases as much as local cows. In other words, policy support for the OGR is needed in areas where credit, milk, and veterinary service markets fail.

It is now clear that, having realized the potential of the OGR, we can no longer justify the prevailing assumption that a Green Revolution is impossible in East Africa. Further, the potential of the OGR leading to a “White Revolution” in milk production just like the one experienced in the Gujarat State of India should not be underestimated in East Africa.

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[11] We found that dairy cows have been used widely for manuring of upland crop fields in Southern India, where the price of a cress-bred heifer is much cheaper than in East Africa.

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