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An Empirical Analysis of Expanding Rice Production in Sub-Sahara Africa

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To What Extent Does the Adoption of Modern Variety Increase Productivity and Income?

A Case Study of the Rice Sector in Tanzania

Yuko Nakano* and Kei Kajisa†

Abstract

Although high-yielding modern rice varieties (MVs) have been gradually disseminating over Sub-Saharan Africa, little is known about how their adoption influences agriculture productivity and household income. To fill this research gap, we analyzed two kinds of data sets in Tanzania: a national representative cross-sectional data and a two-year panel data of irrigated farmers in one district. The most important finding is a strong complementary relationship between MVs and water control; high yield is achieved when MVs are grown with improved bunds in paddy fields of irrigated areas. We also find that the use of chemical fertilizer and the practice of transplanting in rows increase yield and income of both the adopters and nonadopters of MVs in the irrigated areas. In rain-fed areas, we observe a limited impact of MVs. These findings suggest that introducing MVs as a package of technologies with agronomic practices is effective to fully achieve their potential. In the long run, development of irrigation would be important to realize a rice Green Revolution in Sub-Saharan Africa.

Keywords: Modern Variety, Technology Adoption, Green Revolution, Sub-Saharan Africa, Tanzania

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1. Introduction

Food insecurity and poverty are long-lasting and persisting problems faced by most populations in developing countries in general and in Sub-Saharan Africa (SSA) in particular. Crop genetic improvement is widely acknowledged to play a fundamental role in fostering a Green Revolution, which had a significant impact on agriculture productivity improvement and poverty reduction in Asian countries (David and Otsuka 1994; Evenson and Gollin 2003). It is believed that the adoption of fertilizer-responsive, high-yielding modern varieties (MVs) that led to the Green Revolution in Asia could have a similar impact on the livelihood of poor African farmers (Otsuka 2006; World Bank 2008). However, little is known about how far the African Green Revolution has progressed, in other words, how much MVs have diffused and what their impact is on agriculture productivity and household income in SSA. Since socioeconomic and agroclimatic conditions, including the endowment of land and labor, and the conditions of infrastructures are different in SSA than in Asian countries, we must carefully examine the impact of MVs on productivity and income in SSA, where the new technologies have just started to diffuse.

This paper investigates the impact of the adoption of modern varieties of rice on its productivity and income by using the data set collected in Tanzania. Among major cereals, rice is the most rapidly growing food source in SSA, and Tanzania is one of the main rice-producing countries in East Africa (Seck et al. 2008). Recently, several studies have examined the impact of modern varieties on the productivity of rice in SSA. Most existing studies, however, are case studies on the adoption of NERICA (New Rice for Africa) (Kijima et al. 2008; Adekambi et al. 2009; Kijima et al. 2011), and little is known how much other modern varieties are adopted and what their impacts are on the productivity of and income from rice.

Beyond the impact of MVs on the productivity of rice, we will also examine the complementary impact of modern varieties with other agronomic technologies, such as chemical fertilizer use, bund construction, plot leveling, and transplanting in rows. Agronomic trials suggest that construction of bunds and plot leveling are important for proper water management and transplanting in rows for weed management and population control of plants, and thus to increase paddy yield in SSA (Becker and Johnson 2001; Raes et al. 2007; Touré et al. 2009). Assessment of the complementary impact of MVs and these agronomic technologies is important because MVs are designed to achieve a high yield with appropriate agronomic practices. A few socioeconomic studies point out the importance of these technologies to enhance the productivity of rice at the household level in the region (Sakurai 2006; Kijima et al. 2012). As far as the authors know, however, no study exists that examines the complementary impact of MVs and these new agronomic technologies. We try to identify which agronomic practices must be especially promoted to achieve the potential yield of MVs in Tanzania.

To examine these issues, we use two data sets collected by the authors. One set contains cross-sectional data of 760 households in three major rice-growing regions in Tanzania: Morogoro, Mbeya, and Shinyanga regions in 2009. We call these data extensive survey (ES) data. Another one, called case study (CS) data, is a two-year panel data of 403 farmers in two irrigation schemes in Kilosa district, Morogoro region in Tanzania, in 2010 and 2011. The extensive survey data are suitable to understand the current status of the adoption of MVs in the country, since they cover all the major rice-growing regions. On the other hand, by using a case-study data set we can take advantage of panel data to control unobservable household characteristics for estimating the impact of MVs on the productivity of and income from rice in irrigated areas. Using these two data sets, this paper investigates the complementary impact of MVs and other technologies in rain-fed and irrigated areas.

The rest of the paper is organized as follows. Section 2 explains the data set. Section 3 provides the descriptive analyses and is followed by regression analyses in Section 4. The paper ends with the conclusions in Section 5.

2. The study sites and data

In Tanzania, rice is mainly cultivated in three agroecological zones, namely, the Eastern Zone, Southern Highland Zone, and Lake Zone. To construct a nationally representative data set on rice, we covered all three zones in the extensive survey (ES). We chose one representative region from each zone, Morogoro from the Eastern Zone, Mbeya from the Southern Highland Zone, and Shinyanga from the Lake Zone (Fig. 1). The sample regions produce nearly 40% of the rice grown in the country (United Republic of Tanzania 2009). Thus we may be able to regard our survey as nationally representative in terms of rice production. In each region, we have selected two major rice-growing districts: Kilombero and Mvomero in the Morogoro region; Kyela and Mbarali in the Mbeya region; and Shinyanga rural and Kahama in the Shinyanga region.

In our sample area, most of the rice is grown under irrigated or rain-fed lowland conditions, and upland rice cultivation is rarely observed. Therefore we chose the sample villages by stratified random sampling on the basis of the number of rice-growing villages under irrigated and rain-fed conditions. For this purpose, we relied on the agricultural census in 2002/03 in each region. In total, we selected 76 villages in 6 districts as our sample. In each village, we randomly sampled 10 households and generated a total of 760 households. The survey was conducted from September 2009 to January 2010. We collected two levels of data: village and household. The former was collected by a group interview with village key informants, and the latter by an individual interview. During the interviews, farmers were asked to identify the most important rice plot and questioned in detail about the cultivation practices of the crop. We hereafter call this the sample plot. Figure 1 shows the irrigation status of the sample plots. For our analyses, we dropped 64 households that grew no rice either because they had no plots suitable for rice cultivation, or their plots received insufficient rainfall or irrigation water in 2009. We also dropped 24 outliers, which exhibit unrealistic values in the key variables, and our effective sample became 672.

Case study surveys were conducted in Ilonga and Chanzuru irrigation schemes, Kilosa district, Morogoro region. At these sites, farmers grow rice in irrigated plots as well as other crops, such as maize, beans, and vegetables, in upland plots during the main season from October to June. The Ilonga and Chanzuru irrigation schemes are both about 15 km from the nearest town, Kilosa, sharing the water source. Since the Ilonga irrigation scheme is in the upstream area of the Chanzuru scheme, it has better water access. Moreover, Ilonga has a better irrigation infrastructure; its canals are cemented and well maintained, and Ilonga village has government institutions for training and research. Furthermore, the Japan International Cooperation Agency (JICA) conducted training related to rice cultivation in the Ilonga irrigation scheme in 2008, but there was no such training in the Chanzuru irrigation scheme. Thus the Ilonga irrigation scheme is in more favorable conditions in terms of the availability of irrigation water and access to information on rice cultivation technologies than Chanzuru is.

Two rounds of surveys were conducted from August to September 2010 and in September 2011. In 2010, we interviewed 208 randomly selected farmers in Ilonga and 204 in Chanzuru. We requested them to identify the most important rice plot and asked in detail about the rice cultivation in that plot. In 2011, we interviewed 173 households in Ilonga and 178 in Chanzuru that had cultivated the same plot as in 2010. After dropping the outliers, our sample size became 204 in Ilonga and 194 in Chanzuru in 2010, and 169 in Ilonga and 170 in Chanzuru in 2011, a total sample size of 737.

3. Descriptive Analyses

Table 1 shows the paddy yields and the adoption of technologies in the sample regions of the extensive survey. In each region, we classify the sample plots as rain-fed or irrigated. The share of irrigated plots in the entire sample is 22.6% (152 of 672 observations). The overall average yield is 1.8 tons per hectare (t/ha) under rain-fed conditions and 3.7 t/ha under irrigated conditions, resulting in 2.2 t/ha as the overall average.

To have some idea about the emergence of a rice Green Revolution in Tanzania, we explore the application of modern inputs by irrigation status and region. The share of MVs is merely 7.1% in rain-fed areas and 28.7% in irrigated areas on average. In Tanzania, SARO5 (TXD 306), which was released in 2002, is by far the most popular MV, and more than 90% of the adopters of MVs grow this variety[1]. In the irrigated area in Morogoro, the share of modern varieties is 87.5%. This is consistent with the experience in Asia, where farmers tend to adopt MVs in more favorable areas (David and Otsuka 1994). On the other hand, in Mbeya region, which is famous for its aromatic rice, few farmers adopt MVs even in the irrigated area presumably because of their preference for local aromatic varieties over MVs.

In irrigated areas, farmers apply a moderate amount of fertilizer (32.2 kg per ha) partly because irrigation water and chemical fertilizer are complements. In general, however, chemical fertilizer application does not reach the level recommended by agronomists (125-250 kg of urea per ha). With regard to the improved agronomic practices, which consist of bund constructions, plot leveling, and transplanting in rows, all practices are more widely adopted in irrigated areas[2]. However, transplanting in rows, a common practice in Asia for easier weeding and harvesting, is still not popular in Tanzania, and only 28.9% of farmers have adopted this practice even in irrigated areas.

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[1] The only other MV adopted in our study sites is Dakawa, which is named after the government agricultural research institute in Dakawa district in Morogoro region.

[2] Although water is partially controlled in the leveled plots with bunds in rain-fed areas, farmers totally rely on rainfall as the water source in their plots. Thus we hereafter classify these plots as rain fed.

It is important to note that the ES data set reveals that most of those who adopt MVs are in Morogoro region, and only limited numbers of adopters exist either in irrigated or rain-fed areas of Mbeya and Shiyanga regions. Thus a comparison between adopters and nonadopters in all regions may capture the regional differences of productivity and income between Morogoro and the other two regions. To avoid this problem, our analyses hereafter focus only on Morogoro region and compare the adopters and nonadopters of MVs within the region. Since the panel data of CS are available in the irrigated area of Morogoro, we take advantage of using it for our analyses in the irrigated area. Meanwhile, for analysis of the rain-fed area, we use a subsample of ES data in Morogoro region because the panel data was not yet constructed for the rain-fed area. To avoid confusion, we call the former the case study data of the irrigated area and the latter the subsample of extensive survey data of the rain-fed area hereafter.

Table 2 shows the paddy yields, the adoption of technologies, the costs of and income from rice in irrigated areas based on case-study data. Income from rice per hectare here is defined as revenue per hectare (yield times paddy price) minus paid-out costs per hectare, which consist of costs of current inputs, hired labor, and rental machinery and animals. We show the results of *t*-tests comparing figures in 2010 and 2011.

First of all, farmers in Ilonga are more advanced in the adoption of new technologies than those in Chanzuru. The share of modern varieties in the Ilonga scheme is about 30% in both 2010 and 2011, which is much higher than the Chanzuru irrigation scheme (5.3% in 2010 and 9.6 % in 2011). The application of chemical fertilizer is also much higher in the Ilonga irrigation scheme (77.5 kg/ha in 2010 and 96.7 kg/ha in 2011) than in the Chanzuru irrigation scheme (10.3 kg/ha in 2010 and 15.4 kg/ha in 2011). The share of the plot with improved bunds[3], which was newly introduced by JICA training in this area, is also higher in Ilonga (11.8% in 2010 and 20.1% in 2011) than in Chanzuru (2.1% in 2010 and 7.6 % in 2011). The share of the leveled

[3] The difference between (ordinary) bunds and improved bunds is that the soil is compressed and firm enough not to let the water move from plot to plot for improved bunds.

plot is slightly higher in the Ilonga scheme (71.6% in 2010 and 78.1% in 2011) than in the Chanzuru irrigation scheme (66.5 % in 2010 and 65.9% in 2011). The share of the farmers who adopted transplanting in rows also is much higher in the Ilonga irrigation scheme (37.3 % in 2010 and 36.1% in 2011) than in the Chanzuru irrigation scheme (1.5% in 2010 and 2.9% in 2011). As we discussed earlier, there was a training conducted by JICA in 2008 in the Ilonga irrigation scheme. Furthermore, this scheme is in a favorable condition in terms of availability of water. Since some technologies such as chemical fertilizer may be ineffective without enough water in the plot, and some of these technologies are newly introduced by JICA training in this area, farmers in Ilonga may take advantage of being in favorable conditions in terms of availability of irrigation water and information on rice cultivation to adopt new technologies.

Another important finding is change in the adoption of new technologies over time. Although no big change is evident in the adoption of MVs, farmers in both schemes increased the application of chemical fertilizer from 2010 to 2011. The share of plots with improved bunds also increased in the same period. The increase in the adoption of technologies may be because new technologies taught in the JICA training slowly diffused in both Ilonga and Chanzuru irrigation schemes.

Besides the diffusion of new practices, farmers in both schemes received more rainfall, and thus more irrigation water, in 2011. As a result, the paddy yield and rice revenue per hectare is higher in 2011 than in 2010 in both irrigation schemes. Although the costs of cultivation increased, the increase in rice revenue exceeded that of costs, and the rice income per hectare also significantly increased in 2011 compared to 2010 in both schemes. Note also that farmers in Ilonga achieve much higher yield (2.8 t/ha in 2010 and 3.9 t/ha in 2011) and income from rice (494.6 USD/ha in 2010 and 815.9 USD/ha in 2011) than in Chanzuru irrigation schemes. This is partly because more farmers in Ilonga adopted new technologies and partly because they are in a better position to use irrigation water.

Table 3 compares paddy yields, the adoption of technologies, the costs of and the income from rice per hectare by the adoption of MVs in both the rain-fed and irrigated areas. We show the results of *t*-tests comparing between the adopters and nonadopters of MVs. First of all, the adopters of MVs apply more chemical fertilizer than nonadopters in both the irrigated and rain-fed areas. The share of the plot with bunds is higher for the adopters of MVs both in irrigated and rain-fed areas. The share of the plot with improved bunds is higher for the adopters of MVs in the Ilonga irrigation scheme. This may be because farmers there tend to grow MVs in the plot with better water management. The shares of the households that adopt transplanting and transplanting in rows are higher for the adopters of MVs in both rain-fed and irrigated areas. In general, the adopters of MVs are also more active in adopting other technologies than nonadopters of MVs are.

In both rain-fed and irrigated areas, farmers who adopt MVs achieve higher yields. As a result, the adopters of MVs enjoy higher revenue per hectare in the Ilonga irrigation scheme and rain-fed areas. The costs of current input and labor increase significantly for the adopters of MVs because they apply more chemical fertilizer and adopt more labor-intensive practices than nonadopters of MVs do. However, the increase of revenue exceeds that of costs, and the adopters of MVs achieve higher incomes per hectare in the Ilonga irrigation scheme and rain-fed areas. These findings suggest that the adopters of MVs achieve higher yields and incomes from rice per hectare by adopting MVs as well as other new agronomic technologies.

Note, however, that in the Chanzuru irrigation scheme, the revenue and income from rice per hectare is not statistically different between adopters and nonadopters of MVs. Since farmers in Chanzuru receive less irrigation water than in Ilonga, the adopters of MVs in Chanzuru may be unable to realize the potential yield of MVs.

4. Determinants of paddy yield and rice income per hectare

4.1. Methodology and variable construction in irrigated areas

This section investigates how the adoption of MVs and other technologies jointly contribute to the increase of paddy yield and income from rice in Tanzania by means of regression analyses. We start with an analysis of the irrigated area by using the panel data of the case study survey. The dependent variables are paddy yield (t/ha) and income from rice per hectare (USD/ha). We estimate a pooled OLS model, a household fixed-effect model, and a random-effect model. The key independent variable is the dummy variable that takes one if a farmer adopts MVs. We also include chemical fertilizer use (kg/ha), and dummy variables that take one if improved bund construction, leveling of plot, and transplanting in rows are adopted, respectively. To capture the complementary impact of these technologies with modern varieties, we also include the interaction terms of the adoption of MVs with the chemical fertilizer use (kg/ha), the adoption of improved bund construction, plot leveling, and transplanting in rows, respectively. To examine the difference in the coefficients in Ilonga and Chanzuru irrigation schemes, we include the interaction terms of all these variables with the Chanzuru village dummy. We also include the interaction terms of village dummies and yearly dummies to capture time-varying location effects.

For a random-effect model, to control plot and household characteristics that are practically time-invariant between 2010 and 2011 we include the size of the plot (ha), the number of adult household members, the age of household head, the average years of schooling of adult household members, female-headed household dummy, the size of owned plots in upland areas, and the size of owned plots in lowland areas except the sample plot, for all of which we use the values in 2010.

4.2. Regression results in irrigated areas

Table 4 shows the determinants of paddy yield in irrigated areas based on the case study data. Model (1) shows the results of a pooled OLS model. Models (2) and (3) are the results of household fixed-effect models, and models (4) and (5) show the results of random-effect models. In models (3) and (5), we use robust standard errors. Note that there are no farmers in the Chanzuru scheme who adopt both MVs and improved bunds at the same time, as shown in Table 3. Thus we dropped the corresponding interaction term. The Hausman test is not significant, suggesting that the random-effect model is appropriate over the fixed-effect models. Breusch-Pagan test rejects its null hypotheses, supporting the use of the random-effect model over the pooled OLS model. Thus we rely on the random-effect model shown in (4) and (5) for our interpretation. We also show the results of two types of F tests. The first one examines the joint significance of interaction terms of the Chanzuru village dummy with the variables of technology adoption, including the interaction terms of the adoption of MVs and other technologies. The other F test examines the joint significance of the interaction terms of the Chanzuru village dummy and yearly dummies.

Models (4) and (5) indicate that there is no significant impact on the adoption of MVs alone on paddy yield. However, the interaction term of MVs with improved bund construction has positive and significant effects on the paddy yield. These results indicate the importance of proper water management for MVs to achieve potential yield. It is also important to note that the F tests of interaction terms of the Chanzuru village dummy and yearly dummies are significant. Since both coefficients of interaction terms of the Chanzuru village dummy and year 2010 and 2011 dummies are negative, this indicates that the estimated yield function frontier locates significantly lower in the Chanzuru irrigation scheme than in the Ilonga irrigation scheme. Since the Chanzuru irrigation scheme is in a less favorable condition than the Ilonga irrigation scheme in terms of availability of water, this result also suggests the importance of irrigation water for modern technologies to achieve their potential impact on paddy yields.

Chemical fertilizer use and transplanting in rows have positive and significant coefficients in models (4) and (5). Since the interaction term of MVs and chemical fertilizer is insignificant, this result indicates that the chemical fertilizer application can have a positive impact on yield even for the nonadopters of MVs. Note that the marginal return of chemical fertilizer can be positive even for traditional varieties at a low level of fertilizer application, although the rate of return starts declining faster for traditional varieties than for MVs as the application of fertilizer increases. Since farmers in both irrigation schemes apply much less fertilizer than the recommended level of chemical fertilizer (125 kg - 250 kg/ha) by JICA and the local training institution, chemical fertilizer applications have positive effects even for the nonadopters of MVs.

Table 5 summarizes the estimation results of rice income function. Diagnostic tests support the use of the random effect models shown in (4) and (5). The variables significant in the yield functions, namely, the interaction term of MVs and improved bunds, amount of chemical fertilizer, and the adoption of transplanting in rows are, also significant and positive in income functions. These results indicate that those who achieved higher yields through the adoption of technologies realized higher rice income per hectare. Moreover, plot size has negative and significant coefficients, indicating that farmers with smaller plots use inputs more efficiently to maximize their income.

4.3. Methodology and variable construction in rain-fed areas

For the analysis in rain-fed areas, we have only single-year cross-sectional data of extensive surveys and thus estimate OLS models. The dependent variables are paddy yield per hectare (t/ha) or rice income per hectare (USD/ha). The key independent variable is the adoption of modern variety. Furthermore, we include the amount of chemical fertilizer applied, and dummy variables that take 1 if bund construction, leveling of plot, and transplanting in rows are adopted. Since most of the adopters of other technologies are also adopters of MVs, we abandon including interaction terms with the adoption of MVs and the adoption of other technologies.

We control other village and household characteristics. To capture plot characteristics, we include the size of the sample plot (ha). We also include the size of other lowland plots (ha) and the size of upland plots (ha) to capture the land endowment of households, the value of household assets (in millions of Tanzanian shillings), and the number of cows and bulls owned by the household to capture the influence of the physical asset endowment. To capture the impact of human capital endowment, we use the number of adult members older than 15, the age of the household head, the average years of schooling of adult household members, the dummy for a female-headed household, and experience in rice production in the past 5 years.

The village-level explanatory variables consist of the existence of Saving and Credit Cooperative Societies (SACCOs)[4] in the village (dummy) and the existence of private money lenders and other credit organizations in the village (dummy) to capture the supply-side factors of credit. We also include the distance (km) to the nearest extension office to control access to rice-related training. We control the distance (km) from the district capital, the existence of a seed market in the village (dummy),[5] and access to a fertilizer market in the village (dummy) to

[4] Savings and Credit Cooperative Societies (SACCOs) are rural governmental or nongovernmental organizations that provide microfinance at the village or ward level. Some function as mutual savings and credit societies for rural people.

[5] During the village-level interviews, farmers are asked about the number of accessible fertilizer dealers and rice-seed dealers in the village. We take access to a seed market as one if the answer is more than or equal to one.

capture market access to the various inputs. We also include average male agricultural wage rate in the village measured in terms of paddy kilograms.

4.4. Regression results in rain-fed areas

Table 6 shows the estimation results of yield and income functions in the rain-fed area based on the subsample of extensive survey data[6]. The dependent variable of models (1) to (3) is paddy yield, and models (4) to (6) estimate income functions. Models (1) and (4) control no dummies, but (2) and (5) control district dummies and (3) and (6) village dummies. We also show the results of F tests examining the joint significance of district- or village-fixed effects.

Models (1) and (2) show that the adoption of MVs has positive and significant impacts on paddy yields. We also observe the positive and significant coefficients of MVs on income in models (4) and (5). However, when we control the village-fixed effect, the coefficients of the adoption of MVs become insignificant for both yield and income from rice per hectare as shown in models (3) and (6).

Two reasons seem to exist that support these results. The first possible reason is that the positive impact of the adoption of MVs on yield and income is not strong enough to overcome the difference in the social and agroecological conditions in villages, and the yield and income are predominantly determined by them. In fact, the F-test, which examines the joint significance of village dummies, is highly significant, suggesting that the conditions of each village are important determinants of paddy yield and income from rice per hectare. The second possible reason is the low variation of independent variables, especially the adoption dummy of the MVs, among individuals in the same village. In this situation, the possible impacts of MVs are absorbed in the village-fixed effects. Thus we failed to conclude that the adoption of MVs has

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[6] We admit that R-squared in the estimated models is low. However, we must note that the cross-section data have a tendency to generate low R-squared (Wooldridge 2002).

positive impacts on yield or income in the rain-fed areas, though we also cannot completely deny the possible positive impact.

In regard to village characteristics, the existence of SACCOs and the fertilizer market has positive and significant coefficients on both paddy yield and income from rice per hectare. Using ES data set, Nakano and Kajisa (2011) shows that farmers in villages with SACCOs apply more chemical fertilizer and transplanting in rows by using credit. This may be why farmers in villages with SACCOs achieve higher paddy yield and rice income per hectare. However, because both chemical fertilizer and transplanting in rows have no significant coefficient on paddy yield or income from rice, further examination must be done on this issue to obtain more concrete results when the panel data is constructed.

5. Conclusions

This paper investigates the complementary impact of MVs and agronomic technologies on paddy yield and income from rice per hectare. The most important finding is the strong complementary relationship of the MVs with improved bunds. In fact, without proper water management, MVs have no positive impact on either yield or income from rice per hectare. Our analyses also show that in the Chanzuru irrigation scheme, the adopters of MVs and improved bunds achieve lower yield and income than adopters in Ilonga. Because of the limited access to irrigation water, farmers in Chanzuru may be unable to take full advantage of these technologies to achieve high yield and income.

Second, the use of chemical fertilizer and the adoption of transplanting in rows increase yield and income of MV adopters and nonadopters in the irrigated area. Our results suggest that even traditional varieties may respond positively to chemical fertilizer when a small amount is applied. Third, under rain-fed conditions we observed no statistically positive impact of MVs and other agronomic practices on yield and income. This is either because these outcomes are predominantly determined by village characteristics, such as agronomic conditions, or there is little variation in the technology adoption at household level in the same village. We need to carefully examine the impact of the adoption of MVs and other technologies, especially in rain-fed areas, by constructing panel data in the future. We consider this our future research agenda.

These findings suggest that introducing MV as a package of technologies, including other agronomic practices, would be effective for enhancing paddy yields and incomes from rice per hectare in irrigated areas. This is because MVs can perform well only when grown under good water control. Moreover, since we observe limited impacts on MVs in rain-fed areas, investment in irrigation would be important to expand the Green Revolution in Africa.

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Table 1: Paddy yield and adoption of technologies by region and agroecology in the Extensive Survey in 2009

	Morogoro		Mbeya		Shinyanga		Average	
	Rain-fed	Irrigated	Rain-fed	Irrigated	Rain-fed	Irrigated	Rain-fed	Irrigated
Paddy yields (t/ha)	2.0	3.8	1.6	3.5	1.7	4.6	1.8	3.7
Share of modern varieties (%)	18.0	87.5	0.0	2.1	1.9	13.1	7.1	28.7
Chemical fertilizer use (kg/ha)	11.7	40.4	10.7	31.7	0.9	0	6.7	32.2
Share of bunded plot (%)	8.2	84.8	16.3	89.6	95.3	100	49.0	88.8
Share of leveled plot (%)	22.0	69.6	38.5	78.1	87.6	100	54.8	77.0
Share of households that adopted transplanting	12.1	45.7	10.6	71.9	40.2	70	24.4	63.8
Share of households that adopted transplanting in rows	4.4	47.8	3.8	22.9	6.4	0	5.2	28.9
Observations	182	46	104	96	234	10	520	152

Table 2: Paddy yield (t/ha), the adoption of technologies, and costs of and income from rice (USD/ha)[1] in the irrigated area of case-study surveys in 2010 and 2011

	Ilonga		Chanzuru	
	2010	2011	2010	2011
Paddy yields (t/ha)	2.8	3.9***	1.7	2.3***
Share of modern varieties (%)	31.9	28.8	5.3	9.6**
Chemical fertilizer use (kg/ha)	77.5	96.7***	10.3	15.4*
Share of the bunded plot	84.3	85.2	87.1	85.9
Share of plot that has improved bunds	11.8	20.1**	2.1	7.6***
Share of the leveled plot	71.6	78.1*	66.5	65.9
Share of households that adopted transplanting	84.3	82.2	76.8	63.5**
Share of households that adopted transplanting in rows	37.3	36.1	1.5	2.9
Rice revenue (USD/ha)	763.2	1214.6***	486.9	759.3***
Paid-out cost of current inputs use (USD/ha)	69.2	69.5	18.7	21.8*
Paid-out cost of labor use (USD/ha)	174.9	270.5***	114.4	203.3***
Paid-out cost of machinery and animal use (USD/ha)	24.4	58.7***	17.7	24.9**
Rice income (USD/ha)	494.6	815.9***	336.0	509.3***
Observations	204	169	194	170

Note: ***denotes significant at 1%, **significant at 5%, and *significant at 10% in *t*-test comparing between years 2010 and 2011.

1) The exchange rate is 1 USD= 1500 Tanzanian Shillings.

Table 3: Paddy yield (t/ha), the adoption of technologies and costs of and income from rice (USD/ha)[1] by agroecology, and the adoption of MVs based on the case study survey (CS) and the subsample of the extensive survey (ES)

	---------- Irrigated area ----------				--- Rain-fed area ---	
	CS in 2010 & 2011				Subsample of ES in 2009	
	Ilonga		Chanzuru			
	Non-MV	MV	Non-MV	MV	Non-MV	MV
Paddy yields (t/ha)	2.9	3.8***	1.9	2.2*	1.8	2.8***
Share of modern varieties (%)	0.0	80.6***	0.0	68.5***	0	83.8***
Chemical fertilizer use (kg/ha)	67.6	116.8***	11.4	22.9**	6.8	29.8***
Share of the bunded plot	78.4	95.0***	85.5	94.9*	2.8	28.2***
Share of plot that has improved bunds	12.1	21.3***	5.2	0.0*		
Share of the leveled plot	73.3	76.6	66.2	66.7	21.7	23.1
Share of households that adopted transplanting	80.6	87.9**	69.5	79.5*	4.2	61.5***
Share of households that adopted transplanting in rows	25.0	56.0***	1.2	10.3***	0.0	20.5***
Rice revenues (USD/ha)	896.8	1084.4***	610.2	646.7	523.0	835.9***
Paid-out cost of current inputs use (USD/ha)	58.2	87.7***	18.8	31.5***	19.4	39.8***
Paid-out cost of labor use (USD/ha)	203.3	242.8**	150.7	200.2**	149.0	249.3***
Paid-out cost of machinery and animal use (USD/ha)	29.1	57.7***	20.0	30.0*	67.1	24.5
Rice income (USD/ha)	606.2	696.1**	420.8	384.9	287.6	522.3***
Observations	232	141	325	39	143	39

Note: ***denotes significant at 1%, **significant at 5%, and *significant at 10% in *t*-test comparing between the adopters and non-adopters of MVs.

1) The exchange rate is 1 USD = 1500 Tanzanian Shillings.

Table 4: Estimation results of the determinants of paddy yield (t/ha) in the irrigated area of case study survey in 2010 and 2011

VARIABLES	(1) Pooled OLS	(2) Fixed Effect	(3) FE robust SE	(4) Random Effect	(5) RE robust SE
=1 if adopted modern variety	-0.009	0.647	0.647	0.151	0.151
	(0.394)	(0.534)	(0.603)	(0.355)	(0.384)
Chemical fertilizer use (kg/ha)	0.010***	0.003	0.003	0.009***	0.009***
	(0.002)	(0.003)	(0.003)	(0.002)	(0.002)
=1 if plot has improved bunds	-0.297	-0.618*	-0.618**	-0.376	-0.376
	(0.259)	(0.362)	(0.313)	(0.266)	(0.238)
=1 if plot is leveled	0.044	0.284	0.284	0.091	0.091
	(0.205)	(0.276)	(0.317)	(0.192)	(0.199)
=1 if transplanting in rows	0.532**	0.968***	0.968***	0.648***	0.648***
	(0.234)	(0.291)	(0.316)	(0.208)	(0.223)
MV *chemical fertilizer(kg/ha)	-0.001	0.002	0.002	-0.001	-0.001
	(0.003)	(0.003)	(0.004)	(0.002)	(0.003)
MV *improved bunds	1.305***	1.633***	1.633***	1.419***	1.419***
	(0.464)	(0.479)	(0.532)	(0.372)	(0.448)
MV *leveled plot	0.252	-0.295	-0.295	0.135	0.135
	(0.375)	(0.490)	(0.591)	(0.332)	(0.370)
MV *transplanting in rows	-0.072	-0.704	-0.704*	-0.201	-0.201
	(0.368)	(0.433)	(0.406)	(0.315)	(0.348)
Chanzuru *MV	0.357	-0.952	-0.952	0.108	0.108
	(0.481)	(0.774)	(0.782)	(0.527)	(0.485)
Chanzuru *chemical fertilizer use (kg/ha)	-0.004*	0.000	0.000	-0.003	-0.003
	(0.002)	(0.005)	(0.004)	(0.003)	(0.002)
Chanzuru * improved bunds	0.543	0.715	0.715*	0.578	0.578*
	(0.352)	(0.559)	(0.390)	(0.415)	(0.318)
Chanzuru * leveled plot	0.075	-0.258	-0.258	0.005	0.005
	(0.234)	(0.339)	(0.342)	(0.242)	(0.224)
Chanzuru * transplanting in rows	-0.375	-0.648	-0.648	-0.449	-0.449
	(0.447)	(0.829)	(0.404)	(0.659)	(0.399)
Chanzuru * MV *chemical fertilizer use (kg/ha)	0.000	-0.001	-0.001	0.000	0.000
	(0.005)	(0.008)	(0.006)	(0.006)	(0.005)
Chanzuru * MV *leveled plot	-0.575	0.483	0.483	-0.389	-0.389
	(0.562)	(0.806)	(0.829)	(0.564)	(0.560)
Chanzuru * MV *transplanting in rows	0.344	0.748	0.748	0.558	0.558
	(1.002)	(1.472)	(1.001)	(0.982)	(0.941)
Size of the plot (ha)	-0.625			-0.689*	-0.689
	(0.598)			(0.376)	(0.584)
Number of adult household members in 2010	-0.025			-0.017	-0.017
	(0.060)			(0.060)	(0.060)
Female household head in 2010	-0.237			-0.250	-0.250
	(0.213)			(0.193)	(0.212)
Average year of schooling of adult household members in 2010	0.043			0.042	0.042
	(0.047)			(0.037)	(0.047)

Size of owned plot in upland areas (ha) in 2010	-0.194			-0.203	-0.203
	(0.218)			(0.281)	(0.218)
Size of owned plot in lowland areas, except sample plot (ha) in 2010	0.014			0.013	0.013
	(0.178)			(0.169)	(0.180)
Chanzuru *size of the plot (ha) in 2010	0.514			0.581	0.581
	(0.607)			(0.412)	(0.593)
Chanzuru *number of adult household members in 2010	0.084			0.077	0.077
	(0.076)			(0.083)	(0.076)
Chanzuru *female household head in 2010	0.044			0.060	0.060
	(0.259)			(0.267)	(0.258)
Chanzuru *average year of schooling of adult household members in 2010	0.005			0.008	0.008
	(0.053)			(0.051)	(0.054)
Chanzuru *size of owned plot in upland area (ha) in 2010	0.512			0.530	0.530*
	(0.314)			(0.416)	(0.312)
Chanzuru *size of owned plot in lowland area except sample plot (ha) in 2010	-0.015			-0.009	-0.009
	(0.188)			(0.187)	(0.188)
Ilonga *2011	0.915***	0.938***	0.938***	0.915***	0.915***
	(0.145)	(0.132)	(0.153)	(0.121)	(0.143)
Chanzuru *2010	-0.709			-0.724	-0.724
	(0.486)			(0.451)	(0.482)
Chanzuru *2011	-0.080	0.651***	0.651***	-0.091	-0.091
	(0.486)	(0.126)	(0.092)	(0.452)	(0.483)
Constant	1.836***	1.740***	1.740***	1.855***	1.855***
	(0.427)	(0.183)	(0.188)	(0.343)	(0.426)
Observations	737	737	737	737	737
R-squared	0.412	0.315	0.315		
Number of household		403	403	403	403
Hausman test		21.54			
[*p*-value]		[0.308]			
Breusch-Pagan test	23.14				
[*p*-value]	[0.000]				
F-test for Chanzuru*technology adoption	4.80	0.57	1.06	4.80	7.99
[*p*-value]	[0.779]	[0.806]	[0.388]	[0.778]	[0.435]
F-test for Chanzuru*year	28.90	26.56	49.71	28.90	49.59
[*p*-value]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]

Standard errors in brackets. ***p<0.01, **p<0.05, *p<0.1.

Table 5: Estimation results of the determinants of income from rice (100 USD/ha) in the irrigated area of case-study surveys in 2010 and 2011

	(1) Pooled OLS	(2) Fixed Effect	(3) FE robust SE	(4) Random Effect	(5) RE robust SE
=1 if adopted modern variety	0.513	2.353	2.353	0.918	0.918
	(1.141)	(1.642)	(1.819)	(1.092)	(1.083)
Chemical fertilizer use (kg/ha)	0.012**	0.000	0.000	0.010**	0.010*
	(0.005)	(0.008)	(0.009)	(0.005)	(0.005)
=1 if plot has improved bunds	-0.466	-1.449	-1.449	-0.737	-0.737
	(0.900)	(1.113)	(1.132)	(0.818)	(0.826)
=1 if plot is leveled	0.908	1.220	1.220	0.933	0.933
	(0.713)	(0.850)	(1.005)	(0.591)	(0.678)
=1 if transplanting in rows	1.051	2.735***	2.735***	1.443**	1.443*
	(0.783)	(0.893)	(1.047)	(0.640)	(0.758)
MV *chemical fertilizer(kg/ha)	0.000	-0.000	-0.000	-0.001	-0.001
	(0.007)	(0.010)	(0.010)	(0.007)	(0.007)
MV *improved bunds	3.530**	4.505***	4.505**	3.863***	3.863***
	(1.563)	(1.472)	(1.757)	(1.143)	(1.490)
MV *leveled plot	-0.848	-1.614	-1.614	-0.990	-0.990
	(1.114)	(1.507)	(1.723)	(1.021)	(1.080)
MV *transplanting in rows	-0.111	-2.113	-2.113	-0.487	-0.487
	(1.148)	(1.330)	(1.290)	(0.969)	(1.080)
Chanzuru *MV	0.561	-4.924**	-4.924**	-0.427	-0.427
	(1.464)	(2.379)	(2.245)	(1.621)	(1.445)
Chanzuru *chemical fertilizer use (kg/ha)	-0.008	-0.001	-0.001	-0.007	-0.007
	(0.008)	(0.015)	(0.013)	(0.010)	(0.008)
Chanzuru *improved bunds	0.857	1.994	1.994	1.131	1.131
	(1.221)	(1.718)	(1.491)	(1.277)	(1.145)
Chanzuru *leveled plot	-0.501	-1.527	-1.527	-0.702	-0.702
	(0.792)	(1.041)	(1.060)	(0.745)	(0.744)
Chanzuru *transplanting in rows	-0.936	-1.483	-1.483	-1.028	-1.028
	(1.597)	(2.547)	(1.837)	(2.029)	(1.552)
Chanzuru *MV *chemical fertilizer use (kg/ha)	-0.012	0.002	0.002	-0.009	-0.009
	(0.013)	(0.024)	(0.017)	(0.018)	(0.013)
Chanzuru *MV *leveled plot	-1.017	2.801	2.801	-0.350	-0.350
	(1.689)	(2.476)	(2.342)	(1.735)	(1.672)
Chanzuru *MV *transplanting in rows	0.960	0.808	0.808	1.255	1.255
	(3.185)	(4.524)	(4.007)	(3.022)	(3.152)
Size of the plot (ha)	-3.665*			-3.836***	-3.836**
	(1.898)			(1.156)	(1.853)
Number of adult household members in 2010	0.255			0.271	0.271
	(0.177)			(0.185)	(0.175)
Female household head in 2010	-0.415			-0.467	-0.467
	(0.668)			(0.593)	(0.665)

Average year of schooling of adult household members in 2010	-0.132			-0.135	-0.135
	(0.150)			(0.115)	(0.150)
Size of owned plot in upland area (ha) in 2010	-1.334*			-1.313	-1.313*
	(0.684)			(0.864)	(0.693)
Size of owned plot in lowland area except sample plot (ha) in 2010	-0.739			-0.750	-0.750
	(0.549)			(0.519)	(0.549)
Chanzuru *size of the plot (ha)	3.290*			3.447***	3.447*
	(1.940)			(1.267)	(1.897)
Chanzuru *number of adult household members in 2010	-0.242			-0.257	-0.257
	(0.223)			(0.254)	(0.223)
Chanzuru *female household head in 2010	-0.199			-0.163	-0.163
	(0.805)			(0.822)	(0.804)
Chanzuru *average year of schooling of adult household members in 2010	0.131			0.140	0.140
	(0.176)			(0.157)	(0.176)
Chanzuru *size of owned plot in upland area (ha) in 2010	1.548			1.548	1.548
	(0.990)			(1.281)	(0.988)
Chanzuru *size of owned plot in lowland area except sample plot (ha) in 2010	0.620			0.642	0.642
	(0.585)			(0.575)	(0.579)
Ilonga *2011	2.762***	2.945***	2.945***	2.791***	2.791***
	(0.459)	(0.405)	(0.497)	(0.373)	(0.458)
Chanzuru *2010	-1.536			-1.504	-1.504
	(1.611)			(1.388)	(1.596)
Chanzuru *2011	0.197	1.713***	1.713***	0.219	0.219
	(1.624)	(0.388)	(0.270)	(1.392)	(1.609)
Constant	4.962***	3.366***	3.366***	5.035***	5.035***
	(1.434)	(0.563)	(0.612)	(1.055)	(1.422)
Observations	737	737	737	737	737
R-squared	0.232	0.269	0.269		
Number of household		403	403	403	403
Hausman test		20.52			
[*p* value]		[0.364]			
Breusch-Pagan test	27.83				
[*p* value]	[0.000]				
F test for Chanzuru *technology adoption	1.14	0.98	1.37	5.07	9.12
[*p* value]	[0.336]	[0.449]	[0.210]	[0.750]	[0.333]
F test for Chanzuru *year	19.07	19.45	40.30	22.18	39.43
[*p* value]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]

Standard errors in brackets. ***p<0.01, **p<0.05, *p<0.1.

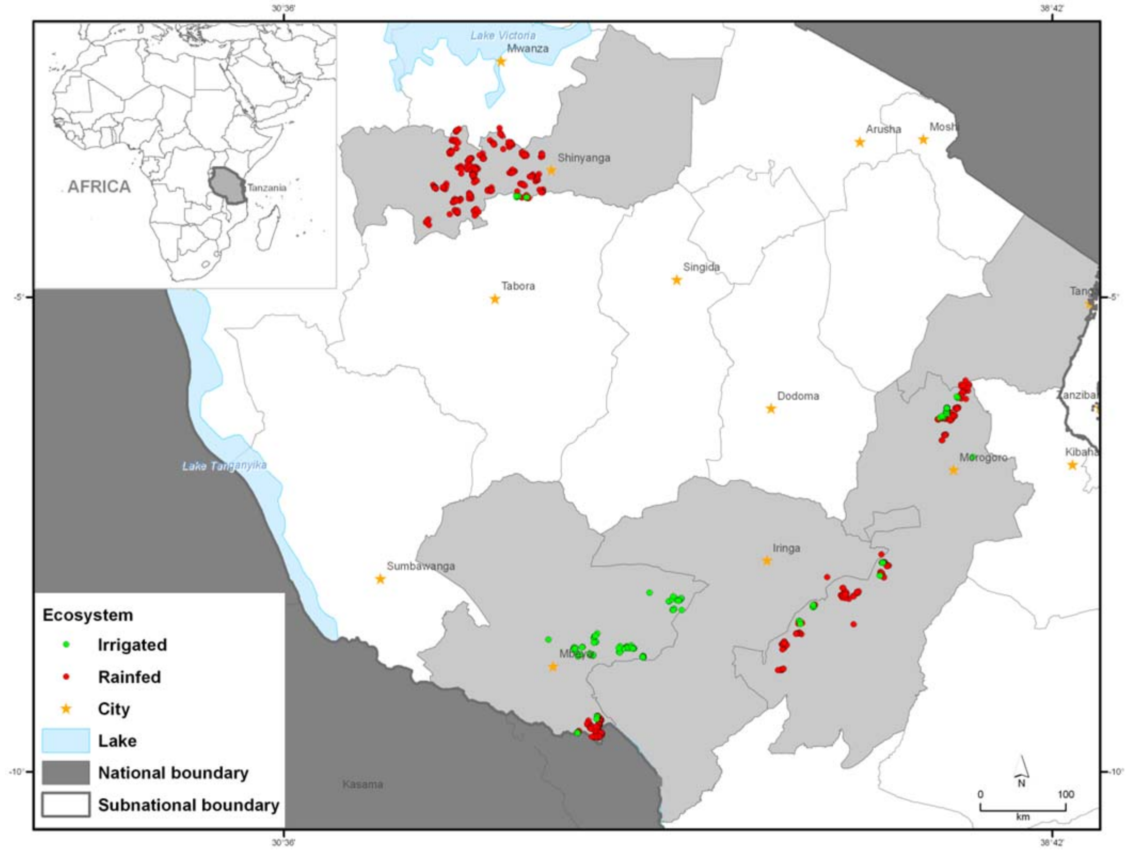
Table 6: Estimation results of the determinants of paddy yields (t/h) and income from rice (100USD/ha) in the rain-fed areas of subsample of extensive surveys in 2009

	(1)	(2)	(3)	(4)	(5)	(6)
		Paddy yield			Income from rice	
	No dummy	District FE	Village FE	No dummy	District FE	Village FE
MVs	0.752**	0.681**	0.364	2.191**	2.013**	1.133
	(0.323)	(0.322)	(0.345)	(0.902)	(0.900)	(0.954)
Chemical fertilizer use (kg/ha)	-0.000	-0.001	0.001	-0.006	-0.008	-0.003
	(0.004)	(0.004)	(0.004)	(0.010)	(0.010)	(0.012)
Plot with bunds (dummy)	0.324	0.267	-0.476	0.792	0.649	-1.339
	(0.429)	(0.425)	(0.462)	(1.196)	(1.189)	(1.277)
Leveled plot (dummy)	-0.307	-0.219	-0.102	-1.037	-0.816	-0.645
	(0.273)	(0.274)	(0.267)	(0.761)	(0.765)	(0.738)
Transplanting in rows (dummy)	0.299	0.277	0.130	-0.296	-0.351	-1.279
	(0.575)	(0.569)	(0.619)	(1.604)	(1.592)	(1.712)
Size of plot (ha)	-0.116	-0.128	-0.072	-0.524	-0.555	-0.333
	(0.134)	(0.133)	(0.135)	(0.374)	(0.372)	(0.372)
The size of plots owned in the lowland area except the sample plot (ha)	0.043	0.053	0.012	0.090	0.114	0.088
	(0.072)	(0.072)	(0.072)	(0.202)	(0.201)	(0.200)
The size of plots owned in the upland area (ha)	-0.019	-0.011	-0.018	0.001	0.020	0.000
	(0.054)	(0.053)	(0.053)	(0.150)	(0.149)	(0.146)
Household asset (million Tsh)	0.174*	0.167	0.148	0.222	0.204	0.135
	(0.103)	(0.102)	(0.104)	(0.286)	(0.284)	(0.288)
Number of cows and bulls owned	0.009	0.013	-0.004	0.027	0.038	-0.068
	(0.054)	(0.053)	(0.054)	(0.150)	(0.149)	(0.150)
Number of adults (age>=15)	-0.205**	-0.201**	-0.130	-0.473*	-0.463*	-0.310
	(0.100)	(0.099)	(0.099)	(0.279)	(0.277)	(0.274)
The age of household head	0.008	0.006	-0.002	0.024	0.020	-0.010
	(0.011)	(0.011)	(0.011)	(0.030)	(0.030)	(0.030)
Average years of schooling of adult household members	0.070	0.081	0.044	0.189	0.215	0.114
	(0.073)	(0.073)	(0.073)	(0.205)	(0.204)	(0.203)

=1 if female household head	-0.110	-0.026	0.022	0.318	0.530	0.597
	(0.350)	(0.349)	(0.349)	(0.977)	(0.976)	(0.964)
Experience in rice production in 5 years	0.058	0.041	0.071	-0.014	-0.056	0.070
	(0.074)	(0.074)	(0.078)	(0.207)	(0.206)	(0.217)
Village Characteristics						
SACCOs	0.628*	0.741**		1.587*	1.872**	
	(0.334)	(0.335)		(0.932)	(0.937)	
Private money lender and other credit organizations in the village	0.042	-0.140		1.520*	1.062	
	(0.315)	(0.324)		(0.879)	(0.906)	
Distance to the nearest extension office (km)	0.005	0.021		-0.010	0.028	
	(0.019)	(0.020)		(0.053)	(0.057)	
Existence of seed market	-0.560	-0.495		-1.169	-1.006	
	(0.365)	(0.363)		(1.018)	(1.014)	
Access to fertilizer market	0.826	1.108**		2.702*	3.413**	
	(0.501)	(0.514)		(1.397)	(1.437)	
Male agricultural wage rate per paddy kilograms	0.022	0.005		-0.062	-0.106	
	(0.022)	(0.024)		(0.062)	(0.066)	
Distance to the district capital (km)	0.006*	0.006*		0.010	0.010	
	(0.003)	(0.003)		(0.009)	(0.009)	
Mvomero district		-0.779**			-1.962*	
		(0.376)			(1.050)	
Constant	0.382	0.798	0.974	0.287	1.335	2.977
	(0.901)	(0.914)	(0.874)	(2.514)	(2.557)	(2.415)
Observations	182	182	182	182	182	182
R squared	0.181	0.202	0.339	0.158	0.176	0.332
F tests of district and village dummies		4.30	2.08		3.49	1.93
[*p* value]		[0.040]	[0.005]		[0.064]	[0.011]

Standard errors in brackets. ***$p<0.01$, **$p<0.05$, *$p<0.1$.

Figure 1: The regions covered by the extensive survey and the irrigation status of sample plots in Tanzania



Abstract (in Japanese)

要約

サブサハラ・アフリカにおいてコメの近代品種が普及し始めているが、その農業生産性および所得への影響を分析した論稿は数少ない。そこで本研究では、同地域の主要コメ生産国であるタンザニアにおいて収集された二種類の家計データを用いて、コメの近代品種の採用が農業生産性および所得に与える影響について検証を行った。その結果、近代品種は灌漑地域において畦畔の設置といった水管理技術と共に採用された場合に、単位面積当たりの収量および所得を向上させる効果があることが明らかになった。また灌漑地域おいて施肥および正条植えの実施が稲作の生産性と所得を向上させることも示された。これらの結果はアフリカにおいてコメの緑の革命を達成するためには、近代品種のみならず、栽培技術を含めて技術普及を進めるべきであることを示唆している。

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