How does the Adoption of Modern Variety increase Productivity and Income? : A Case of the Rice Sector in Tanzania

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Abstract
Although high yielding modern rice varieties (MVs) have been gradually disseminating over Sub-Saharan Africa, little is known on how the adoption of MVs influences agriculture productivity and household income. To fill this research gap, we analyze two kinds of data sets in Tanzania: a national representative cross section data and a two-year panel data of irrigated farmers in one district. The most important finding is strong complementary relationship between MVs and water control; high yield is achieved when MVs are grown with improved bund in paddy fields in irrigated area. 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 non-adopters of MVs in the irrigated area. In rain-fed area, we observe limited impact of MVs. These findings suggest that introducing MVs as a package of technologies including other agronomic practices is effective in order 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.

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1. Introduction

Food insecurity and poverty are long-lasting and persisting problems faced by the large majority of population in developing countries in general and in Sub-Saharan Africa (SSA) in particular. It is widely acknowledged that crop genetic improvement played 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 similar impact on the livelihood of poor African farmers (Otsuka, 2006; World Bank, 2008). However, little is known on how far African Green Revolution have progressed, or in other words, how much MVs have diffused and what their impact is on agriculture productivity and household income in SSA. Since socio-economic and agro-climatic conditions, including the endowment of land and labor, and the conditions of infrastructures are different in SSA from Asian countries, we have to 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 the major cereals, rice is the most rapidly growing food source in SSA, and Tanzania is one of the major 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. However, most existing studies are case studies on the adoption of NERICA (New Rice for Africa) (Kijima et al., 2008; Adekambi et al., 2009; Kjima et al., 2011), and little is known how much other modern varieties are adopted and what their impact is on the productivity of and income from rice.

In addition to the impact of MVs on the productivity of rice, we will also examine a 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 bund and plot leveling are important for the proper water management, and transplanting in rows for the 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 complementary impact of MVs and these agronomic technologies is important because MVs are designed to achieve a high yield with appropriate agronomic practices. There are a few socio-economic studies, which point out the importance of these agronomic technologies to enhance the productivity of rice at the household level in the region (Sakurai, 2006; Kijima et al., 2012). However, as far as the authors know, there exists no study that examines the complementary impact of MVs with these new agronomic technologies. We try to identify which agronomic activities must be particularly promoted to achieve MVs' potential yield in Tanzania.

In order to examine these issues, we use two data sets collected by the authors. One data set is a cross-sectional data of 760 households in three major rice growing regions in Tanzania: Morogoro, Mbeya, and Shinanga regions in 2009. We call this data extensive survey (ES) data. Another data set, 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 is suitable to understand the current status of the adoption of MVs in the country since it covers all the major rice growing regions. On the other hand, by using case study data set, we can take advantage of panel data to control unobservable household characteristics to estimate the impact of MVs on the productivity of and income from rice in irrigated area. Using these two data sets, this paper investigates the complementary impact of MVs and other technologies in both 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 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 cultivated in three agro-ecological zones, namely, the Eastern Zone, Southern Highland Zone, and Lake Zone. In order 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, Morogogoro region from the Eastern Zone, Mbeya region from the Southern Highland Zone, and Shinyanga region from the Lake Zone (Figure 1). The sample regions produce nearly 40% of the rice grown in the country. Hence, 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 from 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 villages. In each village, we randomly sampled 10 households, and generated a total sample of 760 households. The survey was conducted from September 2009 to January 2010. We collected two levels of data: village-level data and household-level data. The former was collected by a group interview with village key informants, while the latter was collected by an individual interview. During the interview, farmers were asked to identify the most important rice plot and asked in detail about the rice cultivation practices in the plot. We call this the sample plot hereafter. Figure 1 shows the irrigation status of the sample plots. For our analyses, we dropped

64 households that did not grow rice either because they did not have plots suitable for rice cultivation or their plots did not receive enough rainfall or irrigation water in 2009. We also dropped outliers and our effective sample became 672.

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

Two rounds of surveys were conducted from August to September 2010 and September 2011. In 2010, we interviewed randomly selected 208 farmers in Ilonga and 204 farmers in Chanzuru. We asked farmers to identify the most important rice plot and asked in detail about the rice cultivation in the plot. In 2011, we tried to interview the same household on the same plot. We could interview 173 households in Ilonga and 178 households in Chanzuru, who cultivate the same plot as 2010. After dropping the outliers, our sample size becomes 204 in Ilonga and 194 in Chanzuru in 2010, and 169 in Ilonga and 170 in Chanzuru in 2011, generating 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 extensive survey. In each region, we classify the sample plots into 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 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 on 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 is released in 2002, is by far the most popular MV, and more than 90% of the adopters of MVs grow this variety. In the irrigated area in Morogoro, the share of modern varieties is 87.5%. This is consistent with the experience of 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 (32.2kg per ha) partly because irrigation water and chemical fertilizer are complements. However, in general, chemical fertilizer application does not reach to the level recommended by agronomists (125-250 kg of urea per ha). Turning now to the improved agronomic practices, which consist of the bund construction, plot leveling and transplanting in rows, all practices are more widely adopted in irrigated areas. Among them, however, transplanting in rows, which is a common practice in Asia for easier weeding and harvesting, is still not popular in Tanzania, and only 28.9% of farmers adopt transplanting in rows even in irrigated area.

It is important to note that ES data set reveals that most of the adopters of MVs are in Morogoro region, and only limited numbers of MV adopters exist either in irrigated or rain-fed

areas of Mbeya and Shiyanga regions. Thus, comparison between adopters and non-adopters in all the regions may capture the regional differences of productivity and income between Morogoro and the other two regions. In order to avoid this problem, our analyses hereafter focus only on Morogoro region and compare the adopters and non-adopters of MVs within the region. Since the panel data of CS is available in irrigated area of Morogoro, we take advantage of using it for our analyses in the irrigated area. Meanwhile, for the analysis of rain-fed area, we use sub-sample of ES data in Morogoro region as the panel data was not yet constructed for rain-fed area. In order to avoid confusion, we call the former the case study data of irrigated area and the latter the sub-sample of extensive survey data of rain-fed area hereafter.

Table 2 shows the paddy yields, the adoption of technologies, costs of and income from rice in irrigated area based on the 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 animal. 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 in Chanzuru. The share of the modern varieties in Ilonga scheme is about 30 % in both 2010 and 2011, which is much higher than Chanzuru irrigation scheme (5.3% in 2010 and 9.6 % in 2011). The application of chemical fertilizer is also much higher in Ilonga irrigation scheme (77.5kg/ha in 2010 and 96.7kg/ha in 2011) than in Chanzuru irrigation scheme (10.3kg/ha in 2010 and 15.4kg/ha in 2011). The share of the plot with improved bund[2], 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 plot is slightly higher in Ilonga scheme (71.6% in 2010 and 78.1% in 2011) than in Chanzuru irrigation scheme (66.5 % in 2010 and 65.9% in 2011). The share of the farmers who adopted

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

transplanting in rows also is much higher in Ilonga irrigation scheme (37.3 % in 2010 and 36.1% in 2011) than in 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 Ilonga irrigation scheme. Furthermore, Ilonga irrigation scheme is in a favorable condition in terms of availability of water. Since some technologies such as chemical fertilizer may not be effective 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 the change in the adoption of new technologies over time. Although there is no big change in the adoption of MVs, farmers in both schemes increased the application of chemical fertilizer from 2010 to 2011. The share of the plots with improved bund has 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 scheme.

In addition to the diffusion of new practices, farmers in both schemes received more rainfall and, thus, 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 the rice revenue exceeded that of the costs, and the rice income per hectare also significantly increased in 2011 compared to 2010 in both irrigation schemes. Note also that farmers in Ilonga achieve much higher yield (2.8t/ha in 2010 and 3.9t/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 adopt new technologies and partly because they are in a better position to take 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 rain-fed and irrigated areas. We

show the results of t-tests comparing between the adopter and non-adopters of MVs. First of all, the adopters of MVs apply more chemical fertilizer than non-adopters of MVs in both irrigated and rain-fed areas. The share of the plot with bund is higher for the adopters of MVs both in irrigated and rain-fed area. The share of the plot with improved bund is higher for the adopters of MVs in Ilonga irrigation scheme. This may be because farmers tend to grow MVs in the plot with better water management. The shares of the household who adopt transplanting and transplanting in rows are higher for the adopters of MVs in both rain-fed and irrigated area. In general, the adopters of MVs are also more active in adopting other technologies than non-adopters of MVs.

In both rain-fed and irrigated areas, farmers who adopt MVs achieve higher yield. As a result, the adopters of MVs enjoy higher revenue per hectare in Ilonga irrigation scheme and rain-fed area. The costs of current input and labor increase significantly for the adopter of the MVs because they apply more chemical fertilizer and adopt more labor intensive practices than non-adopters of MVs. However, the increase of the revenue exceeds that of the costs, and the adopters of MVs achieve higher income per hectare in Ilonga irrigation scheme and rain-fed area. These findings suggest that the adopters of MVs achieve higher yield and income from rice per hectare by adopting MVs as well as other new agronomic technologies. Note, however, that in Chanzuru irrigation scheme, the revenue and income from rice per hectare is not statistically different between adopters and non-adopters of MVs. Since farmers in Chanzuru receive less irrigation water than in Ilonga, the adopters of MVs in Chanzuru may not be able 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 area

This section investigates how the adoption of MVs and other technologies jointly contributes to

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

For random effect model, in order to control plot and household characteristics which 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 area and, the size of owned plots in lowland area except the sample plot, for all of which we use the values in 2010.

4.2. Regression results in irrigated area

Table 4 shows the determinants of paddy yield in irrigated area based on the case study data. Model (1) shows the result of pooled OLS model. Models (2) and (3) are the results of household fixed effect models, while models (4) and (5) show the result of random effect

models. In models (3) and (5), we use robust standard errors. Note that there are no farmers in Chanzuru scheme who adopt both MVs and improved bund 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 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. First one examines the joint significance of the interaction terms of 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 Chanzuru village dummy and year dummies.

The 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 impact on the paddy yield. These results indicate the importance of proper water management for MVs to achieve its potential yield. It is also important to note that the F tests of interaction terms of Chanzuru village dummy and year dummies are significant. Since both coefficients of interaction terms of Chanzuru village dummy and year 2010 and 2011 dummies are negative, this indicates that estimated yield function frontier locates significantly lower in Chanzuru irrigation scheme than in Ilonga irrigation scheme. Since Chazuru irrigation scheme is in a less favorable condition than 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 yield.

Chemical fertilizer use and transplanting in rows have positive and significant coefficient in both models (4) and (5). Since interaction term of MVs and chemical fertilizer is not significant, this result indicates that the chemical fertilizer application can have positive

impact on yield even for the non-adopters 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 MVs as the application of fertilizer increases. Since farmers in both irrigation schemes apply much less fertilizer than recommended level of chemical fertilizer (125kg -250kg/ha) by JICA and the local training institution, chemical fertilizer application have positive impact even for the non-adopters 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 bund, 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 yield thorough the adoption of technologies realized higher rice income per hectare. In addition, plot size has negative and significant coefficient, indicating farmers with smaller plots are more efficiently use inputs to maximize their income.

4.3. Methodology and variable construction in rain-fed area

For the analysis in rain-fed area, we have only single-year cross-sectional data of extensive survey, 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. In addition, we include the amount chemical fertilizer applied, and dummy variables which take 1 if bund construction, leveling of plot, and transplanting in rows are adopted respectively. Since most of the adopters of other technologies are the adopters of MVs, we give up including the 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 million 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 last 5 years.

The village-level explanatory variables consist of the existence of Saving and Credit Cooperative Societies (SACCOs)[3] 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 to the nearest extension office (km) to control access to rice-related training. We control the distance from the district capital (km), the existence of a seed market in the village (dummy),[4] and access to a fertilizer market in the village (dummy) in order to capture market access to the various inputs. We also include average male agricultural wage rate in the village measured in terms of kg of paddy.

4.4. Regression results in rain-fed area

Table 6 shows the estimation results of yield and income functions in the rain-fed area based on the sub-sample of extensive survey data. The dependent variable of models (1) to (3) is paddy yield, while models (4) to (6) estimate income functions. Models (1) and (4) control no dummies, while (2) and (5) control district dummies, and (3) and (6) village dummies. We

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[3] Savings and Credit Cooperative Societies (SACCOs) are rural governmental or non-governmental organizations that provide micro-finance at the village or ward level. Some of them function as mutual savings and credit societies for rural people.

[4] During the village-level interviews, farmers are asked about the number of accessible fertilizer dealers and rice seed dealers from the village. We take access to a seed market as 1 if the answer is more than or equal to 1.

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 impact on paddy yield. We also observe the positive and significant coefficient 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 behind these results. First possible reason is that the positive impact of the adoption of MVs on yield and income is not as strong as to overcome the difference in the social and agro-ecological 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 conditions of each village are important determinants of paddy yield and income from rice per hectare. Second possible reason is the low variation of the independent variables, particularly the MVs adoption dummy, among individuals in the same village. In such a case, possible impacts of MVs are absorbed in the village fixed effects. Thus, we failed to conclude that the adoption of MVs has positive impact on yield or income in the rain-fed area, although we also cannot deny completely the possible positive impact.

The existence of SACCOs and 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 the reason why farmers in villages with SACCOs achieve higher paddy yield and rice income per hectare. However, since both chemical fertilizer and transplanting in rows has 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 bund. In fact, without proper water management, MVs has no positive impact on either yield or income from rice per hectare even in irrigated area. Our analyses also show that in Chanzuru irrigation scheme, the adopters of MVs and improved bund achieve lower yield and income than adopters in Ilonga. Due to the limited access to irrigation water, farmers in Chanzuru may not be able to fully take 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 both MV adopters and non-adopters in the irrigated area. Our results suggest that even traditional varieties may respond positively to chemical fertilizer, when small amount of fertilizer is applied. Third, under rain-fed condition, we did not observe 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 condition 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 area by constructing panel data in the future, which we leave for our future research agenda.

These findings suggest that introducing MV as a package of technologies including other agronomic practices would be effective for enhancing the paddy yield and income from rice per hectare in irrigated area. This is because MVs can perform well only when it is grown under good water control. Moreover, since we observe limited impact on MVs in rain-fed area,

investment in irrigation would be important to expand the Green Revolution in Africa.

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

	Morogoro		Mbeya		Shinyanga		Average	
	Rain−fed	Irrigated	Rain−fed	Irrigated	Rain−fed	Irrigated	Rain−fed	Irrigated
Paddy yield (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 who adopted transplanting	12.1	45.7	10.6	71.9	40.2	70	24.4	63.8
Share of households who 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 survey in 2010 and 2011

	Ilonga		Chanzuru	
	2010	2011	2010	2011
Paddy yield (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 which has improved bund	11.8	20.1**	2.1	7.6***
Share of the leveled plot	71.6	78.1*	66.5	65.9
Share of households who adopted transplanting	84.3	82.2	76.8	63.5**
Share of households who adopted transplanting in rows	37.3	36.1	1.5	2.9
Rice revenue (USD/ha)	763.2	1214.6***	486.9	759.3***
Cost of current inputs use (USD/ha)	69.2	69.5	18.7	21.8*
Cost of labor use (USD/ha)	174.9	270.5***	114.4	203.3***
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 year 2010 and 2011.

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

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

	Irrigated area				Rainfed area	
	CS in 2010 & 2011				Sub-sample of ES in 2009	
	Ilonga		Chanzuru			
	Non MV	MV	Non MV	MV	Non MV	MV
Paddy yield (t/ha)	2.9	3.8***	1.9	2.2*	1.8	2.8***
Share of modern varietie (%)	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 which has improved bund	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 who adopted transplanting	80.6	87.9**	69.5	79.5*	4.2	61.5***
Share of households who adopted transplanting in rows	25.0	56.0***	1.2	10.3***	0.0	20.5***
Rice revenue (USD/ha)	896.8	1084.4***	610.2	646.7	523.0	835.9***
Cost of current inputs use (USD/ha)	58.2	87.7***	18.8	31.5***	19.4	39.8***
Cost of labor use (USD/ha)	203.3	242.8**	150.7	200.2**	149.0	249.3***
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 1USD= 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 bund	-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 bund	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 bund	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 hh members in 2010	0.043			0.042	0.042
	(0.047)			(0.037)	(0.047)
Size of owned plot in upland area (ha)	-0.194			-0.203	-0.203

in 2010

	(1)	(2)	(3)	(4)	(5)
	(0.218)			(0.281)	(0.218)
Size of owned plot in lowland area 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 hh 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 lowlandarea 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 hhid		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 survey in 2010 and 2011

| | (1) | (2) | (3) | (4) | (5) |
| | | | FE | | RE |
	Pooled OLS	Fixed Effect	robust SE	Random Effect	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 bund	-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 bund	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 bund	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)

	(1)	(2)	(3)	(4)	(5)
Average year of schooling of adult hh 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 hh 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 hhid		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 yield (t/h) and income from rice (100USD/ha) in the rain-fed area of sub sample of extensive survey 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 bund (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 the 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 the 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 the 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 adult (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 hh 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 hh 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 hh head	-0.110	-0.026	0.022	0.318	0.530	0.597

	(1)	(2)	(3)	(4)	(5)	(6)
	(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 organization 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 in kg of paddy	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