Part 2:

Case Studies

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Case 1:

On the Possibility of a Lowland Rice Green Revolution in Sub-Saharan Africa: Evidence from the Sustainable Irrigated Agricultural Development (SIAD) Project in Eastern Uganda

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Abstract

In many countries in Sub-Saharan Africa, rapid urbanization has led to a surge in demand for rice in urban areas. However, most of the supply depends on imported rice since rice is not a staple food in the rural areas and domestic production is still limited. In order for domestically grown rice to compete with imported rice, improvements in the productivity of rice cultivation are essential in Eastern Uganda. Although rice production has been expanding since the end of the 1990s, its productivity is quite low because basic rice cultivation practices have not been widely adopted. To raise this low level of productivity, JICA has provided training on basic production practices along with small irrigation schemes that are constructed by the farmers themselves. This study attempts to understand the impacts of the demonstration of or training in improved lowland rice management practices on their diffusion and on rice yields using the case of the JICA program in Eastern Uganda. The most important finding of this study is that lowland rice yields can be extremely high in Uganda if basic production practices, such as bunding, leveling, and straight-row planting, are adopted along with the introduction of modern rice varieties and the use of simple irrigation systems, even if chemical fertilizer is not applied. The major challenge is how to find the most appropriate means of

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disseminating such a package of improved production practices to the farmers. According to our analysis, the intensity of participation in the training is the key to the adoption of these basic production practices. It was also found that training participation decreases the further the distance the participants live from the demonstration plot.

Keywords: lowland rice, cultivation practices, diffusion of technology, yield enhancement, Uganda

1. Introduction

In contrast to the dramatic success in increasing agricultural productivity in Asia since the late 1960s, agricultural productivity has been largely stagnant in sub-Saharan Africa (SSA) (Otsuka and Yamano 2005). Due to the rapid population growth and urbanization in the region, the consumption of rice has been increasing far more rapidly than domestic rice production in SSA, thereby increasing the net importation of rice (Balasubramanian et al. 2007; Africa Rice Center 2008). In addition, the sharp rise in cereal prices since 2008 has resulted in serious food insecurity among the poor in this region (Ivanic and Martin 2008; Benson, Mugarura, and Wanda 2008). Given that rice is a major cereal crop that has great potential for an increase in productivity in SSA, strategic efforts to enhance rice production are required urgently not only for food security, but also for income generation (Diao, Headey, and Johnson 2008; Otsuka and Kijima 2010).

It is well known that the rice Green Revolution in Asia was led by the development of high-yielding modern rice varieties, irrigation investment, and the ample use of chemical fertilizers (Hayami and Godo 2005). In SSA, however, irrigation investment by donors and the governments has been low due partly to the high cost of constructing irrigation facilities and partly to the mismanagement of past large-scale government-led irrigation projects (Fujiie et al. 2005; Balasubramanian et al. 2007; Inocencio et al. 2007; Kajisa et al. 2007). The further expansion of upland rice production is limited by abiotic factors (variable rainfall with droughts and dry spells, low temperatures in high altitude areas, poor and degraded soils, surface sealing, erosion on slopes) and biotic factors (weeds, blast and brown spot disease, nematodes, rodents, bird damage) (Balasubramanian et al 2007). In addition, soil degradation is occurring due to the reduced fallow periods (Sakurai 2006). The recent expansion of the area under rice cultivation in SSA has been concentrated in the rainfed lowlands where adequate water control has seldom been implemented (Dalton and Guei 2003). In addition, the actual yields in the lowland ecosystem are much lower than the potential yields (WARDA 1999; Balasubramanian et al. 2007). In other words, rice production in the rainfed lowlands is considered to have high potential for increasing rice production in SSA.[1]

Poor water control is the main factor that limits rice production in the rainfed lowlands of SSA. Many abiotic and biotic stresses also diminish rice yields in this ecosystem. Abiotic stresses include variable rainfall with drought and flooding occurring in the same season, iron, aluminum and manganese toxicity in the humid forest zones and in the poorly drained soils of the coastal lowlands, and inland salinity and alkalinity in dry areas. Weeds, insect pests (stem borers, African rice gallmidge, rice bugs), diseases (blast, brown spot, rice yellow mottle virus), rats and birds are the major biotic stresses for rainfed lowland rice in SSA (Balasubramanian et al. 2007).

In addition, one of the reasons why the yields of lowland rice are currently far lower than their potential in SSA is that many rice growers cultivate lowland rice without applying appropriate cultivation practices (Balasubramanian et al. 2007). In many countries, chemical fertilizers are so expensive that farmers apply very little fertilizer to their rice crops, leading to continuous soil mining (Sanchez 2002). In some cases, the seeds are broadcasted, which decreases the germination rate and makes it difficult to maintain the proper spacing for planting and to remove weeds when no space is provided to carry out this procedure. Even when transplanting is adopted, the seedling tends to be too old, and straight-row planting is not practiced, which would facilitate weeding and maintain the proper spacing of the plants. Bunding and leveling are not applied or properly practiced so that the available water is not stored evenly in the paddy fields.[2] In order to achieve high productivity in lowland rice farming, the Japan International Cooperation Agency (JICA) has initiated a sustainable irrigated agricultural development (SIAD) project in Eastern Uganda that provides training in lowland rice cultivation practices based on experience in Asia.

1. Water is the main limiting factor for rice production or for that matter, any other crop. Valley bottoms in SSA are the most important locations, but they are not fully exploited even though they can be used to produce rice sustainably with good land preparation, leveling and crop management practices, as described in this paper. However, other constraints such as human diseases associated with marshlands in SSA, the lack of access for the rice production centers in valley bottoms to markets in ,large cities, and the fragile level of cooperation among farmers in relation to water sharing and the maintenance of irrigation structures may limit the full exploitation of these valuable resources. If the infrastructure is developed and human diseases are controlled, rice production in valley bottoms can contribute significantly to food security and a Green Revolution in SSA.

2. Soil leveling is associated with the even distribution of water in the field, which helps to control weeds, and is another critical factor limiting rice yields in the rainfed lowlands.

This study attempts to understand the impact of demonstrations or training based on the new rice technology on its diffusion and on rice yields using the case of the JICA program. Before starting the actual program, the current rice-growing conditions, constraints and problems of the farmers in the study area were assessed and analyzed in order to select suitable solutions and technologies that would address the problems identified. Specifically, the effects of the training on the production performance were divided into four parts: (1) participation in the training, (2) understanding of the recommended cultivation practices, (3) adoption of practices and feedback from the farmers regarding adoption of the technology, and (4) yield enhancement. By conducting this study, the intention was to highlight the potential for a lowland rice Green Revolution. Our empirical analyses show that (1) participation in the training is mainly determined by the distance of the location of the participant from that of the demonstration plot, (2) the training increases the participant's understanding of the recommended cultivation practices but one day of training is not sufficient for farmers to fully understand the appropriate production knowledge, (3) the level of participation in the training increases with the potential for applying bunding and straight-row planting, but not for leveling and planting at the proper age of the seedlings, and (4) lowland rice yields can be extremely high in Uganda if basic production practices are adopted along with the adoption of modern varieties and the use of simple irrigation systems.

The rest of this paper is structured as follows. Section 2 describes the present state of lowland rice production in Eastern Uganda and the contents of the JICA project. Section 3 describes the sample data used in this paper and examines the descriptive statistics. In section 4, the estimation models on participation in the training, the adoption of new cultivation practices, the level of understanding of the training materials, and the yield function are introduced and the estimation results are presented. The last section concludes the paper with a presentation of its policy implications.

2. Lowland rice production in Eastern Uganda and the SIAD project

2-1 Lowland rice production in Eastern Uganda

In Uganda, about 10 percent of the country is covered by wetlands or swamps in valley-bottoms (FAO 2006), which are particularly suitable for lowland rice production. In fact, rice is one of the few profitable cash crops grown in the lowlands in this region. In Eastern Uganda, lowland rice cultivation technology and modern rice varieties were introduced in the 1970s by the Chinese in the Kibimba Rice Scheme and Doho Rice Scheme (FAO 2006).[3] Since then, unutilized swamps (normally covered with papyrus) have been rapidly converted to lowland rice fields.

The modern variety of rice developed by the International Rice Research Institute (IRRI) was crossed with local varieties. "K5" (a rice variety from one of the first rice production attempts under the irrigation scheme, namely Kibimba) and "supa" (meaning rice) are improved local varieties that have been widely adopted in the lowland areas of Eastern Uganda. It is said that the origin of K5 was one of the early modern varieties developed by IRRI, but the origin of supa is less clear. In the upland areas, sweet potato, maize, and cassava are grown for home consumption. Eastern Uganda is located in the bimodal rainfall zone, and farmers in the irrigation schemes are engaged in the double-cropping of rice in both seasons (Nakano 2010). In many rainfed lowlands, unless the rainfall is too low, the double-cropping of rice is common.

2-2 SIAD project

The objective of this JICA project is to increase rice production and productivity by introducing the sustainable rice cultivation practices that have been widely adopted in Asia in combination with small-scale simple irrigation facilities. The project covers 22 districts in Eastern Uganda and was implemented from July 2008 and will be completed in June 2011. The training starts in phases: the first cropping season of 2009 (called Group A in 10 districts), the second cropping season of 2009 (Group B in 6 districts), and the first cropping season of 2010 (Group C in 6 districts).

One project site is selected for each district. The selection of these sites is purposive since lowland rice cannot be grown in upland areas. Indeed, all the project sites are wetlands with seasonal or year-round springs and streams. In addition to this geographical condition, the formation of an association of rice farmers was a prerequisite for implementing the project in the selected areas. Thus, it is reasonable to

3. In the 1970s, the Chinese initiated the development of rice schemes with the Kibimba rice scheme (600 ha) as a rice technology development scheme and the Doho rice scheme (1000 ha) for seed multiplication and the popularization of production. These areas are still major rice production areas in Eastern Uganda.

assume that farmers in the project sites tend to be more motivated and to have relatively more favorable access to water than the average Ugandan farmer and the sites selected by JICA are more or less similar in terms of the environment for rice cultivation.

Training was provided for the district agricultural officer (DAO), extension workers, and lead farmers with a view to disseminating the basic knowledge regarding rice cultivation practices and small irrigation management practices by word of mouth communication. JICA experts and extension workers provided field training to the farmers at demonstration plots in each project site, with the plots ranging from 0.2 ha to 0.4 ha. The training consisted of four parts: (1) the establishment of a demonstration plot and the construction of irrigation channels in the surrounding area [3 days]; (2) the preparation of nursery beds, the seeding of the nursery beds, and leveling the main field [half a day]; (3) transplanting and weeding [half a day]; and (4) harvesting and threshing [half a day].

JICA was responsible for setting up the demonstration plot and building the irrigation channels that connect the demonstration plot with a source of water. The farmers were required to construct their own irrigation channels with guidance and help from JICA by digging the ditches using hand hoes. This small irrigation scheme does not require the establishment of a systematic water sharing mechanism among the farmers. When water needs to be provided to the plots, the farmers do this according to their need. Normally, the channels are not cleaned communally. The farmers only clean the channels adjacent to their own plots. In many schemes, the farmers do not know how to control water or understand the role of drainage.[4] There are no devices for metering the intake of water into individual fields. Even though the title of the project includes the term "irrigation," it does not involve the construction of modern irrigation facilities, which are expensive to construct and maintain. This is because JICA experts believe that even if modern irrigation systems are constructed, the productivity of rice cultivation cannot be enhanced significantly without the institution of proper cultivation practices. Thus, only simple irrigation facilities are being promoted in this JICA project.

4. Evidence that farmers do not understand the role of drainage includes the fact that many of them also use water from drainage sources.

3. Data

3-1 Sampling

Among Group A, five districts have been carrying out similar projects since 2005.[5] To assess the mid-term impact of the training project, two sites from Group A (namely Bugiri and Mayuge, where the water source consists of seasonal streams) were sampled. Although pre-project information on these two sites could not be obtained, information was collected for the new sites (namely Pallisa and Bukedea, where the water source consists of year-round springs) where the training started just prior to data collection. The data on yields and cultivation practices in the previous season were collected. Thus, the adoption of cultivation practices and rice yields were not affected by the JICA training in these new sites. By using this difference in the starting time of the training, measurement of the average effect of the training on treatment, including the spillover effect from the training participants to non-participants, was measured whereby the new sites were the control group and the other two sites were the treatment group.

At each site, 75 households were selected based on the distance from the demonstration plot to the rice plot of each household in order to capture the diffusion process beginning from the demonstration plot.[6]

3-2 Descriptive statistics

Table 1 shows the status of participation in the JICA training by project site. In Bugiri, just after JICA started the training, the number of training participants was large and by the end of 2007, 70% of the sample households had taken part in the training at least once. In contrast, the training participation rate was lower in Mayuge and it was only 35% by 2007. This low participation rate was not due to the lack of information about JICA's demonstration project on the part of non-participants. In the case of the Mayuge site, 41% of the non-participants answered that they were not interested in the training. The intensity of the training received among the participants was also quite different. In Bugiri, 28% of the sample farmers attended the training for more than 5 days. The

5. The name of the project is "The Study on Poverty Eradication through Sustainable Irrigation in Eastern Uganda" (the "Development Project" in short) under which pilot projects were implemented in 2005 and 2006 for the purpose of promoting sustainable irrigation development and the components of the project were about the same as for SIAD.

6. The sample lowland areas are oval shaped with one long diameter and one short diameter. Across the short diameter there are 6-10 plots. One plot was selected randomly at approximately 25-meter intervals from the demonstration plot in two directions along the long diameter. Half of the plots were rented land and 70% of these were rented before 2008.

difference in training intensity is likely to result in a difference in the effect of the training on the comprehension of what was taught in the training sessions.

The trend in yields over time is shown in Table 2. In normal years (i.e., 2007 and 2008), the average rice yield was about 2.7 tons per hectare in the four sites. The yield in the new sites (Bukedea and Pallisa) was significantly lower by 2 tons per hectare than that in Bugiri and Mayuge where JICA provided training from 2005. Since there is no data on pre-program yields in Bugiri and Mayuge, it is not possible to show the difference in yields before and after the training in these areas. It is, however, likely that the situation in the new sites was similar to that in Bugiri and Mayuge before JICA started the training.

In Bugiri, the average rice yield reached 4.7 tons per hectare, while in the new sites, the yield was lower at 1.3 tons to 1.6 tons per hectare. The yield in Mayuge fell somewhere in between. The superior performance of Bugiri may be due to the fact that Bugiri has an irrigation facility covering 10 hectares that was constructed by JICA in addition to the areas outside of the scheme where the farmers created channels between the water source and their fields, which was similar to other project sites. Subsequently, there may be a difference in the yields between the farmers inside the JICA irrigation scheme and those outside in the Bugiri site. The yields are, however, not significantly different between the farmers inside and those outside the scheme (in 2009, 4.05 and 3.99 tons per hectare inside and outside the scheme, respectively). This finding suggests that simple irrigation facilities constructed by farmers can significantly improve the efficiency of rice farming.

Table 3 shows the adoption of improved cultivation practices in the cropping seasons of the September 2008 to August 2009 period. In Bugiri, all the recommended cultivation practices were adopted by most of the sample households including both the training participants and non-participants. In Mayuge and Pallisa, the proper timing of transplanting and straight-row planting was not implemented on a large scale. In Bukedea, the adoption rate of all the practices was as low as 10% to 28%. Although proper chemical fertilizer application was not taught in the SIAD training,[7] the amount of chemical fertilizer used in the sample areas is indicated in the table. It is clear that chemical fertilizer is rarely applied in the sample sites.

Table 4 shows the rice yield separately according to the number of new improved cultivation practices actually adopted between

7. In the Development Project in 2005 the use of chemical fertilizer was taught in the training.

September 2008 and August 2009. It is clear that the average yield rises the more of the practices that are adopted by the farmers. In Bugiri, the yield was 4.5 tons per hectare when four of the practices were adopted, while the yield when only one practice was adopted was 2.3 tons per hectare. This significant difference in yield suggests that there is some complementarity between the improved cultivation practices. There is no clear relationship between the number of practices applied and the yield in the new sites. This suggests that these farmers applied them incorrectly since they had not yet received the training.

Table 5 indicates the availability of water in the rice plots. In Burigi and Mayuge, water is supplied through irrigation channels to most of the rice plots. In the new sites (Bukedea and Pallisa), 21% of the plots have wells in the plots. In Bukedea, water flows into the plot directly from neighboring plots without the use of irrigation channels (cascade irrigation from field to field) in 68% of the plots. The yield tends to be higher when water flows into the plot from irrigation channels and there is also a well in the plot than in plots without these sources. Another measure of water availability is the subjective assessment of the farmers. Farmers were asked about the moisture status of the soil at the flowering stage when the availability of water critically affects the yield. The table shows that about 20% of the plots were dry at the flowering stage and 53% of the households actually controlled the water intake at the flowering stage. The yield in the plots with water at the flowering stage is much higher than in those without water. However, the difference is not significant, probably because the drought negatively affected the plots with water at the flowering stage as well.

4. The models and their results

In this section, four empirical models are analyzed. Firstly, the determinants of participation in the training are examined. This is because, as indicated in the previous section, the participation rates in the training vary according to the program sites. Even when the training enhances the productivity of rice harvests, the effect of the training will be limited without the participation of the farmers. Secondly, an examination was conducted as to whether the farmers understood the contents that were taught in the training. This is important since participation in the training does not guarantee that the information has been adequately acquired by the participants. If this is correct, then an increase in the amount of participation in the training will not necessarily contribute to an increase in rice productivity. Thirdly, the determinants of the adoption of the practices taught in the training are analyzed. Even when farmers participate in the training and understand the materials of the training, the farmers that participated may not adopt the technologies that were taught in the training. In this case, it is crucial to identify the factors that prevent these farmers from adopting the technology in order to accelerate its adoption. Fourthly, the yield function is estimated in order to quantify the impact of participation in the training, the participant's understanding of the technology, and the level of adoption of the technology.

4-1 Participation in the training

To increase the effectiveness of the training, it is important to understand the factors that determine participation in these training sessions. For the Bugiri and Mayuge sites, it is difficult to examine this properly since there is no pre-program data. For the new sites (Bukedea and Pallisa), it is possible to assess more accurately the determinants of participation in the training.

Since those farmers whose plots are close to the demonstration plot and who belong to a farmers group are expected to have better access to information concerning the training through established geographical and social networks among the farmers, their participation rates in the training are expected to be higher. Thus, the decision as to whether a particular household participates in the training is assumed to be a function of the distance from the demonstration plot to their own plot and the social network that the household has access to. The dependent variable is the number of days of training that the households participated in between September 2008 and August 2009 since the program was initiated in August 2009 at the new sites. The explanatory variables were measured in September 2008. This model is estimated according to Ordinary Least Squares (OLS) analysis.

Table 6 shows the results of the estimation. At the new sites, the number of days of training that the participants attended is mainly determined by the distance from the demonstration plot, not by the number of farmers in the group that the household belongs to. This is to be expected since the program had just started establishing the new sites and JICA was preparing to expand the number of training participants by offering training sessions to neighboring households during the remaining period of the program. When the effects of the training become apparent to the training participants and information concerning the positive effects of the training is shared with the non-participants, the distance to the demonstration plot may become an insignificant determinant of participation in the training.

4-2 Does training enhance understanding of the improved production practices?

Examination of the factors that enhance understanding of the cultivation practices is important since the training materials first need to be understood correctly, otherwise the training cannot be effective. It is reasonable to postulate that the level of understanding of the materials is higher when the period of participation is longer and the farmers are better educated. To analyze this rigorously, a regression model was run.

To measure the level of knowledge concerning cultivation practices by the farmers, the sampled farmers were asked to take a simple quiz about rice cultivation. This quiz was given on the last page of the questionnaire so that it would not affect the responses to the rest of the questionnaire. The quiz covers what was taught in the JICA training sessions such as the importance of field leveling and using seedlings of an appropriately young age for transplanting. In this model, the dependent variable takes unity when the households answer the quiz questions correctly and is zero otherwise. The data indicates that the proportion of sample households that correctly answered the quiz concerning leveling and the seedling age for transplanting was 40% and 62%, respectively. There is a positive correlation between the proportion of positive responses and the number of days of training.

In order to measure the intensity of the training, which is an important explanatory variable, the number of days of training accumulated by the time the quiz with the farmers was conducted was used as the variable. This means that this variable takes non-negative values at the new sites since some farmers had already participated in the JICA training just before the collection of the data. Since it is the more able farmers who tend to seek training opportunities and such farmers would have also performed better on the quiz than non-participants, even if they had not participated in the training, the training participation variable can be endogenous. To correct the bias arising from this simultaneity, the instrumental variable Probit estimation model was applied, where the distance from the demonstration plot to the household's rice plot was used as an instrumental variable for the training participation variable.

Table 7 shows the results of this estimation, whereby the estimated coefficients demonstrate the marginal effects. In the first column, the dependent variable is a dummy variable representing whether a farmer answered the question on leveling correctly or not. In the second column, the dependent variable takes unity if the farmers answered the question on the appropriate seedling age for transplanting correctly and zero otherwise. In both columns, participation in the training increases the probability of giving the correct answer for the questions on cultivation practices taught in the training. The estimated marginal effect of the training suggests that one additional day of training increases the probability of correctly answering the question by 12% to 15%. Thus, it is desirable to provide repeated training sessions for the farmers in order to enable them acquire the appropriate production knowledge.

4-3 Effect of training participation on the adoption of the cultivation practices

Whether the recommended cultivation practices were adopted or not should be affected by the characteristics of the household such as access to information, rice cultivation experience, and asset holdings, as well as the plot characteristics such as water availability and land tenancy. As shown in the previous sub-section, participation in the JICA training enhances the knowledge that was gained regarding the improved production practices, which is expected to increase the adoption rate. Even without the training, some farmers may learn effective ways of growing rice according to their experience, which leads to an increased adoption rate among experienced farmers. Since these practices require more labor inputs and households may need to hire labor, asset holdings may affect their adoption. These practices also have particularly significant impacts on rice production when water is available, thus their adoption is also determined by the availability of water. If the plot is rented, these farmers may attempt to maximize the net returns to at least recover the land rental fee, which requires intensification such as the adoption of better cultivation practices.

In the regression analyses, a dependent variable takes unity if a new cultivation practice (bunding, leveling, timing of transplanting, or straight-row planting) was adopted between September 2008 and August 2009. Explanatory variables at the household level take the values at the beginning of September 2008 and those at the plot level are measured in each respective cropping season. As explained above, the training variable is considered to be an endogenous variable. Thus, the IV Probit model is applied.

Table 8 shows the estimation results for the adoption of the four critically important cultivation practices taught in the JICA training. The probability of applying bunding and straight-row planting increases with any increase in the number of days that households participated in the JICA training. The adoption rate of straight-row planting increases with greater lowland rice cultivation experience. Better access to water, measured by a well dummy, also increases the likelihood of using proper young seedlings and applying straight row planting, indicating the complementarity between water availability and the improved production practices related to the planting. When a plot is rented, the use of proper young seedlings is less likely to be implemented.

4-4 Effect of the training on rice yields

Whether participation in the training increases rice yields is examined in this sub-section. The determinants of the yield in the cropping seasons of 2008-2009 are examined using cross-sectional data. The yield in the cropping season between September 2008 and August 2009 is assumed to be determined by the household characteristics such as participation in the training before September 2008, knowledge and application of the recommended practices, rice cultivation experience, asset holdings, and household composition in September 2008 as well as the plot characteristics such as water availability and the security of tenure of the plot in the respective cropping seasons. Given that training participation, knowledge, and application of the recommended practices are highly correlated, these variables are used separately. Although the training variable seems endogenous, the test for endogeneity shows that it is not endogenous. Thus, the yield function is estimated using OLS.

Table 9 shows the estimation results of the yield function in the cropping seasons of 2008-2009. As shown in column 1, participation in the training increases the rice yields: Each additional day of training increases the yield by 0.2 tons per hectare. The correct knowledge about seedling age has a positive effect on yield, suggesting 0.6 tons per hectare, if the farmers answered the quiz correctly. In terms of its actual application, only straight-row planting has a significant impact on yield.

Unexpectedly, lowland rice cultivation experience does not increase the yield. Recent migrant households tend to have a lower yield in all specifications. Households owning a larger per capita land area tend to obtain higher yields. The other household characteristics do not have a significant impact on rice yields. Among the plot characteristics, the size of the plot is the only variable that is significant. A smaller plot is associated with higher yields, probably due to better field leveling and water control and good crop management.

Conclusions

The most important finding of this study is that lowland rice yields can be extremely high in Uganda if basic production practices, such as bunding, leveling, the use of young seedlings, and straight-row planting, are adopted along with the adoption of modern varieties and the use of simple irrigation systems, even if chemical fertilizer is not applied. Thus, there is no question that a lowland rice Green Revolution is possible in Eastern Uganda and in similar areas (valley bottoms) of sub-Saharan Africa.[8] Note that aside from the lack of the application of chemical fertilizer, the other production practices are those commonly adopted in Asia, which suggests the high transferability of Asian rice farming practices to SSA. The major challenge is how to disseminate such a package of improved production practices to a large number of farmers with limited education and experience in modern rice cultivation.

According to our analysis, the intensity of training participation is the key to the adoption of the basic production practices. It was also found that participation in the training decreases as the distance from the demonstration plot increases. At the same time, however, non-participants in the training learn from those who participated. Further research is obviously needed to identify the most effective ways of disseminating new lowland production practices towards the achievement of major productivity gains in rice farming in Uganda and possibly in other areas of SSA.

8. Soils in the valley bottoms are rich in nutrients due to runoff and leaching from the adjacent slopes and uplands. As such, yields will be high in the initial stages, but with continuous cultivation yields may decline due to mining of the soil nutrients and the development of multiple nutrient deficiencies. Maintenance of the soil nutrient status and soil fertility is critical to sustaining high yields over the long term. In addition, new insect pests and diseases may emerge and precautions must be taken from the beginning to prevent such attacks by developing resistant varieties and clean cultivation practices.

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Table 1. Participation in the JICA training

	Bugiri	Mayuge	Pallisa	Bukedea
Number of sample households	75	75	75	75
Year the JICA training started	2005	2005	2009	2009
No. of HH participating in the JICA training for the first time in 2005	30	9	0	0
No. of HH participating in the JICA training for the first time in 2007	20	11	0	0
No. of HH participating in the JICA training for the first time in 2008	3	5	0	0
No. of HH participating in the JICA training for the first time in 2009	0	4	15	25
Percentage of households with				
Number of training days=0	29.3	61.3	66.7	80.0
0 < Number of training days <=5	42.7	26.7	24.0	14.7
5 < Number of training days <=10	22.7	12.0	9.3	5.3
10 < Number of training days <=20	5.3	0.0	0.0	0.0
Number of Non-participants in the JICA training	22	46	60	50
% of non-participants who did not know about the demonstration plot	27.9	8.8	19.8	14.0
Reason why they did not participate in the JICA Training (% of Non-Participants)				
Did not know about it	68.9	45.5	83.1	78.7
Not interested	15.6	40.9	11.9	21.3
Busy	13.3	9.1	3.4	0.0
Did not have the money to pay to join the association	2.2	4.6	1.7	0.0

Table 2. Rice yields in 2007 - 2009

	All	Bugiri/ Mayuge	Bukedea/ Pallisa		Bugiri	Mayuge	Bukedea	Pallisa
2005	3.08	3.60	1.77	*	3.98	2.72	1.40	2.10
	(2.52)	(2.72)	(1.11)		(2.96)	(1.81)	(0.94)	(1.16)
2007	2.65	3.50	1.52	*	4.64	2.17	1.31	1.61
	(2.85)	(2.98)	(1.03)		(3.35)	(1.71)	(0.98)	(1.06)
2008	2.65	3.40	1.43	*	4.75	2.32	1.35	1.56
	(2.83)	(2.79)	(1.46)		(2.80)	(2.90)	(1.51)	(1.40)
2009	2.50	3.02	1.35	*	4.03	1.82	1.29	1.46
	(2.61)	(2.78)	(1.69)		(3.21)	(1.43)	(1.89)	(1.26)

The numbers show the means for the rice yield and the standard deviations are in parentheses.
* This asterisk indicates that the difference in the yields between the treatment districts and the control districts is statistically significant at the 5% level.

Table 3. Adoption of cultivation practices in September 2008 – August 2009

	All	Bugiri	Mayuge	Bukedea	Pallisa
	Adoption %				
Bunding	83.8	100.0	95.2	24.1	81.5
Leveling	69.7	83.3	84.1	27.6	48.1
Transplanting	75.1	100.0	71.4	10.3	92.6
Proper timing of transplanting	43.8	69.7	39.7	10.3	25.9
Straight-row planting	33.0	81.8	4.8	10.3	3.7
Fertilizer use	1.1	2.8	0.0	0.0	0.0
Fertilizer application (kg/ha)	13.2	13.2	---	---	---
(s.d.)	(1.4)	(1.4)	---	---	---
Adoption % among the training participants *					
Number of observations**	90	49	25	12	4
Bunding	92.2	100.0	92.0	58.3	100.0
Leveling	73.3	85.7	76.0	25.0	50.0
Transplanting	81.1	100.0	68.0	25.0	100.0
Proper timing of transplanting	54.4	75.5	32.0	25.0	25.0
Straight-row planting	57.8	93.9	12.0	25.0	0.0
Fertilizer use	2.1	3.8	0.0	0.0	0.0
Fertilizer application (kg/ha)	13.2	13.2	---	---	---
(s.d.)	(1.4)	(1.4)	---	---	---
Adoption % among the training non-participants					
Number of observations	95	17	38	17	23
Bunding	75.8	100.0	97.4	0.0	78.3
Leveling	66.3	76.5	89.5	29.4	47.8
Transplanting	69.5	100.0	73.7	0.0	91.3
Proper timing of transplanting	33.7	52.9	44.7	0.0	26.1
Straight-row planting	9.5	47.1	0.0	0.0	4.4
Fertilizer use	0.0	0.0	0.0	0.0	0.0
Fertilizer application (kg/ha)	---	---	---	---	---
(s.d.)	---	---	---	---	---

* The "Participants" in Bukedea and Pallisa participated in the training after the survey period. The difference in the adoption rate between the participants and non-participants in these two districts cannot be interpreted as the impact of the training.
** The number of observations is lower than that shown in Table 1 (those who participated in the training) because some households had not obtained any harvest by the end of August 2009 and such households were dropped in the plot-level analyses below.

Table 4. Rice yields according to the cultivation practices adopted in September 2008 – August 2009

	All	Bugiri	Mayuge	Bukedea	Pallisa
4 practices	4.13	4.47	2.89	1.22	0.37
	(3.14)	(3.20)	(1.83)	(0.74)	---- a
3 practices	3.20	4.15	1.89	---	1.54
	(2.78)	(3.17)	(1.31)	---	(1.14)
2 practices	2.25	3.07	2.00	3.95	2.26
	(1.75)	(3.44)	(1.44)	(1.40)	(1.09)
1 practice	1.81	2.30	1.91	1.89	1.38
	(1.43)	(0.80)	(1.13)	(1.87)	(1.23)
Non-adopters	1.33	---	0.79	1.42	0.66
	(1.99)	---	---a	(2.10)	(0.56) b
Fertilizer use	7.55	7.55	---	---	---
	(2.28) c	(2.28) c	---	---	---

The numbers show the means for the rice yield in tons per hectare and the standard deviations are in parentheses.
a Only 1 observation. b Only 3 observations. c Only 4 observations.
4 practices = bunding, leveling, proper timing of transplanting, straight-row planting.
3 practices = among the 4 practices, 3 of the practices were implemented.

Table 5. Water availability in September 2008 – August 2009

	All	Bugiri	Mayuge	Bukedea	Pallisa
% of plots where					
Water comes through irrigation channels	71.0	95.4	79.1	10.6	53.6
Well in the plot	5.9	0.0	0.0	21.3	21.4
Water flows through neighboring plots	23.1	4.6	20.9	68.1	25.0
Yields					
Water comes through irrigation channels	3.16	4.17	2.10	0.84	1.75
	(2.76)	(3.21)	(1.44)	(0.75)	(1.00)
Well in the plot	1.79	---	---	1.51	2.26
	(1.54)	---	---	(1.52)	(1.59)
Neither	1.88	4.42	1.57	1.81	1.19
	(1.97)	(2.20)	(1.02)	(2.24)	(1.14)
Subjective water availability					
Flowering stage: with water	49.8	54.6	46.5	46.8	46.4
Flowering stage: wet	29.7	26.9	29.1	36.2	32.1
Flowering stage: dry	20.4	18.5	24.4	17.0	21.4
Controlling water at the flowering stage	53.2	60.2	57.0	23.4	64.3
Yield					
Plot with water at the flowering stage	2.93	4.13	1.71	2.33	2.32
	(2.37)	(2.73)	(0.87)	(2.33)	(1.15)
Dry plot at the flowering stage	2.26	3.53	1.84	1.23	0.85
	(2.49)	(3.35)	(1.31)	(1.95)	(0.95)

The numbers show the means and the standard deviations are in parentheses.

Table 6. Determinants of the number of days of training that were participated in (OLS)

	Bukedea (1)	Pallisa (2)
Distance from demonstration plot (km)	-1.136	-0.168
	(3.65)**	(3.57)**
Number of farmers groups the participant belonged to	-0.267	0.023
	(1.26)	(0.55)
Year the household started cultivating lowland rice	-0.008	-0.003
	(0.63)	(1.15)
Moved to this area after 2000 dummy	0.305	0.030
	(1.26)	(0.67)
Female-headed household dummy	0.080	0.057
	(0.21)	(0.46)
Land owned (ha)/number of adult family members (aged 15-64)	0.292	0.081
	(1.28)	(1.67)+
Initial assets (household, agricultural, livestock) (USD)	0.000	0.000
	(0.86)	(0.22)
Household head's age	0.036	-0.000
	(2.54)*	(0.27)
Household head's years of education	-0.018	0.015
	(0.50)	(2.24)*
R-squared	0.69	0.68
Observations	52	75

The numbers shown are coefficients and the t-statistics are in parentheses.
Household-level data. + significant at 10%; * significant at 5%; ** significant at 1%

Table 7. Effect of the training on understanding of the technology (Household level, IV Probit, Marginal Effects)

	Leveling (1)	Seedling age (2)
Number of days of training a	0.119	0.147
	(1.89)+	(2.17)*
Member of a non-rice association	0.034	0.461
	(0.21)	(1.23)
Year the household started cultivating lowland rice	0.015	-0.062
	(1.23)	(0.34)
Moved to this area after 2000 dummy	-0.119	-0.211
	(0.63)	(0.13)
Female-headed household dummy	-0.344	1.850
	(0.86)	(2.19)*
Land owned (ha)/number of adult family members (aged 15-64)	0.228	0.198
	(1.40)	(0.42)
Initial assets (household, agricultural, livestock) (USD)	-0.000	0.000
	(0.19)	(1.01)
Household head's age	0.004	0.006
	(0.55)	(0.82)
Household head's years of schooling	0.003	0.051
	(0.15)	(2.03)*
Bugiri	-0.429	-0.727
	(1.68)+	(2.57)*
Pallisa	-0.141	-1.247
	(0.51)	(2.18)*
Bukedea	-0.040	-0.888
	(0.15)	(0.41)
Number of observations	276	276

The numbers shown are the marginal effects at the means and the z-statistics are in parentheses.
[a] Training participation = endogenous, instrumented by distance to the demonstration plot.
[+] significant at 10%; * significant at 5%; ** significant at 1%

Table 8. Effect of training participation on the adoption of the new technology (cultivation practices)
(Plot-level, IV Probit Model, Marginal Effects)

	Bunding (1)	Leveling (2)	Proper seedling age (3)	Straight-row planting (4)
Number of days of training participated in (before Sep. 2008)	0.176	0.069	0.132	0.362
	(2.08)*	(0.63)	(1.42)	(14.15)**
Year the household started cultivating lowland rice	0.001	-0.033	-0.009	-0.005
	(0.03)	(1.10)	(1.10)	(1.75)+
Moved to this area after 2000 dummy	-0.208	0.049	-0.275	-0.344
	(0.58)	(0.53)	(0.34)	(1.45)
Female-headed household dummy	-0.215	0.109	-0.656	
	(0.31)	(0.13)	(1.00)	
Land owned (ha)/number of adult family	0.221	0.108	0.108	0.161
members (aged 15-64)	(0.82)	(0.26)	(0.09)	(0.33)
Initial assets (household, agricultural, livestock)	0.000	0.000	0.000	0.000
(USD)	(0.24)	(0.50)	(1.26)	(0.98)
Household head's age	-0.005	-0.024	-0.024	-0.032
	(0.42)	(2.06)*	(0.36)	(1.61)
Household head's years of schooling	-0.036	0.067	-0.017	-0.023
	(0.94)	(0.52)	(1.12)	(0.97)
Water from channels	0.388	0.486	0.323	0.942
	(1.02)	(0.81)	(0.81)	(0.91)
Well in the plot	0.549	0.480	0.878	0.616
	(1.09)	(0.45)	(1.71)+	(1.88)+
Plot is rented	0.403	0.870	-0.200	-0.104
	(1.02)	(0.68)	(1.98)*	(0.54)
Size of the plot (ha)	0.809	0.252	-0.798	-0.624
	(1.06)	(0.44)	(1.47)	(1.12)
Plot is under a customary tenure system	-0.064	0.507	-1.337	0.215
	(0.13)	(0.58)	(0.58)	(0.38)
Bugiri		-0.342	0.200	
		(0.92)	(0.53)	
Pallisa	-0.305	-1.352	0.784	-0.427
	(0.43)	(1.36)	(1.36)	(0.55)
Bukedea	-1.852	-1.805	-1.491	-2.379
	(2.31)*	(2.81)**	(1.23)	(1.88)+
Constant	-0.698	69.581	18.530	-1.316
	(1.81)+	(1.14)	(1.14)	(26.00)**
Wald chi-squared	47.3	60.0	60.5	208.4
Observations	253	253	253	253

The numbers shown are the marginal effects at the means and the z-statistics are in parentheses.
+ significant at 10%; * significant at 5%; ** significant at 1%

Table 9. Yield function (ton/ha), September 2008 - August 2009 (OLS)

	(1)	(2)	(3)
Number of days of the JICA training (before Sep. 2008)	0.188		
	(4.47)**		
Answered quiz on leveling correctly =1		0.096	
		(0.29)	
Answered quiz on the seedling age correctly =1		0.594	
		(1.85)+	
Bunds =1			0.347
			(0.62)
Leveling =1			0.284
			(0.76)
Proper seedling age =1			-0.205
			(0.63)
Straight row planting =1			0.734
			(1.71)+
Household head's age	-0.009	-0.013	-0.012
	(0.68)	(0.99)	(0.88)
Household head's years of schooling	-0.041	-0.031	-0.027
	(1.01)	(0.75)	(0.64)
Female-headed household	-0.792	-0.818	-0.707
	(1.03)	(1.03)	(0.88)
Year the household started cultivating lowland rice	0.257	0.249	0.236
	(0.97)	(0.91)	(0.86)
Moved to this area after 2000 dummy	-0.036	-0.046	-0.042
	(1.76)+	(2.18)*	(1.96)+
Land owned (ha)/number of adult family members (aged 15-64)	0.615	0.574	0.680
	(1.79)+	(1.61)	(1.88)+
Initial assets (household, agricultural, livestock) (USD)	0.000	0.000	0.000
	(1.12)	(1.09)	(1.23)
Water from channels	-0.309	-0.296	-0.366
	(0.75)	(0.69)	(0.84)
Well in the plot	0.073	0.139	0.037
	(0.11)	(0.21)	(0.06)
Plot is rented	-0.459	-0.256	-0.384
	(1.56)	(0.84)	(1.26)
Size of the plot (ha)	-4.120	-4.200	-4.112
	(5.39)**	(5.30)**	(5.13)**
Plot is under a customary tenure system	0.102	0.134	0.091
	(0.16)	(0.20)	(0.14)
Bugiri =1	1.376	1.913	1.454
	(3.89)**	(5.51)**	(3.16)**
Bukedea =1	-0.472	-0.501	-0.432
	(0.64)	(0.65)	(0.51)
Pallisa =1	-0.571	-0.684	-0.739
	(0.71)	(0.81)	(0.87)
Constant	76.314	96.522	87.350
	(1.84)+	(2.26)*	(2.03)*
Observations	268	268	268
R-squared	0.36	0.32	0.32

The numbers shown are estimated coefficients at the means and the t-statistics are in parentheses.
+ significant at 10%; * significant at 5%; ** significant at 1%. a This variable is tested to see whether it is an endogenous variable or not. It is found that it is not endogenous (by using the Stata command "estat endogenous"; the test statistics cannot reject that they are exogenous variables). OLS is therefore used.

Case 2:

Expansion of Lowland Rice Production and Constraints on a Rice Green Revolution: Evidence from Uganda

Yoko Kijima*

Abstract

In Uganda, rice production has increased rapidly in the past 10 years while the yield has been stagnant. To examine this mixed story in detail, we use data on 600 rural households with access to wetlands. The estimation results on the expansion of rice cultivation show that the high population density in upland farm areas has pushed farmers to rice cultivation in wetlands. Although applying proper cultivation practices such as constructing bunds, leveling, and transplanting is considered to be critical in yield enhancement, as well as using chemical fertilizer and improved varieties, such cultivation practices are rarely adopted in Uganda. The rice production function estimation results show that these practices do not increase the yield significantly once village fixed effects are controlled for. This suggests that these practices are not being adopted since the rice yield is not enhanced effectively by the cultivation practices. This is probably explained by the fact that the water supply in wetlands tends to be unstable and to suffer from drought and floods.

Keywords: agricultural intensification, lowland rice, cultivation practices, Uganda

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1. Introduction

In many countries in Sub-Saharan Africa (SSA), the consumption of rice has been increasing far more rapidly than domestic rice production due to rapid population growth and urbanization in the region (Africa Rice Center 2008). When the price of rice surged in 2007 and 2008, food insecurity among the poor became more serious (Ivanic and Martin 2008; Benson et al. 2008). Since rice is a major cereal crop that can improve food productivity in SSA, policies to enhance rice production are urgently needed not only for food security but also for income generation (Diao et al. 2008; Otsuka and Kijima 2010; Larson et al. 2010).

Uganda is one of the few countries in SSA in which domestic rice production has been increasing and where imports of rice have declined recently. Therefore, it is worth examining how Uganda was able to enhance rice production over the past 10 years. Until recently, rice production in Uganda had been conducted mainly in a few irrigation schemes in Eastern regions where rice production had been introduced by the Chinese in the 1970s. Although rice is not a traditional crop in Uganda, to meet the gap between domestic production and consumption, which has been increasing at a higher rate due to urbanization and rapid population growth, since 2003 the Ugandan government has been promoting rice production with support from donor agencies by introducing a new upland rice variety suitable for the African environment (the NERICA variety) and through a training program for extension workers. In addition, the Ugandan government has imposed a 75% tariff on imported rice to protect rice growers from competition with cheap imported rice and to give farmers an incentive to grow rice by making the price of rice relatively higher than that of other cereal crops.

All these policies should have partially accounted for the increase in rice production in Uganda. There is, however, another likely cause to explain this change. Until the late 1990s, many wetlands had been underutilized because upland farms had been relatively abundant. As the population has grown at an extremely high rate (the annual growth rate was 3.24% between 2000 and 2005), upland farms have become scarcer in most regions. As shown in Figure 1, rice production has been increasing rapidly since the late 1990s in Uganda. This increase is mainly due to the extension of the rice cultivation area (Figure 2). Productivity measured in terms of the average yield has been stagnant between 1 and 1.5 tons per hectare (Figure 3). Thus, the impressive increase in rice production in Uganda has been achieved without improving productivity.

Previous studies on upland rice production in Central and Western Uganda show that introduction of the NERICA variety has increased the rice cultivation area and has changed the upland farming system by replacing mainly maize (Haneishi et al. 2012; Kijima et al. 2008). It is not clear, however, how the lowland rice production area has been expanded. To fill this knowledge gap, in the present study, data has been collected for 600 households in 60 villages with access to wetlands in six districts in the East, North, Northeast, and Central regions. The estimation results show that the increase in population density in the upland farm areas pushes farmers to rice cultivation in the wetlands. It has also been found that better market access, which results in a higher producer price at the farm gate, and a secure tenure system in the wetlands encourages lowland rice production in Uganda.[1] Although the rice yield tends to be higher in plots with proper cultivation practices such as constructing bunds, leveling, and transplanting, the adoption of such practices does not enhance the yield once village fixed effects are controlled for. The results suggest that inadequate use of chemical fertilizer and unfavorable wetland conditions (prone to flooding and water shortages) account for the low productivity of rice cultivation in Uganda.

The rest of the paper is organized as follows. Section 2 describes the data used in this study and the characteristics of the sample households. Section 3 examines the area of expansion of rice production. In Section 4, the adoption function of rice cultivation practices and production functions are estimated. Section 5 presents conclusions.

2. Data and sample households

The data used in this study were collected in 2010 in collaboration with Makerere University. To cover different rice cultivation experiences and agro-ecological conditions, one district was selected from each geographical region (namely East, North, Northeast, and Central regions) where there are wetlands that can be used for rice cultivation. In each district, two sub-counties with active rice production and with

1. Lowland rice is rice grown on land that is flooded or irrigated. Upland rice is rice grown in dry soil. Wetlands are land areas that are saturated with water, either permanently or seasonally.

access to wetlands were purposively selected. From these sub-counties, 60 LC1s (the lowest administrative unit in Uganda) were randomly drawn as sample communities. The number of LC1s selected per district is 15 in Lira district, 5 in Dokolo district, 15 in Butaleja district, 15 in Kamuli district, and 10 in Kumi district. In each LC1, 10 households were randomly sampled, and thus the number of sampled households is 600.

Table 1 shows the descriptive statistics of the sample communities and households. Eastern region (Butaleja district) has a relatively long history of rice cultivation because the irrigation scheme introduced by the Chinese is located in this region. In Central-East region (Kamuli district), lowland rice production began after 2000. In Northern (Lira/Dokolo district) and North-Eastern regions (Kumi district), there are still abundant cultivable areas in the uplands and there are larger wetlands. Traditionally, some of the wetlands are communal or government owned lands; they have been used as grazing land, openly accessed by community members. To show that rice is an attractive cash crop in Uganda, the last row of the upper panel indicates the price relative to maize, which is one of the major cash crops in most regions in Uganda. It was about 4.7 on average.

In the sample LC1s, 65% of the households grew rice in wetlands in 2009. The proportion is the highest in Butaleja district and the lowest in Dokolo district. The average size of a rice plot is 0.58 hectares. The average size of upland farms owned is 1.3 hectares, which shows that upland farming areas are no longer abundant when considering the average number of adult household members (3.5). In terms of assets, there are two measures: the current values of livestock (cattle, goats, sheep, chickens, pigs, donkeys, and ducks); and household assets (radios, bicycles, mobile phones, beds, chairs, motorcycles, vehicles, car batteries, and mosquito nets) owned at the beginning of agricultural production in 2009. Agricultural related assets are not included in household assets. Households in Dokolo and Kumi districts, where the community wetland area per household is larger than in the other districts, tend to own more livestock. Access to rice related training, whether offered by the government, NGOs, or donor agencies, is limited.[2] Only 12.6% of the sample households received training on rice cultivation. Thus, most of the rice-growing households in the sample areas learn how to cultivate rice via information sources such as neighbors and relatives.

2. In the data, there is no further information on training in terms of what kind of training was provided and who provided it.

3. Determinants of rice area expansion

In this section, the factors explaining the expansion of the rice cultivation area in wetlands are examined. For that purpose, it is important to understand the differences in cultivation in upland and wetland areas and the agro-ecological conditions in Uganda, where traditionally wetlands had been left unused for crop production. Partly due to the environmental protection policy of the Ugandan government, many wetlands were not used for cultivation before rice cultivation began. In the dry season, wetlands had been used as grazing land, while during the rainy season local people were afraid of working in wetlands because of waterborne diseases. Especially when farmers do not have access to machines and draft animals usable in wetlands, land preparation in wetlands requires more labor than in upland farms. In the sample areas, such machines are not available. Although draft animals can be used when the water level is low, only 26% of the rice plots in the sample were ploughed by draft animals. Under such conditions, households may not have an incentive to utilize wetlands for cultivation as long as households have access to upland farms of sufficient size for crop production.

As the upland cultivation area accessed by households becomes smaller due to population growth, it is likely to be found that households intensify agricultural production by applying land-saving technologies such as the use of chemical fertilizer (Hayami and Ruttan 1985). It is possible, however, that households expand their cultivation area into wetlands, instead of investing in upland farms, when they have access to unused wetlands. Since the agro-ecological and socio-economic conditions are different across communities and households, whether to expand the cultivation area into wetlands or to intensify upland farms should depend on the costs and benefits of these two options.

Given the higher labor requirements of utilizing wetlands compared to upland farming, family labor availability can be a constraint on expanding the cultivation area into wetlands. In contrast, ownership of a bull can save labor inputs in upland farming, which may release family labor for cultivation in wetlands. Wetland accessibility decreases the cost of cultivation in wetlands, while wetland tenure insecurity decreases the benefit of using wetlands by increasing the risk of losing some of the outputs. The difference in tenure system is important in this setting since the wetlands owned by the government tend to be openly accessed.

Although some portions of the wetlands in the sample areas are used for purposes other than rice cultivation, such as grazing and vegetable production, rice accounts for the main portion partly because of its marketability and storability. Some may question why rice is not produced in upland farms if it is such an attractive crop. In the sample areas, upland rice production is not common due to a lack of sufficient rainfall for rice production (in this sample, only 36 households out of 600 grow rice in upland farms, and most of these are NERICA varieties which have a shorter maturity than traditional upland rice varieties). Since rice, including NERICA, grows well with abundant water, growing it in upland farms tends to perform worse due to the shortage of water compared to the wetlands. Even in the wetlands, production conditions are unpredictable (it is difficult for households to control the water level), and it is too risky for farmers to grow rice on a larger scale. In addition, farmers tend to produce traditional food crops for their home consumption since rice is a cash crop rather than a major staple food in Uganda. Thus, labor can be a constraining factor in expanding rice cultivation.

To examine the households' decision of whether and to what extent rice is grown in wetlands, we run two models: a probit model with a dependent variable of a dummy variable indicating whether a household grew rice in the last 12 months; and a Tobit model with a dependent variable of the proportion of wetland area under rice cultivation over the total cultivation area. Explanatory variables are the household and community characteristics shown in Table 2.

The estimation results are shown in Table 2. There are two specifications: columns 1 and 3 use a variable "the size of wetlands accessed by the community per household" as a proxy of wetland availability, while in columns 2 and 4, the wetland size separated according to the tenure system is used in order to test whether differences in the wetland tenure system have different affects on the decision to grow rice.

The coefficient of the size of upland farms owned is negative and significant in all columns, implying that the shortage of upland land for cultivation pushes farmers to grow rice in wetlands. As the wetland size that is available to the community increases, the probability that households grow lowland rice becomes higher. However, the size of openly accessed wetlands such as government owned wetlands negatively affects the decision to cultivate rice in wetlands, meaning that unless land tenure for the households is secure, households are less likely to grow rice in wetlands. The other community-level variables with significant coefficients are driving time to district town and average rainfall. These coefficients imply that households in communities with better market access and rice production conditions are more likely to grow rice in wetlands, which is as expected since rice is grown mainly as a cash crop and requires more water than traditional upland crops such as maize and cassava.

Other household characteristics affecting the probability of growing rice in wetlands are the number of adult family members, age of household head, bull ownership, and immigrant dummy. Since rice cultivation tends to be more labor intensive than upland crops, households with an older household head, few family members, and no draft animal may be constrained in growing rice in wetlands. A dummy variable of immigrant households takes a negative coefficient, which suggests that households whose origins are outside the community have limited access to wetlands. While some of these significant variables (immigrant dummy, number of female adults, and bull ownership) do not determine the intensity of rice growing in wetlands, education of household head turns significant in columns 3 and 4. These empirical results suggest that the increase in rice production by expanding the area under cultivation in communities with access to wetlands is explained partly by the decrease in upland farming area per capita.

4. Cultivation practices and rice yields

In this section, why the productivity of rice production in Uganda has been stagnant is examined in detail. Table 3 shows the characteristics of rice plots among sample households. As shown in Table 1, the number of observations in Dokolo district is small since fewer households grow rice in its wetlands. The average rice plot size is less than 0.4 hectares. The average yield is 2.5 tons per hectare, which is higher than the average rice yield in SSA. This high yield is, however, only achieved in Butaleja and Kamuli districts. In other districts, the average yield is less than 2 tons per hectare. These yield differences across districts may be explained by differences in the cultivation practices applied. In Kumi, Lira, and Dokolo districts, transplanting is rarely undertaken, meaning that seeds are broadcasted. It is known that the yield tends to be lower when seeds are broadcasted since the germination rate of the seeds becomes low and the resulting plant density is uneven over the cultivated area. Although leveling is critically important for water to be evenly stored over the rice plot, in these sample districts, less than 50% of plots conduct leveling. In Kumi and Lira/Dokolo districts, water control (constructing bunds and canals) and proper land preparation (leveling and puddling) are applied in only 30% of the rice plots.

The use of the improved variety seeds is not common in all districts (27% of the plots). Chemical fertilizer and herbicide are rarely used in all sample districts (1.2 kilograms of chemical fertilizer per hectare and 4% of rice plots with application of herbicide on average). The rice plots are located far away from the homestead (39 minutes on foot). This is especially the case for Butaleja district.

The bottom of Table 3 also shows the labor use on rice plots per season. The amount of labor used for rice cultivation is much higher than that observed in Asia. One reason could be because most of the sample households cultivate rice using manual labor, not machines. Another reason could be because quite a lot of labor hours are used in scaring away birds, which accounts for about 30% of the total labor.

Table 4 shows the adoption of technologies and the yield by the number of cultivation practices and technologies (such as transplanting, leveling/puddling, bunds/canal, fertilizer, and improved variety) that were applied to a given plot. Except in Butaleja and Kamuli districts, the number of such cultivation practices and technologies used is at most three. On one-third of rice plots in Kumi and Lira/Dokolo districts, none of the practices are applied. The bottom of the table shows the yield separately for the number of technologies adopted. The average yields across all sample districts increase as more technologies are adopted. However, this relationship does not seem to hold when yields with a different number of technologies adopted are compared within each district (figures in the same column).

Before examining the yield function, therefore, the constraints on farmers leading to their not adopting such cultivation practices are analyzed. Since the cultivation of lowland rice began recently in many parts of Uganda, households may not know about these practices. Thus, the availability of training related to rice production could have an impact on the adoption of cultivation practices. Even without training, farmers may learn proper cultivation practices through their own experience. It is also possible that those who know about these practices may not adopt them because applying these practices requires more labor inputs. For example, households who cannot hire labor due to credit constraints may not be able to adopt labor-intensive practices.

In order to examine the causes of this low application of proper cultivation practices more rigorously, the adoption functions of cultivation practices and improved variety are estimated using a community-level fixed effect model to control for unmeasured heterogeneities such as wetland water conditions. The dependent variable is an indicator variable taking unity if a practice is applied to a particular plot or not. In the case of chemical fertilizer, the amount of chemical fertilizer used in a particular plot is used as the dependent variable. The main explanatory variables are the availability of training on rice production at the village level, the size of upland farms owned, a dummy variable for whether or not households are credit constrained, and the number of adult household members. The other plot-level variables such as tenure system and plot size are also controlled.

Table 5 shows the estimation results. Columns 1-4 are adoption functions of transplanting, leveling, constructing canals, and improved variety, respectively, while column 5 is the input demand function for chemical fertilizer. Contrary to expectations, the availability of rice related training does not affect the probability of applying such cultivation practices. Rice cultivation experience significantly increases the probability of adopting the improved variety. The positive coefficient of the number of female adult household members in columns 1 and 5 suggests that the availability of female family labor is one of the constraints on applying transplanting and chemical fertilizer. When the rice plot is rented in, households are less likely to implement puddling and to conduct leveling/puddling. When households own rice plots and when the source of water for the rice plot is a stream, the probability of constructing bunds becomes higher. Households with smaller upland plots are more likely to conduct leveling and making bunds. None of the asset variables have significant effects on applying proper cultivation practices. The empirical results suggest that the ownership of the rice plot and the size of upland farms owned as well as access to a stable water source lead to adoption of proper cultivation practices.

In the rest of this section, why the rice yield has been stagnant in Uganda is examined by estimating the rice production function using an ordinary least squares (OLS) and stochastic frontier model. The dependent variable is rice yield per hectare at plot level. Regarding the explanatory variables, in addition to inputs commonly considered in production function estimation such as plot area size, fertilizer use, amount of seeds used, labor used, and their squared terms, the adoption of improved seed, application of the cultivation practices, and the availability of rice related training are included as explanatory variables.

Table 6 shows the production function estimation result. Columns 1 and 4 use only conventional input variables while columns 2 and 5 include district dummies, and in columns 3 and 6 the village fixed effects are controlled for. Similar to previous studies, the conventional inputs such as the amount of chemical fertilizer and seeds, use of improved variety, and labor inputs have positive associations with rice production in all specifications. Columns 1 and 3 show that the application of transplanting and leveling increases the rice yield, while in rest of the columns these variables no longer have significant effects on rice yields. This suggests that transplanting and leveling tend to be applied in better environments. Once these conditions are controlled for, the effects of applying the cultivation practices disappear. This suggests that these practices are not adopted because the rice yield is not effectively enhanced by the cultivation practices. This is probably explained by the fact that water in the wetlands tends to be unstable and to suffer from drought and floods. The results in all columns show that the availability of rice training at the village level does not increase rice yields. Since there is no information about what was taught in the training, it is difficult to know why the availability of training does not increase rice production.

5. Conclusions

This study examines the causes of increases in rice production through cultivation area expansion in Uganda using data covering major rice production areas with access to wetlands. The expansion of the area under rice cultivation in wetlands was mainly due to the push factor, meaning that as the size of upland farms owned decreases, the area under wetland rice cultivation increases. The size of wetlands at the village level increases the probability that households grow rice in wetlands, but does not significantly increase the proportion of the rice area over total cultivation areas. This is probably because there are still unutilized wetlands and the cultivation area can be expanded in the wetlands in our sample areas.

Although applying proper cultivation practices such as constructing bunds, leveling, and transplanting is considered to be critical in yield enhancement, especially for lowland rice cultivation, such cultivation practices are rarely adopted by the sample households. The rice production function estimation results show that these practices do not increase the yield significantly once the village fixed effects are controlled for. Since the water conditions in wetlands tend to be unstable and to suffer from drought and floods, the adoption of such cultivation practices may not lead to an increase in rice yields, which results in low adoption of proper cultivation practices. Therefore, in order to introduce Asian-type cultivation practices to significantly increase the rice yield, it may be necessary to introduce water management technologies.

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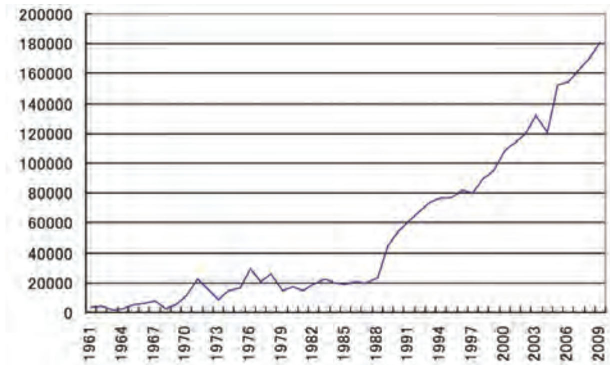
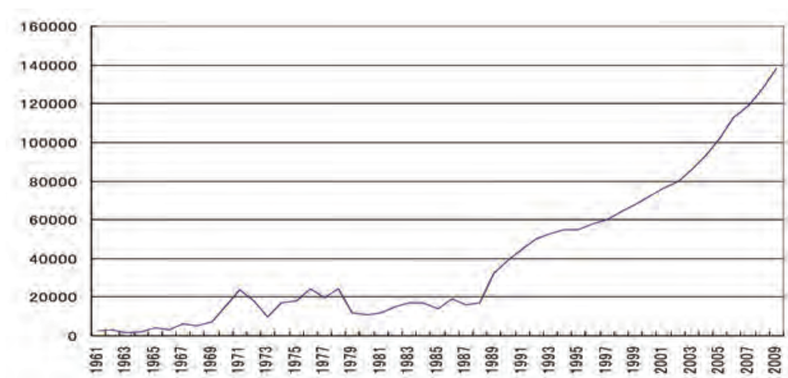
Figure 1. Rice production in Uganda (Tons)



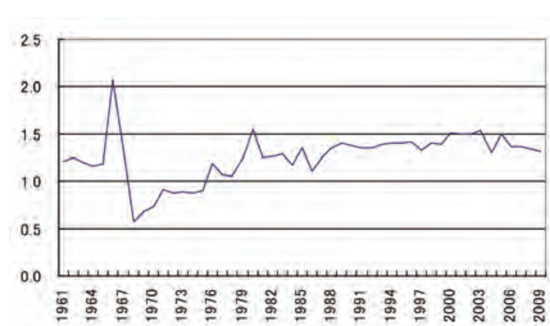
Source: FAO STAT, accessed on July 2, 2011

Figure 2. Rice area harvested in Uganda (Ha)



Source: FAO STAT, accessed on July 2, 2011

Figure 3. Average rice yield in Uganda (Ton/Ha)



Source: FAO STAT, accessed on July 2, 2011

Table 1. Descriptive statistics

	All	Kumi	Butaleja	Kamuli	Lira	Dokolo
LC1 level variables						
Average upland cultivated land area in LC1[a]	2.33	1.83	1.81	2.34	3.00	3.02
	(1.19)	(0.63)	(0.91)	(1.38)	(1.29)	(0.32)
Community wetland area per household (ha) [b]	29.96	115.9	13.71	1.268	14.49	39.26
(per household in nearby villages)	(65.42)	(121.1)	(17.53)	(1.748)	(10.70)	(39.52)
Land tenure of wetland is customary land [b]	0.22	0.61	0.00	0.04	0.31	0.42
	(0.41)	(0.49)	(0.00)	(0.13)	(0.45)	(0.49)
Land tenure of wetland is government owned [b]	0.01	0.30	0.00	0.00	0.21	0.00
	(0.29)	(0.46)	(0.00)	(0.00)	(0.39)	(0.00)
Years since rice was grown for the first time	17.87	19.26	29.35	15.95	10.13	6.208
in this LC1 [b]	(12.18)	(17.61)	(5.92)	(7.679)	(6.567)	(3.377)
Driving time from LC1 to nearest district	42.35	45.44	38.63	42.20	40.12	53.85
town (minutes) [b]	(14.15)	(8.826)	(15.33)	(10.21)	(14.28)	(19.90)
Average annual rainfall (mm) (district level) [c]	1471.6	1389.5	1404.4	1667.1	1485.5	1245.1
Rice-maize relative price (per kg) at	4.717	5.138	5.211	4.369	1.952	4.637
harvesting season [b]	(2.268)	(2.889)	(2.447)	(0.958)	(0.326)	(2.017)
Household level variables						
Rice growing household in 2009 dummy	0.650	0.633	0.896	0.688	0.504	0.229
	(0.477)	(0.485)	(0.307)	(0.465)	(0.502)	(0.425)
Household's lowland area under rice (ha)	0.58	0.37	0.65	0.47	0.73	0.72
in 2009 (only among growers)	(0.701)	(0.24)	(0.81)	(0.44)	(1.00)	(0.42)
Size of upland farms owned (ha)	1.32	1.28	0.70	0.96	2.05	2.33
	(1.49)	(1.33)	(1.02)	(1.31)	(1.65)	(1.71)
Household head moved from other LC1	0.167	0.067	0.118	0.278	0.176	0.146
(immigrant dummy)	(0.373)	(0.251)	(0.324)	(0.449)	(0.382)	(0.357)
Number of male adults (15-65)	1.767	2.056	2.049	1.535	1.504	1.792
	(1.230)	(1.433)	(1.464)	(0.982)	(0.980)	(1.071)
Number of female adults (15-65)	1.756	2.211	1.890	1.542	1.466	1.938
	(1.124)	(1.457)	(1.123)	(0.860)	(0.939)	(1.245)
Age of household head	44.60	44.69	46.74	41.41	45.53	45.09
	(14.11)	(12.51)	(13.71)	(13.21)	(16.35)	(12.97)
Years of education of household head	5.865	5.972	5.563	6.173	5.492	6.667
	(3.349)	(3.193)	(3.585)	(2.851)	(3.521)	(3.692)
Female headed household dummy	0.095	0.033	0.042	0.104	0.198	0.063
	(0.294)	(0.181)	(0.201)	(0.307)	(0.400)	(0.245)
Total size of land owned (ha)	1.65	1.49	1.25	1.25	2.28	2.65
	(1.71)	(1.62)	(1.48)	(1.52)	(1.88)	(1.72)
Value of household assets (USD)	75.06	77.17	77.18	75.51	64.17	93.14
(before rice production in 2009)	(73.76)	(71.46)	(78.19)	(70.82)	(68.75)	(84.04)
Value of livestock owned	276.84	427.24	232.1	144.1	309.2	439.3
(before rice production in 2009)	(326.85)	(380.04)	(300.5)	(204.0)	(331.0)	(390.5)
Own bull (dummy)	0.315	0.500	0.213	0.053	0.473	0.560
	(0.465)	(0.503)	(0.411)	(0.225)	(0.501)	(0.501)
Households with members of local organization	0.490	0.311	0.410	0.590	0.496	0.750
(dummy)	(0.500)	(0.466)	(0.493)	(0.493)	(0.502)	(0.438)
Households who received training (dummy)	0.126	0.111	0.118	0.028	0.260	0.104
	(0.332)	(0.316)	(0.324)	(0.165)	(0.440)	(0.309)

The first row for each variable is the mean and the number in parentheses is the standard deviation. [a] The variable is constructed using household-level data. For each household, the LC1-level average is calculated by excluding its household (non-self average or leave-out means). [b] The variable comes from a community questionnaire involving an interview with a group of 8-10 community members consisting of a community leader, key informants, male and female farmers, elders, and youths. [c] Rainfall data were obtained from the Department of Meteorology.

Table 2. Determinants of rice growing in 2009 (household level)

	Household grew rice in wetlands (dummy variable) Probit, dF/dX		Proportion of lowland rice area over total cultivated land Tobit, dF/dX	
	(1)	(2)	(3)	(4)
Household level variables				
Size of upland owned (ha)	-0.038	-0.037	-0.027	-0.026
	(2.25)*	(2.19)*	(3.26)**	(3.18)**
Household head moved from other LC1 (dummy)	-0.171	-0.166	-0.046	-0.043
	(2.58)**	(2.50)*	(1.45)	(1.36)
Number of male adults (15-65)	0.050	0.050	0.022	0.021
	(2.30)*	(2.30)*	(2.24)*	(2.22)*
Number of female adults (15-65)	0.035	0.033	0.007	0.007
	(1.59)	(1.51)	(0.70)	(0.67)
Age of household head (years)	-0.007	-0.007	-0.003	-0.003
	(4.06)**	(4.08)**	(3.99)**	(3.99)**
Years of education of household head	-0.013	-0.013	-0.006	-0.006
	(1.82)+	(1.86)+	(1.87)+	(1.91)+
Female headed household dummy	0.108	0.096	0.007	-0.000
	(1.40)	(1.22)	(0.16)	(0.00)
Value of household assets (thousand USD)	0.181	0.180	0.062	0.062
(before rice production in 2009)	(1.13)	(1.12)	(0.95)	(0.96)
Value of livestock (except bull) owned	0.029	0.017	0.032	0.027
(thousand USD) (before rice production in 2009)	(0.38)	(0.23)	(0.97)	(0.82)
Credit constraints dummy a	0.018	0.021	0.003	0.004
	(0.41)	(0.47)	(0.15)	(0.21)
HHs with members of local organization (dummy)	0.070	0.070	0.025	0.025
	(1.51)	(1.51)	(1.13)	(1.15)
Own bull (dummy)	0.153	0.160	0.030	0.031
LC1 level variable	(2.89)**	(2.99)**	(1.15)	(1.21)
Average wetland size (ha) per household	0.001		0.000	
	(1.93)+		(1.55)	
Average freehold wetland size (ha) per household		0.001		0.000
		(1.30)		(0.87)
Average customary wetland size (ha) per household		0.001		0.000
		(1.22)		(1.00)
Average government wetland size (ha) per household		-0.008		-0.005
		(1.82)+		(1.95)+
Driving time from LC1 to nearest district town	-0.003	-0.003	-0.002	-0.002
(minutes)	(1.70)+	(1.54)	(2.22)*	(2.09)*
Average annual rainfall (mm)	0.001	0.001	0.000	0.000
	(2.43)*	(1.81)+	(1.89)+	(1.26)
Rice-maize relative price at harvesting season	0.004	0.004	-0.000	-0.001
	(0.37)	(0.33)	(0.04)	(0.15)
Rice training available at LC1 (dummy)	-0.039	-0.049	-0.008	-0.012
	(0.73)	(0.90)	(0.32)	(0.46)
District dummies	Yes	Yes	Yes	Yes
Observations	577	577	577	577
Pseudo R-squared	0.19	0.20	0.41	0.43

[a] Credit constraint is defined if households applied for credit but did not obtain the amount they wanted or were refused, or if households needed credit but there was no access to credit or households did not ask because they were afraid of being refused. The numbers in parentheses are t-values.
+ significant at 10%; * significant at 5%; ** significant at 1%

Table 3. Lowland rice yield, cultivation practices, and labor use per hectare (plot level)

	All	Kumi	Butaleja	Kamuli	Lira	Dokolo
Number of lowland rice plots	533	64	226	124	111	8
Number of lowland rice plots with family labor data*	343	58	121	84	73	7
Size of lowland rice plot (ha)	0.38	0.41	0.35	0.30	0.50	0.77
	(0.45)	(0.26)	(0.35)	(0.22)	(0.76)	(0.43)
Yield (ton/ha)	2.51	1.79	3.31	2.44	1.55	0.79
	(1.68)	(1.32)	(1.60)	(1.44)	(1.52)	(0.36)
% of plots with:						
Transplant	59.4	2.7	94.3	68.3	5.7	0.0
Selecting seeds	77.5	90.4	80.6	91.0	50.4	27.3
Leveling/puddling	83.0	43.8	94.7	91.6	61.0	36.4
Bunds/canals	65.3	30.1	90.5	23.4	73.2	36.4
Improved seeds	26.9	1.4	31.2	37.7	25.2	9.1
Stream as a water source	63.4	67.1	76.0	74.3	18.7	27.3
Chemical fertilizer application (kg/ha)	1.22	0.0	1.9	0.0	1.5	0.0
% of plowing by hand hoe	73.9	17.1	91.8	92.6	52.1	72.7
% of herbicide use	4.0	0.0	1.7	4.1	10.1	0.0
Walking time from homestead to lowland plot (minutes)	38.7	24.7	58.2	17.3	27.4	25.5
Labor use on rice plot (man-days/ha)*	490.8	641.7	441.5	570.9	391.5	438.4
	(324.2)	(384.8)	(255.8)	(333.2)	(310.4)	(411.7)
Land preparation (clearing, plowing, making	131.5	98.8	116.9	177.6	143.1	137.9
bunds, maintaining canals, leveling, puddling)	(116.9)	(101.4)	(73.8)	(153.3)	(145.2)	(107.0)
Crop establishment (sowing, preparing seedlings,	41.8	5.2	41.0	87.6	28.9	33.6
making nursery beds, transplanting)	(58.2)	(11.9)	(31.9)	(107.1)	(36.3)	(40.7)
Crop care (weeding, applying chemicals)	75.2	118.6	45.6	72.3	86.4	69.7
	(101.5)	(111.5)	(43.5)	(60.5)	(101.5)	(77.1)
Harvesting/threshing	68.6	209.9	35.0	81.9	72.9	48.3
	(88.2)	(295.3)	(34.3)	(73.9)	(86.5)	(25.5)
Post harvest (hauling, drying, bagging)	28.9	25.1	50.8	15.7	12.3	17.7
	(41.1)	(38.8)	(48.9)	(22.6)	(22.4)	(30.4)
Bird scaring	144.9	205.9	139.7	206.7	63.1	73.9
	(155.8)	(169.5)	(132.0)	(159.0)	(105.1)	(67.0)

Source: Household survey

* Family labor use is only available for one plot per household. The numbers in parentheses are standard deviations.

Table 4. Combinations of technologies adopted and yield (plot level)

	All	Kumi	Butaleja	Kamuli	Lira/ Dokolo
Number of technologies adopted (% of plots)					
5	3.1	0.0	7.6	0.0	0.0
4	15.3	0.0	26.6	5.4	0.0
3	30.9	0.0	54.4	30.5	4.5
2	24.4	13.7	6.8	46.1	39.6
1	14.1	50.7	1.9	12.0	21.6
0	12.2	35.6	2.7	6.0	34.3
Yield (ton/ha) with					
5 technologies	4.65	---	4.65	---	---
	(1.76)		(1.76)		
4 technologies	3.49	---	3.56	1.97	---
	(1.39)		(1.37)	(0.55)	
3 technologies	2.91	---	3.06	2.59	1.55
	(1.54)		(1.63)	(1.14)	(0.75)
2 technologies	2.08	1.71	2.92	2.46	1.46
	(1.61)	(1.59)	(1.15)	(1.61)	(1.49)
1 technology	1.77	1.94	---	2.06	1.43
	(1.44)	(1.29)		(1.54)	(1.54)
No technologies	1.61	1.61	---	2.33	1.57
	(1.45)	(1.27)		(1.05)	(1.58)

Technologies: Transplanting, leveling/puddling, bunds/canal, fertilizer, and improved variety.

Table 5. Adoption of cultivation technologies (LC1 fixed effects model)

	Trans planting	Puddle/ leveling	Bunds/ canal	Improved variety	Fertilizer (kg/ha)
	(1)	(2)	(3)	(4)	(5)
Availability of rice training at LC1 level	-0.012	-0.005	-0.014	-0.037	-0.882
	(0.97)	(0.28)	(0.64)	(1.40)	(2.66)**
Value of livestock owned (except bull)	0.000	0.000	0.000	-0.000	0.001
(thousand USD)	(0.14)	(0.72)	(1.36)	(1.14)	(1.55)
Value of household assets owned (thousand	0.000	-0.000	-0.000	-0.000	-0.000
USD) (before rice production in 2009)	(1.15)	(1.32)	(1.61)	(1.28)	(0.28)
Own bull (dummy)	0.015	-0.032	-0.006	0.035	0.193
	(0.60)	(0.84)	(0.13)	(0.65)	(0.29)
Walking time from home to rice plot	-0.000	0.000	-0.000	0.002	0.007
(minutes)	(0.59)	(0.33)	(0.11)	(4.04)**	(0.91)
Years of lowland rice cultivation	-0.000	0.001	0.001	0.005	-0.060
	(0.35)	(1.32)	(0.52)	(3.35)**	(1.16)
Lowland rice plot size (ha)	-0.002	-0.002	0.042	-0.011	-0.103
	(0.09)	(0.07)	(1.10)	(0.23)	(0.18)
Plot owner (dummy)	0.031	0.006	0.085	0.062	0.228
	(1.09)	(0.15)	(1.68)+	(1.04)	(0.30)
Tenant of plot (dummy)	0.019	-0.100	-0.081	-0.115	-0.318
	(0.64)	(2.23)*	(1.51)	(1.82)+	(0.40)
Water source is stream	0.027	-0.004	0.077	0.023	0.582
	(1.15)	(0.12)	(1.87)+	(0.47)	(0.96)
Head's years of education	-0.002	0.003	0.005	0.007	-0.180
	(0.72)	(0.68)	(0.99)	(1.11)	(2.33)*
Head's age	0.002	0.000	0.002	-0.000	-0.085
	(1.69)+	(0.08)	(0.97)	(0.22)	(3.38)**
Female headed household	-0.050	-0.046	-0.017	0.011	-0.981
	(1.09)	(0.67)	(0.21)	(0.12)	(0.81)
Number of males aged 15-64	-0.009	-0.018	-0.008	-0.027	-0.509
	(1.11)	(1.44)	(0.51)	(1.54)	(2.29)*
Number of females aged 15-64	0.019	0.018	0.040	0.002	0.829
	(1.98)*	(1.30)	(2.34)*	(0.09)	(3.30)**
Immigrant household dummy	0.023	-0.063	0.036	-0.035	0.583
	(0.72)	(1.34)	(0.64)	(0.53)	(0.70)
Size of upland owned (ha)	-0.012	-0.024	-0.026	-0.014	-0.024
	(1.57)	(2.10)*	(1.95)+	(0.90)	(0.12)
Credit constrained	-0.033	0.044	-0.050	0.033	-0.070
	(1.70)+	(1.51)	(1.45)	(0.80)	(0.14)
Risk of confiscation of wetland plot [a]	-0.014	0.134	0.054	0.013	0.123
	(0.59)	(1.59)	(1.22)	(0.25)	(0.19)
Observations	498	498	498	498	498
R-squared	0.05	0.07	0.08	0.11	0.12

[a] Subjective measure taking unity if household believes there is a risk of confiscation of wetland plots. The numbers in parentheses are t-values. + significant at 10%; * significant at 5%; ** significant at 1%

Table 6. Production function (ton/ha)

	OLS			Stochastic	Frontier	Model
	Base model (1)	Base + district dummies (2)	Base + village fixed effects (3)	Base model (4)	Base + district dummies (5)	Base + village fixed effects (6)
Availability of rice	-0.002	0.031	-0.124	-0.002	0.031	-0.124
training at LC1 level	(0.02)	(0.29)	(0.97)	(0.02)	(0.30)	(1.09)
Chemical fertilizer	0.110	0.103	0.080	0.110	0.103	0.080
(kg/ha)	(2.25)*	(2.11)*	(1.70)+	(2.30)*	(2.16)*	(1.83)+
Chemical fertilizer	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002
squared	(2.20)*	(2.12)*	(1.69)+	(2.24)*	(2.17)*	(1.90)+
Improved variety	0.377	0.370	0.177	0.377	0.370	0.177
dummy	(2.04)*	(1.96)+	(0.87)	(2.08)*	(2.01)*	(0.98)
Seed (kg/ha)	0.011	0.009	0.010	0.011	0.009	0.010
	(3.47)**	(2.98)**	(3.02)**	(3.54)**	(3.05)**	(3.40)**
Seed squared	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
	(1.16)	(0.76)	(0.71)	(1.18)	(0.78)	(0.80)
Labor (man-days)	0.000	0.000	0.001	0.000	0.000	0.001
	(1.30)	(1.63)	(1.75)+	(1.33)	(1.67)+	(1.97)*
Labor squared	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
	(0.06)	(0.30)	(0.22)	(0.07)	(0.31)	(0.24)
Transplanting dummy	0.953	0.393	0.004	0.953	0.393	0.004
	(5.23)**	(1.32)	(0.01)	(5.33)**	(1.36)	(0.01)
Puddle/Leveling dummy	0.376	0.246	0.208	0.376	0.246	0.208
	(1.70)+	(1.04)	(0.77)	(1.73)+	(1.07)	(0.86)
Bund/canal dummy	-0.088	-0.104	-0.335	-0.088	-0.104	-0.335
	(0.50)	(0.52)	(1.48)	(0.51)	(0.54)	(1.66)+
Land (plot size ha)	-0.275	-0.235	-0.281	-0.275	-0.235	-0.281
	(1.65)	(1.41)	(1.62)	(1.68)+	(1.44)	(1.82)+
District dummies	No	Yes	Yes	No	Yes	Yes
Village fixed effects	No	No	Yes	No	No	Yes
Observations	330	330	330	330	330	330
R-squared	0.34	0.35	0.27			
Log-likelihood				-569.7	-565.9	-516.1

The numbers in parentheses are t-values. + significant at 10%; * significant at 5%; ** significant at 1%

Case 3:

The Determinants of Technology Adoption: The Case of the Rice Sector in Tanzania

Yuko Nakano* and Kei Kajisa†

Abstract

Using an extensive household-level data set collected in Tanzania, this paper investigates the determinants of technology adoption in rice cultivation by focusing on the role of credit. We find that credit enhances fertilizer use and the adoption of labor-intensive agronomic practices such as transplanting in rows, for which monitoring of hired labor is easy. We also find that new technologies are adopted more widely in irrigated areas and small-scale farmers are not at a disadvantage. Based on these findings, we argue that with appropriate policies including credit, a rice Green Revolution can improve the productivity of small-scale farmers in Tanzania.

Keywords: technology adoption, Green Revolution, Sub-Saharan Africa, Tanzania

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1. Introduction

Agriculture development is important for poverty reduction and food security in Sub-Saharan Africa (SSA) (World Bank 2008). Among major cereals grown in the region, the importance of rice is now increasing rapidly (Balasubramanian et al. 2007). Total milled rice production in SSA increased from 2 million tons in 1961 to 16 million tons in 2009. At the same time, milled rice imports into SSA increased from 0.5 million tons in 1961 to 10 million tons in 2009 due to insufficient domestic production to meet the growing demand (Otsuka and Kijima 2010; Seck et al. 2010). So far, the increase in rice production is mainly due to the expansion of cultivated areas, while the paddy yield in African countries has grown slowly from around 1.5 to 2.5 tons per hectare over 50 years (FAO 2012).[1] Since the population continues to grow rapidly in SSA, and arable land per agricultural population has started to decline, improving productivity is regarded as a key to boosting domestic rice production and to ensuring food security.

One possible strategy for achieving productivity improvement is to seek a rice Green Revolution in SSA (Spencer 1994; Otsuka and Kalirajan 2005; Otsuka 2006; World Bank 2008). The Asian Green Revolution can be characterized as an increase in paddy yield through the diffusion of high-yielding modern varieties (MVs) together with an increase in chemical fertilizer application and the adoption of better crop and water management practices, such as bund construction and leveling of plots, along with transplanting in rows (Evenson and Gollin 2003). Emerging cases from the Sahel in West Africa show that this style of cultivation achieves yields of 3 to 5 tons per hectare, which is comparable to yields in Asian countries (Nakano et al. 2011). This implies that the potential for a rice Green Revolution is high in SSA. Therefore, it is important to investigate the current status of these technologies in SSA and the determinants of their adoption. However, most existing studies are case studies based on data from areas with particular production and socioeconomic conditions; thus, they do not reveal how a rice Green Revolution can be realized beyond their case study areas (Diagne 2006; Sakurai 2006; Kijima et al. 2010; Kajisa and Payongayong 2010).

In order to draw lessons on how to realize a Green Revolution in SSA, this paper investigates the strategies for rice productivity improvement

1. Note that this figure is based on FAO statistics, which include northern African countries. Paddy yields in northern African countries are much higher in general than those in SSA countries.

in Tanzania, the largest rice producing country in East Africa, by using an extensive household-level data set collected in 2009. The situation of rice production in Tanzania is largely similar to Africa as a whole: the paddy yield is stagnant while arable land per agricultural population is declining due to rapid population growth (FAO 2012; United Republic of Tanzania 2009). Therefore, increasing the yield is critical for further increasing production in the country. Our survey is the first effort to collect detailed information on rice farming households in the major rice-growing regions of the country. This paper gives a nationally representative picture of Tanzania's rice sector, beyond the snapshots of particular places provided by existing case studies (Meertens et al. 1999; Ngailo et al. 2007). To the authors' knowledge, this is the first such attempt not only in Tanzania but also among the East African countries.

Using this unique data set, we examine the determinants of the adoption of MVs, chemical fertilizer, and improved agronomic practices, including construction of bunds, leveling of plots, and transplanting in rows, which we regard as the key components of the Asian Green Revolution. We start with a description of the current status of farming practices and the adoption of these technologies, because little is known yet about rice farming practices in the country. We then examine the circumstances under which new technologies become more likely to be adopted, by particularly focusing on the role of credit in technology adoption. This aspect is crucially important, because emerging empirical studies point to the lack of credit access as being a key constraint for the adoption of new agricultural technologies (Feder et al. 1985; Carter 1989; Gine and Klonner 2005; Moser and Barrett 2006; Miyata and Sawada 2007; Foster and Rosenzweig 2010). Since we use a single-year cross-sectional data set, our analyses basically rely on reduced-form and instrumental variable (IV) approaches to avoid statistical problems due to self-selection and reverse causality in the adoption of modern technologies and practices. Through these analyses, we believe that this paper contributes to a better understanding of the current status of rice farming in Tanzania and possible strategies for future productivity improvement.

The rest of the paper is organized as follows. Section 2 explains the data set. Section 3 explains our hypotheses, followed by the descriptive analyses in Section 4. Sections 5 and 6 present the results of the statistical analyses on, respectively, the determinants of access to credit and technology adoption. The paper ends with the conclusions in Section 7.

2. The data

In Tanzania, rice is cultivated in three agro-ecological zones, namely, the Eastern Zone, Southern Highland Zone, and Lake Zone. In order to obtain a general picture of rice cultivation in the whole country, we covered all three zones. We chose one representative region from each zone: the Morogoro region from the Eastern Zone, the Mbeya region from the Southern Highland Zone, and the Shinyanga region from the Lake Zone (Figure 1). The sample regions are the major producers of rice, and they produce nearly 40% of the rice grown in the country. We can regard our survey as being 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 2002-03 agricultural census in each region. In total, we selected 76 villages in six 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 types of data: village-level data and household-level data. The former was collected by a group interview with village key informants, whereas the latter was collected by an individual interview. During the individual interviews, farmers were asked to identify their most important rice plot and asked in detail about their practices of rice cultivation on that plot, which we call a sample plot hereafter.[2] Figure 1 shows the location and irrigation status of our 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 some observations that had missing values in the key variables, and our effective sample became 672.

2. Our data show a higher proportion of irrigated plots in the sample plots than in the other plots. The average paddy yield for the sample plots is 2.2 t/ha while that for the other plots is 1.8 t/ha. The adoption rate of MVs is also statistically higher for the sample plots than the other plots. Thus, we have to be careful in interpreting the results, as the data are not representative of all the plots.

3. Hypotheses

The Asian-style rice Green Revolution can be characterized by the adoption of a set of new technologies. The set of new technologies can be classified into two components: modern inputs and improved practices. Modern inputs include fertilizer-responsive high-yield MVs as well as chemical fertilizer, while improved practices include bund construction and leveling of plots for better water management, and transplanting in rows for better crop management. Henceforth, we use the term "the adoption of new technologies" when we refer to the progress of all these components; otherwise, we use the name of the respective components.

In our analyses, we first investigate what factors underlie the adoption of these technologies. Relying on the past empirical literature, we particularly focus on the role of credit (Feder et al. 1985; Carter 1989; Moser and Barrett 2006; Foster and Rosenzweig 2010). We argue, however, that the importance of credit can differ for different technologies and practices. In order to adopt MVs, farmers have to buy seed when they switch varieties, but usually they self-produce it several times until the seed performance declines significantly. Hence, credit may have a limited impact on the adoption of MVs. On the other hand, farmers need cash on hand to purchase chemical fertilizer to the extent that the credit market is malfunctioning.[3] We expect that those who can access credit or those who can self-finance can adopt fertilizer.

Improved practices, including bund construction, plot leveling, and transplanting in rows, are all labor intensive. Of these practices, it is easy for farmers to monitor if transplanting in rows is done properly. In this case, access to credit would have a positive impact on the adoption of transplanting in rows as farmers can rely on hired agricultural labor. On the other hand, it is difficult to monitor hired labor to check whether they properly expend the expected effort for bund construction and leveling of plots. For these practices, farmers are not inclined to rely on hired labor (Otsuka 2007), and thus credit may not have a strong impact.

4. Descriptive analyses

This section aims to examine the current status of rice cultivation in Tanzania and the possible constraints on the adoption of modern

3. Seeds are a more expensive input than fertilizer as the average cost of purchased seed is 20 USD, and that of purchased chemical fertilizer is 80 USD / ha for those who purchased inputs.

technologies. Table 1 summarizes the basic statistics of rice cultivation in the sample regions in Tanzania. 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.[4] Focusing only on the top 25% of high-yield farmers, they achieve 5.9 t/ha in irrigated areas and 3.7 t/ha even under rain-fed conditions. These facts imply a high potential for both irrigated and rain-fed rice cultivation in Tanzania even though the overall average is not high, especially in the rain-fed areas. A critical research issue is how to realize the potential yield.

To gain insight into the emergence of a rice Green Revolution in Tanzania, we first 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. However, in the irrigated area in Morogoro, the share of MVs 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). In Mbeya region, which is famous for its aromatic rice, few farmers adopt MVs even in irrigated areas 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. However, in general, chemical fertilizer application does not reach the level recommended by agronomists (125-250 kg of urea per ha). Turning now to the improved practices, all practices are more widely adopted in irrigated areas than in rain-fed areas. Among them, 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 areas.

Next, we examine the possible constraints on the adoption of modern technologies. First of all, we explore the role of credit in financing the cost of cultivation. In rice farming, unless farmers have sufficient funds on hand, one way to finance paid-out costs is to borrow money from formal or informal sources. In Tanzania, a formal source available in rural areas is a micro-finance organization called a Savings and Credit

4. In the household interviews, we asked the farmers to report their harvest in terms of the number of bags they use to store the paddy rice, and then convert it into kilograms. To compute the yield, the total harvest is divided by the size of plot reported in the interview.

Cooperative Society (SACCOS).[5] Many informal sources also exist, such as traders, rice millers, and moneylenders, as well as family, relatives, and friends. The other way to handle the paid-out cost in farming is to postpone the payment of fees or wages until the time of harvesting. We can regard this, too, as a kind of credit arrangement that relies on an informal agreement between resource sellers and buyers.

It is worth exploring what types of farmers use which kinds of credit arrangements and what type of farmers cannot use any kind of credit. To shed light on this subject, Table 2 shows village- and household-level characteristics by credit status. During the interviews, we asked farmers whether they used credit for rice cultivation in the sample plot or for any other purpose, including rice cultivation in other plots. If they answered that they did not use credit at all, we also asked the reason why they did not use credit. Based on this information, we classified the credit status of farmers into four categories: (1) farmers using credit or making payment after harvesting rice in the sample plot (credit user for rice cultivation in sample plot), (2) farmers using credit for any other purpose except for rice in the sample plot (credit user for other purposes), (3) farmers who do not use credit because they do not need it (credit non-needy), and (4) farmers do not use credit although they need it (involuntary non-credit user).

A discernible difference in terms of access to credit is observed between credit users and non-users. The credit users have better access to SACCOS than non-users. The share of households in a village that has at least one SACCOS is 35.1% for credit users for rice cultivation in sample plots and 51.4% for credit users for other purposes, while it is 21.3% for involuntary non-credit users. The existence of private moneylenders and other credit organizations in the village for credit users for rice cultivation in sample plots (51.4%) is almost the same as that for involuntary non-credit users (54.0%). This may be because farmers do not use credit from private moneylenders for agricultural purposes due to high interest rates. The distance from the district capital is 68.7 km on average for credit users for rice cultivation while it is 53.8 km for involuntary non-credit users. This implies that credit users do not necessarily live in a village that is near the district capital with better access to the market. The share of irrigated plots is higher for credit users in sample plots (51.4%) than it is for those who are in the other

5. 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.

categories. As discussed with reference to Table 1, farmers in irrigated areas use more inputs and adopt more labor-intensive practices, resulting in higher demand for credit in irrigated areas. Any types of farmers who use credit and who do not need credit show higher asset value than involuntary non-credit users (0.7 million Tanzanian shillings), which suggests that wealthy farmers have better access to credit or can self-finance expenditures.

How does the credit constraint affect the adoption of technologies? Table 3 compares the adoption of modern inputs and improved practices by credit and irrigation status. Because of the fungibility of credit, here we classify farmers into three categories: credit users, including credit for both rice and non-rice purposes; those who do not use credit because they do not need it (credit non-needy); and those who do not use credit although they need it (involuntary non-credit users). The table also shows the results of *t* tests, comparing between the involuntary non-credit users and either of the other two categories. First of all, under rain-fed conditions, there is little difference in the adoption of technologies among credit users, credit non-needy households, and involuntary non-credit users, except that credit users adopt bund construction slightly more often than involuntary non-credit users. Moreover, regardless of the credit status, adoption of new technology is low. The returns to adoption are lower under rain-fed conditions than in irrigated areas because modern inputs are complementary to irrigation water, and some improved practices such as transplanting in rows are difficult to apply when there is no water control.

Turning now to irrigated areas, a clear difference among the three categories is observed for some technologies. We observe that those who use credit apply more chemical fertilizer than the other categories of farmers. Credit users in irrigated areas apply 47.8 kg of fertilizer per hectare whereas involuntary non-users apply 27.2 kg. Note also that the adoption rate of MVs is not higher for credit users than it is for involuntary credit non-users. Between credit users and involuntary non-users, the adoption of bund construction is slightly higher for credit users in irrigated areas. We do not observe a large difference in the levels of adoption of plot leveling (79.4 and 73.4) and transplanting in rows (29.4 and 28.7).

We also show the paid-out costs of rice cultivation in the lower part of Table 3. Although the difference is not statistically significant, total paid-out costs of agricultural labor are higher for credit users than for involuntary non-credit users. Total paid-out costs to hire labor are 241.5

USD per hectare for credit users in irrigated areas and 122.8 USD in rain-fed areas, while they are 213.0 USD in irrigated areas and 101.9 USD in rain-fed areas for involuntary non-credit users. Among these costs, the paid-out costs of hiring labor for leveling are very small (0.2-4.4 USD per hectare) and there is no large difference among credit users and non-users. On the other hand, the paid-out cost of transplanting is significantly higher for credit users (59.0 USD per hectare) than for involuntary non-credit users (42.6 USD). These results suggest that farmers are inclined to hire more agricultural labor to do transplanting, for which monitoring of hired labor is relatively easy, than to level plots. In fact, our data show that the share of hired labor in the total number of hours spent for leveling is 26%, while it is 54% for transplanting. Farmers could be able to hire more agricultural labor to adopt transplanting in rows by using credit. Note, however, that hired labor is not used for plot leveling not because it does not require labor input. In our field interviews, most farmers claimed a lack of labor or traction power to level their plots.

5. The determinants of credit use

(a) Methodology and variable construction

This section statistically examines the determinants of credit status, by applying a multinominal logit model. The credit status variable takes 1 if farmers use credit for any purpose, and 2 if they do not use credit because they do not need it. The base category is that of farmers who do not use credit although they need it (involuntary non-credit users). We include district dummies in model (1) and village dummies in model (2).

The village-level explanatory variables consist of the existence of SACCOS in the village (dummy) and the existence of private moneylenders 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),[6] and access to a fertilizer market in the village (dummy) in order to capture market access to the various inputs. We also include the average male agricultural wage rate in the

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

village measured in terms of kg of paddy, which may have a positive impact on credit use because the costs of rice cultivation increase when the agricultural wage rate is higher.

To capture plot characteristics, we include a dummy variable, which takes 1 if the plot is irrigated, and 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 physical asset endowment. To capture the impact of human capital endowment, we use the number of adult household members older than 15, the age of the household head, the average years of schooling of adult household members, a dummy for a female-headed household, and experience in rice production in the last five years.

(b) Regression results

The regression results of the determinants of credit status are presented in Table 4. Model (1) shows that the existence of SACCOS apparently increases credit use. Note that, although the credit may not be used directly for the sample rice plots, due to the fungibility of credit, it could still have an impact on rice farming of sample plots. The dummy variable, which takes 1 if the plot is irrigated, has a positive and significant coefficient for being credit non-needy. Due to the high productivity of rice cultivation in previous years, farmers may not need to rely on credit to finance the expenditure. The size of the plots owned in upland areas and household assets have positive and significant coefficients for being credit non-needy, which is consistent with our intuition that wealthy farmers do not need credit. The age of household head significantly decreases the probability of being credit non-needy. The experience in rice production in the last five years significantly increases the probability of being credit non-needy, suggesting that experienced farmers can self finance the expenditure.

6. Determinants of technology adoption

(a) Methodology and variable construction

This section investigates the determinants of the adoption of technologies. The dependent variables are the adoption of MVs (dummy variable takes 1 if adopted), chemical fertilizer use (kg/ha), and the adoption of bund construction, leveling of plots, and transplanting in rows (dummy variable takes 1 if adopted). Similar to the previous section, we first estimate reduced-form regressions for each technology with the same exogenous variables as the credit status model, including district and village dummies in models (1) and (2), respectively. We apply the Tobit estimation method to estimate the chemical fertilizer model since many observations are censored at zero. For the other models, we apply probit or OLS estimation methods.[7]

In model (3), we include the variables of being a credit user and that of being credit non-needy and estimate the model using the same estimation method as the reduced form regression. Since farmers decide if they use credit or not by themselves, these variables can be endogenously determined. In order to circumvent the possible endogeneity biases, we also estimate models using an instrumental variable (IV) method. Although both being a credit user and being credit non-needy may be endogenous variables, our models suffer a weak instrument problem when we treat both variables as endogenous in a single equation. Thus, we instrument the variable of being a credit user by using the existence of SACCOS in the village and the existence of private moneylenders and other credit organizations in the village as instrumental variables in model (4).[8] In this model, we compare credit users with both voluntary and involuntary non-credit users. In model (5), we include the variable of being an involuntary credit user and instrument it by using the same instrumental variables as model (4).[9,10]

7. Since many farmers have not yet adopted these technologies, the probit model suffers the problem of perfect prediction by village dummy variables, resulting in too few remaining observations for the analysis. In order to avoid this problem, we estimate the linear probability model by applying the OLS method for village fixed effect models. For the adoption of MVs, we apply OLS to both district and village fixed effect models for the same reason.

8. In our field interviews, we did not find strong evidence that the establishment of a SACCOS is strongly associated with rice cultivation potential. Rather, the aim of SACCOS is to meet multiple kinds of demands for credit. In fact, our data show that SACCOS are the source of 33.7% of total loans and 50.0% of agricultural loans, including loans for non-rice purposes. We also tried an over-identification test, which partially justifies the validity of SACCOS and other variables as instrumental variables for credit use as we discuss below.

9. We also estimate the just-identified model by using only the existence of SACCOS in the village as an instrumental variable both for models (4) and (5). We also estimate models (4) and (5) by using the limited information maximum likelihood method. Both results are largely the same as the reported results.

10. Although the results are not shown, both the existence of SACCOS and the existence of private moneylenders and other credit organizations have negative and significant coefficients on being an involuntary credit non-user when we estimate the first stage regression with the same exogenous variables as the credit-status model.

We compare the involuntary non-credit user, who can be considered as most seriously credit constrained, with the other two categories of farmers including credit users and credit non-needy farmers in model (5). We would interpret credit as having a positive impact on the adoption of technologies when we observe a negative coefficient of being an involuntary credit non-user in model (5).

Table 5 shows the regression results for the adoption of MVs. Since the endogeneity test does not reject the null hypotheses that the variable of being a credit user is exogenous, we mainly rely on the OLS model shown in column (3) for our interpretation. Note, however, that the first-stage *F* test is highly significant, and the over-identifying test does not reject its null hypothesis, indicating that our IV models are validly estimated in models (4) and (5).

The existence of SACCOS does not have a positive and significant coefficient in model (1). Furthermore, the variable of being a credit user does not have a significant coefficient in model (3). The results of the IV models are also consistent with this result and find no significant impact of being a credit user or being an involuntary non-credit user on the adoption of MVs. Given that SACCOS are significant in the credit use function, these results suggest that there is no serious credit constraint to the adoption of MVs. All the models indicate that farmers in villages with a seed market are likely to switch to MVs. Furthermore, we observe a negative and significant coefficient of the distance from the district capital. Although farmers can reproduce a seed after they adopt it, it seems that access to the seed market matters for the adoption of MVs. Another possible explanation of the negative coefficient of the distance from the district capital is proximity to information or training. Our data indicate that farmers living in a village near to the district capital attend rice-related training more often. This may be one of the reasons why farmers near to the district capital adopt MVs more often. Note, however, that the distance to the nearest extension office has no significant impact on the adoption of MVs, making the impact of training ambiguous.

As expected from the descriptive analysis, we find that MVs are used more commonly in irrigated plots in all the models from (1) to (5). This is consistent with the experience of Asian countries, where farmers in irrigated areas adopt MVs more quickly than farmers in rain-fed areas (David and Otsuka 1994). It is important to note that the size of the plots has a negative coefficient in all the models from (1) to (5), although it is not significant in some of the models. This result suggests that not only large-scale farmers but also small-scale farmers are adopting MVs, which are scale-neutral. Furthermore, the household assets variable does not have significant impact on the adoption of MVs. This suggests that wealth is not a serious constraint to adopting MVs. The sizes of the plots owned in both lowland and upland areas consistently have no positive impact on the adoption of MVs. These results suggest that wealthy and large-scale farmers have no advantage in the adoption of MVs.

Table 6 presents the estimation results of the determinants of chemical fertilizer use. The diagnostic tests presented in the lower part of the table indicate that credit use and being an involuntary non-credit user are endogenous variables (endogeneity test) but they are significantly predicted by the identifying instrumental variables (first-stage *F* test) that have no strong evidence of correlation with the error term (over-identification test), providing confidence in the validity of the model specification. Hence we rely mainly on models (4) and (5) for our interpretation. A key finding on chemical fertilizer use is that the existence of SACCOS in model (1) has a positive and significant coefficient. Furthermore, the coefficient of being a credit user in model (4) is positive and significant, while that of being an involuntary non-credit user is negative and significant in model (5). These results suggest that credit users apply more chemical fertilizer than credit non-users. In all the models, the distance to the district capital has a negative and significant coefficient, which may imply that the relative price of fertilizer is an important determinant of fertilizer application. In fact, our data show that the relative price of urea measured in kilograms of paddy is 1.8 in villages within 50 km of the district capital and 2.3 in villages farther than 50 km from the district capital, and the difference is statistically significant. Another possible interpretation of this negative coefficient is better access to information or training in villages near to the district capital, as we discussed earlier. The size of the plot has a negative and significant coefficient in all five models. Furthermore, the sizes of the plots in lowland areas and in upland areas, and household assets, have no significant and positive impact on fertilizer application. These results suggest that small-scale farmers are not in a disadvantageous position even to purchase fertilizer.

Table 7 shows the results of the adoption of bund construction. Since the endogeneity test does not reject the null hypothesis that the variable is exogenous in both models (4) and (5), we mainly rely on the OLS model shown in column (3) for our interpretation. Note, however, that both the first-stage *F* test and the over-identifying test justify the use of the IV models shown in columns (4) and (5). In model (1), SACCOS do not have a positive and significant coefficient, and being a credit user has no positive and significant coefficient in model (3). The IV models are also consistent with this result and find no significant coefficient of being a credit user or being an involuntary non-credit user in models (4) and (5). Hence, bund construction is not more widely adopted among credit users than credit non-users. The distance from the district capital has negative and significant coefficients in all the models, suggesting that access to information or training can be an important determinant of the adoption of bund construction. Under any model, the dummy of irrigated plots has a positive and highly significant coefficient because most irrigated plots have a bund for water control.

Table 8 summarizes the results of the adoption of plot leveling. The endogeneity test rejects the null hypothesis that the variable of being a credit user is exogenous. Thus, we mainly rely on the IV models shown in columns (4) and (5) for our interpretation. Note also that the first-stage *F* test rejects the null hypothesis of a weak instrument and the over-identifying test does not reject its null hypothesis in both models (4) and (5), suggesting that the IV models are validly estimated. The coefficient of the existence of SACCOS is insignificant in model (1). Being a credit user also is not significant in model (4). On the other hand, being an involuntary credit non-user has a negative impact on the adoption of plot leveling, and the coefficient is significant at 10% in model (5). Since plot leveling is a labor-intensive technology, farmers who have credit access or can self-finance costs may be able to hire more agricultural labor than involuntary non-credit users. Note, however, that the coefficients of being a credit user or being an involuntary non-credit user are smaller and less statistically significant for the adoption of plot leveling than for transplanting in rows, as we will discuss later. This may be because farmers are less inclined to use hired labor to adopt plot leveling as they are for transplanting in rows due to the high monitoring cost. The dummy of being an irrigated plot has a positive and significant coefficient in all the models from (1) to (5). Farmers may have a higher incentive to level a plot in order to utilize irrigation water effectively.

The size of the plot has a negative and significant coefficient in all the models because it is easier to level a small plot than a large plot. This is also consistent with our observation that farmers cannot rely on hired labor to level plots since the adoption of this technology requires great care. The dummy variable of being a female-headed household consistently has a negative and significant coefficient in models (2) and

(4), suggesting that a lack of family labor is a constraint on adopting plot leveling. Five years of rice production experience significantly increases the adoption of plot leveling in all the models from (1) to (5). This may be because experienced farmers understand the importance of good water management.

Table 9 summarizes the results of the adoption of transplanting in rows. Endogeneity tests reject the null hypotheses that the variables of being a credit user and being an involuntary non-credit user are exogenous in models (4) and (5). The first-stage *F* tests reject the null hypothesis of a weak instrument and over-identifying tests do not reject the null hypothesis. Therefore, we rely mainly on the IV models shown in columns (4) and (5) for our interpretation. Model (1) indicates that the existence of SACCOS has a positive and significant impact on the adoption of transplanting in rows. Furthermore, being a credit user in model (4) has a positive and significant coefficient, while being an involuntary credit non-user has a negative and significant coefficient, indicating that credit access is important for the adoption of transplanting in rows. Since transplanting in rows is a labor-intensive practice and it is easy to monitor whether it is implemented properly, farmers are inclined to hire labor to adopt this technology. This may be why credit users are adopting transplanting in rows more frequently than credit non-users. Distance to the district capital has a negative and significant coefficient in models (1) to (4), suggesting that access to information or training can be an important determinant of the adoption of transplanting in rows. Being an irrigated plot has a positive and significant coefficient in all the models from (1) to (5). This may be because water control is very important for the adoption of transplanting in rows. Plot size has a negative and significant coefficient in models (1) to (5), which suggests that farmers may not be able to hire as much labor as they want, presumably due to the high labor price at peak season caused by an imperfect labor market.

7. Conclusions

Using extensive data collected in Tanzania, our paper sought to understand the current practice of rice cultivation and to identify the factors underlying the adoption of new rice cultivation technologies such as MVs, chemical fertilizer, and improved agronomic practices. Overall, it was found that the adoption of these technologies is not high, but is gradually emerging.

Statistical analyses of our extensive data set reveal that credit users are applying more chemical fertilizer, which requires cash for purchase, than credit non-users. Meanwhile, the adoption rate of MVs, which can be self-produced to some extent, is not higher for credit users than credit non-users. In terms of improved practices, credit users adopt transplanting in rows more frequently than credit non-users. A possible reason for this is that this practice can be monitored relatively easily even when farmers use hired labor, and credit access allows labor-constrained farmers to rely on hired labor. On the other hand, we observe smaller difference between credit users and credit non-users in the adoption of bund construction and plot leveling than in that of transplanting in rows. Unlike transplanting in rows, farmers do not tend to rely on agricultural labor to adopt these technologies, which are difficult to monitor. In short, improvement in credit access may selectively enhance technology adoption. However, we should be careful in interpreting these results. Since both bund construction and plot leveling are long-term investments, observing the limited impact of credit access in this particular year does not necessarily mean that credit has no impact on the adoption of these technologies. Furthermore, since we cannot deny the possibility that SACCOS are established in favorable areas, we need to carefully interpret the causal relationship between credit use and the adoption of technologies. Further investigation of this issue is needed before we can conclude that credit access can enhance technology adoption in an area where there is currently no credit access as it does in an area with credit access.

Our results also indicate the new technologies are more widely adopted in irrigated areas than in rain-fed areas. Nakano and Kajisa (2012) and Tokuda and Nakano (2013) suggest that the adoption of MVs effectively enhances paddy yield and the profitability of rice cultivation only when they are grown in an irrigated area with proper water management and fertilizer application. There is some possibility that irrigation is installed in favorable areas, and thus we cannot rigorously examine the causal impact of irrigation on the adoption of new technologies in this paper. However, our results suggest that irrigation is a prerequisite for the adoption of new technologies because the adoption rate of these technologies is low in rain-fed areas.

The distance from the district capital is also indicated as being important for the adoption of MVs and chemical fertilizer, as well as some labor-intensive technologies such as bund construction and transplanting in rows. For the adoption of modern inputs, market access and low prices due to proximity to the market may be important determinants of adoption. Our data also show that farmers near to the district capital attend rice-related training more often. This could be one possible reason why farmers near to the district capital adopt these new technologies. However, we do not observe a significant impact of the distance from an extension office, which we consider to be a proxy for attendance at rice-related training. Since the distance from the district capital can capture many other possible effects, more careful examination is needed before we conclude that access to information or training on the adoption of these technologies has a positive impact.

It is also important to note that plot size in general has a negative impact on the adoption of new technologies. Furthermore, we do not observe any strong positive impact of household assets or the size of plots owned in lowland or upland areas on the adoption of new technologies. This suggests that small-scale and poor farmers are not disadvantaged in technology adoption. Therefore, our results suggest that with appropriate policies, including enhancing access to credit, a rice Green Revolution can contribute to improving the productivity of small-scale farmers in Tanzania.

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Table 1. Yield and modern inputs and practices for rice cultivation by region and irrigation status

	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
Paddy yield of top 25% (t/ha)							3.7	5.9
Modern inputs use								
Share of modern variety (%)	17.8	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	0.0	6.7	32.2
Improved practices								
Share of bunded plots (%)	8.2	84.8	16.3	89.6	95.3	100.0	49.0	88.8
Share of leveled plots (%)	22.0	69.6	38.5	78.1	87.6	100.0	54.8	77.0
Share of straight row transplanting plots	4.4	47.8	3.8	22.9	6.4	0.0	5.2	28.9
Observations	182	46	104	96	234	10	520	152

Table 2. Characteristics of villages and households by credit status

	Credit user		Credit non-user	
	Credit user for rice cultivation in sample plot	Credit user for other purposes	Credit non-needy	Involuntary non-credit user
Existence of SACCOS (%)	35.1	51.4	28.9	21.3
Existence of private moneylender and other credit organization (%)	51.4	63.9	62.7	54.0
Distance to the district capital (km)	68.7	43.9	43.6	53.8
Share of irrigated plots (%)	51.4	20.8	28.9	19.6
Household assets (million Tsh)	1.1	0.8	1.0	0.7
Observations	37	72	83	480

Table 3. Modern inputs and improved practices for rice cultivation by credit and irrigation status

	Rain-fed			Irrigated		
	Credit use for any purpose	Credit non-needy	Involuntary non-credit user	Credit use for any purpose	Credit non-needy	Involuntary non-credit user
Modern inputs						
Share of modern variety (%)	4.1*	3.4*	8.2	15.2**	27.3	33.9
Chemical fertilizer use (kg/ha)	7.2	3.1	7.1	47.8*	29.9	27.2
Improved practices						
Share of bunded plots (%)	56.0*	49.2	47.7	94.1*	95.8*	85.1
Share of leveled plots (%)	58.7	55.9	53.9	79.4	87.5*	73.4
Share of straight row transplanting plots	4.0	5.1	5.4	29.4	29.2	28.7
Hired labor and rental capital cost						
Labor cost per hectare in USD1)	122.8	88.1	101.9	241.5	255.6	213.0
Paid-out cost of labor use for plot leveling per hectare in USD	2.2	0.2	1.0	4.4	2.1	3.0
Paid-out cost of labor use for transplanting per hectare in USD	12.8	7.5	8.6	59.0**	64.3**	42.6
Paid-out cost of rental machinery or animals for land preparation per hectare in USD	28.6	28.8	29.1	76.7***	19.1	31.4
Paid-out cost of rental machinery or animals for plot leveling per hectare in USD	0	1.2	.89	5.0	2.3	1.6
Observations	75	59	386	34	24	94

Note: *** denotes significant at 1%, ** significant at 5%, and * significant at 10% in *t* test comparing between involuntary non-credit users and either of the other two categories.
[1)] The exchange rate used is 1 USD = 1,320.3 Tanzanian shillings.

Table 4. The determinants of credit status (multinominal logit estimation)

	[1]		[2]	
	District FE		Village FE	
	Credit user	Credit non-needy		
Existence of SACCOS in the village	0.961***	0.396		
	[0.000]	[0.183]		
Private moneylender and other credit organization in the village	0.174	0.558*		
	[0.505]	[0.052]		
Distance to the nearest extension office (km)	-0.006	-0.027		
	[0.800]	[0.362]		
Existence of seed market	0.502	-0.443		
	[0.216]	[0.364]		
Access to fertilizer market	0.221	-0.035		
	[0.499]	[0.921]		
Male agricultural wage rate in kg of paddy	0.018	-0.016		
	[0.419]	[0.631]		
Distance to the district capital (km)	-0.001	-0.005		
	[0.798]	[0.324]		
= 1 if plot is irrigated	-0.294	0.850**	-0.574	1.688***
	[0.502]	[0.029]	[0.325]	[0.009]
Size of the plot (ha)	0.105	0.055	-0.023	-0.008
	[0.185]	[0.600]	[0.826]	[0.956]
The size of plots owned in a lowland area except the sample plot (ha)	-0.019	-0.150*	-0.006	-0.142
	[0.731]	[0.099]	[0.928]	[0.202]
The size of plots owned in an upland area (ha)	0.064	0.168**	0.111	0.283***
	[0.392]	[0.010]	[0.198]	[0.002]
Household assets (million Tsh)	0.044	0.197*	0.122	0.454**
	[0.696]	[0.087]	[0.400]	[0.015]
Number of cows and bulls owned	-0.003	-0.009	-0.008	-0.010
	[0.795]	[0.531]	[0.593]	[0.518]
Number of adults (age ≥ 15)	0.076	0.020	0.064	0.011
	[0.288]	[0.820]	[0.471]	[0.906]
The age of hh head	-0.019*	-0.043***	-0.021	-0.044***
	[0.087]	[0.001]	[0.100]	[0.005]
Average years of schooling of adult hh members	0.054	-0.140*	-0.024	-0.158*
	[0.429]	[0.058]	[0.768]	[0.055]
=1 if female hh head	0.715**	-0.252	0.368	-0.436
	[0.049]	[0.583]	[0.405]	[0.414]
Experience in rice production in last 5 years	0.040	0.197**	0.078	0.201*
	[0.589]	[0.026]	[0.373]	[0.061]
Constant	-2.669***	-1.408	0.324	0.242
	[0.004]	[0.213]	[0.766]	[0.869]
Observations	672	672	672	672

p-values in brackets.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 5. The determinants of the adoption of MVs

	(1) District FE OLS	(2) Village FE OLS	(3) District FE OLS	(4) District FE IV (2SLS)	(5) District FE IV (2SLS)
Credit use for any purpose			0.006	-0.078	
			[0.851]	[0.682]	
Credit non-needy			-0.022		
			[0.509]		
Involuntary non-credit user					0.108
					[0.466]
Village characteristics					
SACCOS	-0.008				
	[0.744]				
Private moneylender and other credit organization in the village	-0.023				
	[0.322]				
Distance to the nearest extension office (km)	-0.002		-0.002	-0.002	-0.002
	[0.251]		[0.282]	[0.273]	[0.219]
Existence of seed market	0.179***		0.172***	0.182***	0.181***
	[0.000]		[0.000]	[0.000]	[0.000]
Access to fertilizer market	0.031		0.033	0.037	0.037
	[0.299]		[0.260]	[0.222]	[0.216]
Male agricultural wage rate in kg of paddy	0.001		0.001	0.002	0.002
	[0.620]		[0.575]	[0.491]	[0.470]
Distance to the district capital (km)	-0.001***		-0.001***	-0.001***	-0.001***
	[0.002]		[0.002]	[0.002]	[0.002]
Household characteristics					
= 1 if plot is irrigated	0.441***	0.195***	0.444***	0.438***	0.448***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Size of the plot (ha)	-0.015*	-0.007	-0.016*	-0.014	-0.014
	[0.063]	[0.384]	[0.063]	[0.102]	[0.116]
The size of plots owned in a lowland area except the sample plot (ha)	0.003	0.002	0.003	0.003	0.002
	[0.608]	[0.621]	[0.610]	[0.560]	[0.750]
The size of plots owned in an upland area (ha)	-0.008	-0.007	-0.007	-0.008	-0.006
	[0.203]	[0.248]	[0.258]	[0.211]	[0.398]
Household assets (million Tsh)	-0.009	-0.007	-0.008	-0.009	-0.007
	[0.415]	[0.515]	[0.446]	[0.414]	[0.562]
Number of cows and bulls owned	-0.000	-0.001	-0.000	-0.000	-0.000
	[0.731]	[0.505]	[0.699]	[0.696]	[0.649]
Number of adults (age ≥ 15)	0.008	0.010	0.008	0.008	0.009
	[0.239]	[0.100]	[0.261]	[0.226]	[0.205]
The age of hh head	-0.001	-0.001	-0.001	-0.001	-0.001
	[0.336]	[0.303]	[0.331]	[0.315]	[0.243]
Average years of schooling of adult hh members	-0.002	0.003	-0.002	-0.001	-0.003
	[0.761]	[0.591]	[0.692]	[0.814]	[0.656]
= 1 if female hh head	-0.050	0.006	-0.052	-0.043	-0.042
	[0.161]	[0.841]	[0.143]	[0.289]	[0.259]
Experience in rice production in last 5 years	0.004	0.002	0.004	0.004	0.006
	[0.602]	[0.692]	[0.593]	[0.599]	[0.452]
Constant	0.372***	0.387***	0.355***	0.351***	0.270**
	[0.000]	[0.000]	[0.000]	[0.000]	[0.046]
Observations	672	672	672	672	672
R-squared	0.426	0.613	0.426		
First-stage *F*				7.596	8.521
				[0.001]	[0.000]
Endogeneity test (Durbin statistics)				0.214	0.496
				[0.644]	[0.481]
Over-identifying test (Sargan statistics)				0.988	0.570
				[0.330]	[0.450]

p-values in brackets.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 6. The determinants of chemical fertilizer use (kg/ha)

	(1) District FE Tobit	(2) Village FE Tobit	(3) District FE Tobit	(4) District FE IV (2SLS)	(5) District FE IV (2SLS)
Credit use for any purpose			22.527	101.364***	
			[0.473]	[0.006]	
Credit non-needy			16.474		
			[0.650]		
Involuntary credit non-user					-81.585***
					[0.004]
Village characteristics					
SACCOS	63.406**				
	[0.021]				
Private moneylender and other credit organization in the village	-7.203				
	[0.791]				
Distance to the nearest extension office (km)	0.348		-0.621	0.166	0.405
	[0.903]		[0.834]	[0.639]	[0.277]
Existence of seed market	-1.438		16.695	-5.879	-0.525
	[0.969]		[0.648]	[0.468]	[0.942]
Access to fertilizer market	23.591		35.467	1.656	3.255
	[0.537]		[0.321]	[0.778]	[0.570]
Male agricultural wage rate in kg of paddy	1.308		1.430	-0.824*	-0.686
	[0.539]		[0.509]	[0.060]	[0.105]
Distance to the district capital (km)	-1.594***		-1.459***	-0.227***	-0.204***
	[0.000]		[0.000]	[0.000]	[0.001]
Household characteristics					
= 1 if plot is irrigated	22.214	12.810	28.302	10.831	2.380
	[0.488]	[0.644]	[0.381]	[0.120]	[0.735]
Size of the plot (ha)	-38.047**	-27.409**	-40.360**	-4.253**	-4.094**
	[0.015]	[0.031]	[0.011]	[0.012]	[0.014]
The size of plots owned in a lowland area except the sample plot (ha)	-5.963	-0.252	-8.487	-0.999	0.011
	[0.431]	[0.963]	[0.272]	[0.326]	[0.991]
The size of plots owned in an upland area (ha)	-5.900	-1.392	-11.021	-0.173	-1.808
	[0.612]	[0.873]	[0.376]	[0.884]	[0.158]
Household assets (million Tsh)	7.311	11.650	6.559	0.499	-1.242
	[0.469]	[0.155]	[0.525]	[0.815]	[0.574]
Number of cows and bulls owned	1.141	0.211	0.900	0.176	0.225
	[0.429]	[0.892]	[0.546]	[0.381]	[0.265]
Number of adults (age ≥ 15)	-10.472	-1.289	-11.530	-2.210	-2.090
	[0.243]	[0.857]	[0.209]	[0.105]	[0.121]
The age of hh head	0.191	-1.577*	0.349	0.125	0.388
	[0.847]	[0.068]	[0.730]	[0.527]	[0.109]
Average years of schooling of adult hh members	16.058**	12.532**	16.079**	0.809	2.092*
	[0.025]	[0.038]	[0.026]	[0.498]	[0.074]
= 1 if female hh head	19.391	8.736	26.036	-1.377	2.591
	[0.573]	[0.749]	[0.453]	[0.861]	[0.720]
Experience in rice production in last 5 years	-4.882	-4.081	-3.099	-0.858	-2.263
	[0.490]	[0.493]	[0.664]	[0.507]	[0.113]
Constant	-90.240	-43.971	-111.301	41.734***	103.242***
	[0.306]	[0.541]	[0.183]	[0.007]	[0.000]
Observations	672	672	672	672	672
First-stage *F*				7.596	8.521
				[0.001]	[0.000]
Endogeneity test (Durbin statistics)				12.973	14.417
				[0.000]	[0.000]
Over-identifying test (Sargan statistics)				0.7411	0.335
				[0.3893]	[0.855]

p-values in brackets.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 7. The determinants of adoption of bund construction

	(1) District FE Probit	(2) Village FE OLS	(3) District FE Probit	(4) District FE IV (2SLS)	(5) District FE IV (2SLS)
Credit use for any purpose			-0.102	0.021	
			[0.644]	[0.918]	
Credit non-needy			0.126		
			[0.594]		
Involuntary credit non-user					-0.032
					[0.838]
Village characteristics					
SACCOS	-0.024				
	[0.898]				
Private moneylender and other credit organization in the village	0.156				
	[0.376]				
Distance to the nearest extension office (km)	-0.010		-0.011	-0.001	-0.001
	[0.525]		[0.511]	[0.729]	[0.785]
Existence of seed market	0.555**		0.569**	0.129***	0.129***
	[0.031]		[0.022]	[0.003]	[0.001]
Access to fertilizer market	-0.224		-0.246	-0.048	-0.048
	[0.315]		[0.265]	[0.133]	[0.125]
Male agricultural wage rate in kg of paddy	0.024		0.024	0.002	0.002
	[0.155]		[0.164]	[0.300]	[0.288]
Distance to the district capital (km)	-0.008***		-0.008***	-0.001***	-0.001***
	[0.006]		[0.006]	[0.002]	[0.003]
Household characteristics					
= 1 if plot is irrigated	2.025***	0.386***	2.003***	0.562***	0.560***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Size of the plot (ha)	-0.085	-0.006	-0.086	-0.011	-0.012
	[0.187]	[0.494]	[0.174]	[0.212]	[0.197]
The size of plots owned in a lowland area except the sample plot (ha)	0.007	0.002	0.006	0.001	0.002
	[0.856]	[0.699]	[0.882]	[0.825]	[0.783]
The size of plots owned in an upland area (ha)	-0.071	-0.009	-0.072	-0.005	-0.005
	[0.209]	[0.173]	[0.198]	[0.461]	[0.443]
Household assets (million Tsh)	-0.058	-0.009	-0.061	-0.011	-0.012
	[0.493]	[0.455]	[0.471]	[0.342]	[0.332]
Number of cows and bulls owned	0.008	0.000	0.008	0.000	0.000
	[0.499]	[0.702]	[0.501]	[0.813]	[0.799]
Number of adults (age ≥ 15)	0.055	0.007	0.060	0.008	0.008
	[0.291]	[0.307]	[0.248]	[0.249]	[0.251]
The age of hh head	-0.006	-0.000	-0.006	-0.001	-0.001
	[0.408]	[0.649]	[0.416]	[0.308]	[0.467]
Average years of schooling of adult hh members	-0.024	-0.005	-0.020	-0.005	-0.004
	[0.584]	[0.423]	[0.646]	[0.453]	[0.478]
= 1 if female hh head	-0.354	-0.036	-0.337	-0.039	-0.040
	[0.163]	[0.337]	[0.182]	[0.359]	[0.313]
Experience in rice production in last 5 years	-0.003	-0.002	-0.004	-0.000	-0.001
	[0.952]	[0.816]	[0.941]	[0.958]	[0.899]
Constant	-0.783	0.047	-0.668	0.245***	0.268*
	[0.189]	[0.667]	[0.243]	[0.003]	[0.058]
Observations	672	672	672	672	672
R-squared		0.752			
First-stage *F*				7.596	8.521
				[0.001]	[0.000]
Endogeneity test (Durbin statistics)				12.973	0.051
				[0.000]	[0.822]
Over-identifying test (Sargan statistics)				0.7411	0.599
				[0.3893]	[0.807]

p-values in brackets.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 8. The determinants of the adoption of plot leveling

	(1) District FE Probit	(2) Village FE OLS	(3) District FE Probit	(4) District FE IV (2SLS)	(5) District FE IV (2SLS)
Credit use for any purpose			-0.060	0.513	
			[0.718]	[0.102]	
Credit non-needy			-0.042		
			[0.820]		
Involuntary credit non-user					-0.484*
					[0.052]
Village characteristics					
SACCOS	0.223				
	[0.111]				
Private moneylender and other credit organization in the village	0.218				
	[0.102]				
Distance to the nearest extension office (km)	-0.006		-0.009	-0.002	-0.000
	[0.568]		[0.382]	[0.541]	[0.923]
Existence of seed market	0.088		0.184	0.014	0.036
	[0.663]		[0.350]	[0.840]	[0.573]
Access to fertilizer market	-0.171		-0.190	-0.089*	-0.083*
	[0.319]		[0.263]	[0.071]	[0.096]
Male agricultural wage rate in kg of paddy	0.004		0.005	-0.000	0.000
	[0.768]		[0.681]	[0.904]	[0.994]
Distance to the district capital (km)	0.001		0.001	0.000	0.000
	[0.760]		[0.750]	[0.954]	[0.763]
Household characteristics					
= 1 if plot is irrigated	1.161***	0.359***	1.138***	0.387***	0.340***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Size of the plot (ha)	-0.087*	-0.030**	-0.087*	-0.030**	-0.030**
	[0.064]	[0.031]	[0.063]	[0.037]	[0.038]
The size of plots owned in a lowland area except the sample plot (ha)	-0.046	-0.010	-0.049*	-0.012	-0.006
	[0.113]	[0.249]	[0.089]	[0.168]	[0.525]
The size of plots owned in an upland area (ha)	-0.021	-0.010	-0.028	-0.006	-0.015
	[0.568]	[0.310]	[0.443]	[0.561]	[0.170]
Household assets (million Tsh)	0.109*	0.031*	0.108*	0.025	0.015
	[0.092]	[0.078]	[0.098]	[0.158]	[0.435]
Number of cows and bulls owned	0.012	0.003	0.013*	0.002	0.002
	[0.106]	[0.108]	[0.088]	[0.217]	[0.173]
Number of adults (age ≥ 15)	-0.048	-0.017	-0.048	-0.016	-0.016
	[0.207]	[0.125]	[0.203]	[0.171]	[0.177]
The age of hh head	-0.001	0.000	-0.002	0.000	0.002
	[0.810]	[0.825]	[0.650]	[0.998]	[0.415]
Average years of schooling of adult hh members	-0.005	0.001	-0.002	-0.006	0.001
	[0.880]	[0.876]	[0.948]	[0.535]	[0.948]
= 1 if female hh head	-0.242	-0.093*	-0.213	-0.112*	-0.098
	[0.220]	[0.096]	[0.274]	[0.092]	[0.120]
Experience in rice production in last 5 years	0.076**	0.018*	0.085**	0.021*	0.012
	[0.042]	[0.089]	[0.022]	[0.055]	[0.322]
Constant	-1.075**	0.171	-0.857*	0.226*	0.590***
	[0.021]	[0.295]	[0.055]	[0.083]	[0.010]
Observations	672	672	672	672	672
R-squared		0.428			
First-stage *F*				7.596	8.521
				[0.001]	[0.000]
Endogeneity test (Durbin statistics)				3.458	5.297
				[0.063]	[0.021]
Over-identifying test (Sargan statistics)				1.782	0.400
				[0.182]	[0.527]

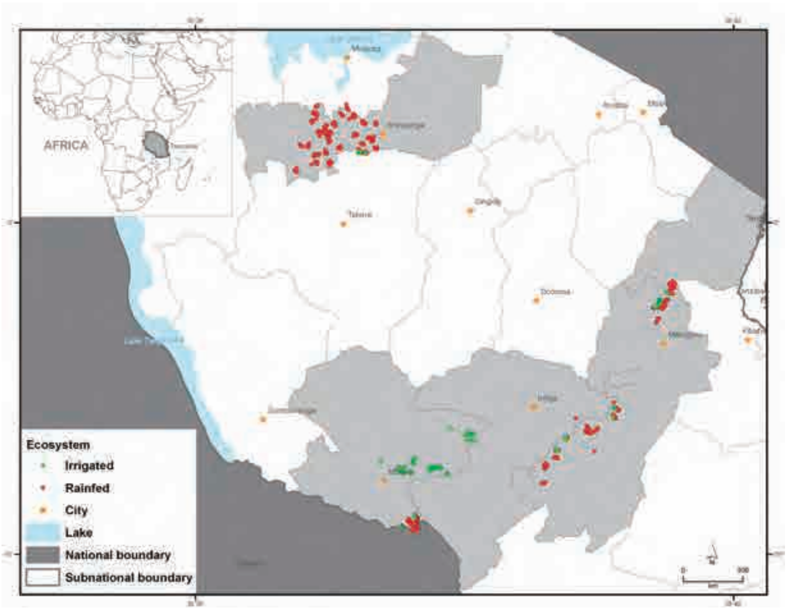
p-values in brackets.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 9. The determinants of the adoption of transplanting in rows

	(1) District FE Probit	(2) Village FE OLS	(3) District FE Probit	(4) District FE IV (2SLS)	(5) District FE IV (2SLS)
Credit use for any purpose			-0.111	0.715***	
			[0.621]	[0.009]	
Credit non-needy			0.038		
			[0.874]		
Involuntary credit non-user					-0.526***
					[0.009]
Village characteristics					
SACCOS	0.462***				
	[0.009]				
Private moneylender and other credit organization in the village	0.032				
	[0.860]				
Distance to the nearest extension office (km)	0.001		-0.001	0.001	0.002
	[0.932]		[0.933]	[0.765]	[0.390]
Existence of seed market	0.446*		0.565**	0.039	0.080
	[0.056]		[0.011]	[0.513]	[0.115]
Access to fertilizer market	-0.054		0.000	-0.021	-0.008
	[0.804]		[0.999]	[0.631]	[0.842]
Male agricultural wage rate in kg of paddy	-0.001		0.005	-0.004	-0.003
	[0.971]		[0.731]	[0.234]	[0.360]
Distance to the district capital (km)	-0.006**		-0.006**	-0.001*	-0.001
	[0.035]		[0.039]	[0.056]	[0.102]
Household characteristics					
= 1 if plot is irrigated	0.888***	0.203***	0.881***	0.241***	0.184***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Size of the plot (ha)	-0.462***	-0.018**	-0.465***	-0.038***	-0.036***
	[0.001]	[0.039]	[0.001]	[0.002]	[0.002]
The size of plots owned in a lowland area except the sample plot (ha)	0.082**	0.010*	0.073**	0.007	0.014*
	[0.026]	[0.073]	[0.044]	[0.336]	[0.065]
The size of plots owned in an upland area (ha)	0.057	-0.002	0.038	0.003	-0.007
	[0.224]	[0.735]	[0.435]	[0.692]	[0.422]
Household assets (million Tsh)	-0.002	-0.003	-0.005	-0.005	-0.016
	[0.982]	[0.781]	[0.947]	[0.759]	[0.301]
Number of cows and bulls owned	0.001	-0.001	0.001	0.000	0.001
	[0.895]	[0.580]	[0.857]	[0.764]	[0.597]
Number of adults (age ≥ 15)	-0.099	-0.004	-0.099	-0.015	-0.014
	[0.104]	[0.527]	[0.100]	[0.129]	[0.143]
The age of hh head	0.012*	0.000	0.013*	0.003**	0.004***
	[0.084]	[0.789]	[0.068]	[0.048]	[0.009]
Average years of schooling of adult hh members	0.082*	0.009	0.086*	0.005	0.014*
	[0.085]	[0.122]	[0.069]	[0.556]	[0.090]
= 1 if female hh head	-0.104	-0.005	-0.001	-0.058	-0.026
	[0.702]	[0.887]	[0.996]	[0.318]	[0.611]
Experience in rice production in last 5 years	0.027	0.005	0.044	0.005	-0.004
	[0.585]	[0.456]	[0.381]	[0.590]	[0.711]
Constant	-1.892***	0.135	-1.984***	0.006	0.403**
	[0.003]	[0.201]	[0.001]	[0.960]	[0.028]
Observations	672	672	672	672	672
R-squared		0.398			
First-stage F				7.596	8.521
				[0.001]	[0.000]
Endogeneity test (Durbin statistics)				12.925	11.522
				[0.000]	[0.001]
Over-identifying test (Sargan statistics)				0.031	0.674
				[0.861]	[0.412]

p-values in brackets.
*** $p < 0.01$, ** $p < 0.05$,* $p < 0.1$.

Figure 1. The regions covered by the survey and the location of surveyed plots by irrigation status in Tanzania



Case 4:

Extensification and Intensification Process of Rainfed Lowland Rice Farming in Mozambique

Kei Kajisa* and Ellen Payongayong†

Abstract

This paper explores the extensification and intensification process of rice production in Mozambique's dominant rice ecology, i.e., rainfed lowland area. Our household-level data show that the potential of extensification is not fully exploited, as only 41% of the cultivable lowland is used for rice. The lack of power predominantly constrains rice area expansion. High potential also exists in land intensification as indicated by the average yield of 2.5 t/ha among the top 25% of rainfed farmers. Intensification through technology adoption and intensive crop care (i.e., Boserupian process) seems to be emerging among the farmers reaching their rice land limits.

Keywords: Green Revolution, rice, Sub-Saharan Africa

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Introduction

Rice consumption in Mozambique has been increasing rapidly from 86 thousand tons in 1990 to 519 thousand tons in 2010 at an annual growth rate of 8.6% (USDA 2011). This is a faster growth rate than the three other major cereals: maize (5.5%), wheat (7.4%), and sorghum (4.7%) (USDA 2011). Meanwhile, local rice production has stagnated since then, resulting in a rapid increase in rice imports. Facing the trend of rising rice prices in the world market, high priority has been placed on the development of the domestic rice sector in the country. For example, under the initiative of the Coalition for African Rice Development (CARD), the country has drafted a national development strategy emphasizing the modernization of the sector (CARD 2011).

About 90% of the rice area is classified under rainfed lowland ecology in Mozambique (Seck et al. 2010), while irrigated ecology accounts for only 3%. Although the potential of the latter agro-ecology is very high according to analysis of the Chokwe irrigation scheme by Kajisa and Payongayong (2011), it is not easy to realize a massive increase in irrigated area in the short-term. Hence, a major contribution to the increase in rice production should come from rainfed lowland ecology.

However, our knowledge on rice farming and rice farmers in rainfed lowland areas is limited. A few exceptions include Agrifood Consulting International (2005) and Zandamela (2008), in which they describe rice farming in this agro-ecology that is characterized as the use of a traditional variety with little fertilizer input on small farms. This is useful to understand the current prevailing farming practices. For the country's rice sector development, however, what we need to know is whether there is potential in this area beyond the current level of production and how the development process will start.

This paper attempts to identify the potential of and constraints on production increase in rainfed lowland areas in Mozambique, using household-level data collected in Zambézia and Sofala in 2008. These two provinces consist of about 65% of the rice area of the country (Ministry of Agriculture 2005). In line with Boserup (1965), which discussed the transformation process to modern farming, our analyses shed light on the process from two angles: by area expansion and/or by land intensification (or yield improvement). Since Mozambique exploits less than 20% of the area suitable for rice production (Agrifood Consulting International 2005), our analyses start with identification of the factors underlying rice area expansion. Then, secondly, we examine the determinants of land productivity because some farmers have already achieved high yields by modernizing their practice even under rainfed conditions. In other words, we try to detect the emergence of the Boserupian process (intensification with modern technologies) for the farmers who have already reached their rice land limit (Boserup 1965). Through analyses with these two approaches, we discuss what constraints hinder farmers in achieving their potential in our study area and what kind of policy interventions could be effective to remove the constraints.

1. Rice in Mozambique

Similar to other African countries, a shift in consumer preference to rice – as a result of an increase in urbanization and the convenience of preparing rice meals – has been rapidly increasing rice demand in Mozambique (Hossain 2006). Figure 1 shows a rapid increase in consumption since 1990. It also shows that in response to this increase, production grew initially at 12.1% annually from 1993 to 1998, but that growth has stagnated since then. As shown in Figure 2, the growth of production in this period was largely attributed to area expansion resulting from the re-settlement of rural populations after the peace agreement in 1992, rather than yield increases (Zandamela 2008). Paddy yield has stagnated at around 1 t/ha for the last three decades. Therefore, once the re-settlement was completed, production growth lost its momentum at the end of the 1990s. The result was a rapid increase in rice imports as indicated by the widening gap between consumption and production in Figure 1.

Rice in Mozambique is produced mostly under rainfed lowland ecology (Table 1) where the farmers follow traditional cultivation practices. The seed varieties commonly used are either traditional varieties or old improved varieties developed in the 1960s or 1970s (Agrifood Consulting International 2005).[1] Only 2.5% of the rice farmers use fertilizer, 5.2% use pesticides, 11% use animal traction, and 25% use some mechanization on farms with an average size of 1.28 hectares (Agrifood Consulting International 2005). Similar to some other African countries, rice is a cash crop for Mozambican farmers. Among rainfed lowland areas, Zambézia and Sofala are the two major provinces in the

1. The names of the traditional varieties are Chupa, Chibica, Agulha, Faia, Mmima, and Muaia Muriangani. Old improved varieties include C4, ITA312, and Limpopo.

country (Table 1).

2. Data

The International Rice Research Institute (IRRI) conducted a household survey in 2008 for the agricultural season 2007-08, covering the period from September 2007 to August 2008. The survey was conducted in parallel with the National Agricultural Survey of 2008 (*Trabalho de Inquérito Agrícola* 2008 (hereafter, TIA08)) in collaboration with the Department of Statistics within the Directorate of Economics of the Ministry of Agriculture.

TIA08 is a nationally representative dataset covering all provinces. Based on the TIA08 survey, 33 villages in 9 districts out of 151 villages in 17 districts in Zambézia and Sofala are identified as rice-growing villages (Figure 3). TIA08 has sampled about 8 households in each village, generating a sample of 248 farmers from 33 villages. IRRI has additionally conducted a detailed rice survey for these sample farmers. Of them, 197 farmers produced rice in the 2007-08 season.

3. Summary statistics and research issues

Table 2 shows summary statistics on rice farming and household characteristics of the data set. Paddy yield is merely 1.1 t/ha, which is lower than other African countries with the same agro-ecological conditions, where most of them achieved about 2 t/ha (Seck et al. 2010). It does not, however, mean that all of them are low productivity farmers. The top 25% of the farmers achieved an average yield of 2.5 t/ha, which is an attractive yield level under these agro-ecological conditions. This means that the potential exists but only 25% of the farmers have currently realized it. Important research questions are what type of farmer has achieved high yield and how we can close the yield gap.

The table shows that only 1% of the area cultivated use modern varieties with no application of any kinds of chemical inputs. Improved rice farming practices such as construction of bunds and transplanting are observed to some extent, but still less than half the farmers have adopted these practices. In terms of power sources, either tractors or animals are seldom used; indicating rice farming is largely done manually. Careful examination of each factor reveals the strategies for productivity improvement.

The table also shows that only 41% of their cultivable lowland is used for rice cultivation on average, indicating the potential of area expiation for production increase. Household size is 5.23 on average and the number of working members is 2.23. The household size is not so different from the Asian standard. Different from Asia, however, is that there are few landless rural households in Mozambique. In this regard, Mozambique faces more serious labor constraints than Asia for rice farming. At the same time, animals or machines are seldom used. Therefore, the lack of power could be one of the bottlenecks for area expansion.

In the study area, the proportion of female-headed household is 26%, and the average schooling of household members is 2.92 years. These socio-economic factors are also considered as possible determinants in the analyses.

4. The determinants of rice cultivated area

Methodology

We investigate the determinants of the rice cultivated area by a framework akin to Skoufias (1995). If the markets function perfectly, the level of inputs including the size of the cultivated area is determined solely by the output price, the quality of land, technology, a farmer's farming ability (these four items as the determinants of marginal return), and input prices (as the determinant of marginal cost) but not by factor endowments and wealth of the farmer. Therefore, a significant influence of the endowments would indicate this factor cannot be acquired from the market and becomes a constraint for the optimal use of the inputs. In this section we try to identify the constraints on the optimal use of the lowland area for rice cultivation by examining the influence of the household-level resource endowments, controlling the influence from land quality, technology, ability and prices as much as possible.

The dependent variable we use is the rice cultivated area in hectares. Of the explanatory variables, the resource endowments of a household are understood by landholding size of the lowland area, the number of working age members, and the number of owned draft animals. Farming ability may be understood by the age of the household head, the average years of education over household member, the participation in agricultural training, and the gender of the household head. The agricultural training variable also includes access to technologies. We run linear and quadratic models where the latter model includes squared terms of the household variables except the female head dummy. Price effects are captured by village-level variables on price and market access. Our model includes rice price (milled rice equivalent), access to seed markets, access to fertilizer markets, access to credit markets, the existence of tractor rental markets, and the existence of animal rental markets in a village. To understand the access to markets in general we also include the variable for access to paved roads and the variable indicating access to roads throughout the year (i.e., non-seasonal access). The variables for market access would also include the access to technologies. The other important price variables are male and female wage rates. Unfortunately, however, such variables are missing in many villages in our data set. Hence, we use the average proportion of non-agricultural workers as the proxy.

Because our data are about one fifth left-censored (no rice cultivation) observations, we use the Tobit model for the estimation. We run the Tobit model with district fixed effects and village fixed effects. The former includes village-level variables in order to explore how the village-level variables on price and market access affect the proportion of the rice cultivated area. The latter is estimated in order to completely control village-level effects because some important village-level prices like wage rates are not fully available in our data set. We also expect that land quality can be controlled as a village fixed factor. In this regard, the village fixed effect models add statistical confidence to our influence on the household-level resource endowment.

Descriptive Analysis

For descriptive analysis, to have some idea on what kind of farmers are approaching their land limit, instead of cultivated land size, we classify the farmers based on the proportion of rice area into three groups: (1) no rice cultivation, (2) below-median proportion, and (3) above-median proportion at the median of 33%. By group, Table 3 shows the household- and village-level characteristics. First of all, it is difficult to find some systematic pattern between no rice farmers and rice farmers. One possible reason could be that the farmers in this group include those who have decided not to cultivate simply because their lowland is not suitable for rice cultivation.

Meanwhile, we can observe a few discernible features between the below-median group and the above-median group. First, the labor endowment measured by the number of working members per hectare of land is larger among the above-median group. Second, although there are no tractor owners in our sample, we observe there are draft animal owners only in the above-median group. Consistent with this, in the above-median group, we observe more villages with draft animal rental markets, although the difference is small. These imply that the lack of power is one of the bottlenecks for area expansion. Third, it appears that the rice area increases with average schooling years, which may include farm management abilities. Fourth, although we expect that profitability is a major incentive for rice area expansion, the table shows that the rice price is almost the same over the three groups.

Regression Analysis

Table 4 shows the estimation results of the determinants of the rice cultivated area. A key finding is that a positive and significant coefficient of labor endowment in both models indicates that the greater the labor force is in a household, the larger the land the household uses for rice cultivation. As expected in previous discussions, this suggests that farming households cannot hire as many agricultural laborers as they wish and that the lack of power is a major constraint to rice area expansion.

Being consistent with this finding, the existence of animal rental markets in a village contributes to area expansion, as indicated by its positive and significant coefficient. Since the number of owned draft animals is insignificant, even the farmers who do not own animals seem to be able to use animals for agriculture as long as the rental market exists in the village. Although a tractor is another important power source, the existence of its rental market is not statistically significant. Note that most of the tractors available in our study area are four-wheeled tractors, which are not suitable for the land preparation of small rice plots. Hence, our results may simply imply that the existing types of tractors are not effective for rice cultivation. Two-wheeled hand tractors are more commonly used in many rice producing countries. Our results might change if such tractors become locally accessible.

Average schooling years are not significant. Existing empirical studies on the impact of education on agricultural performance have found that a basic level of education is sufficient to acquire the benefits of modern agricultural practices (Feder et al. 1985; Foster and Rozenzweig 1996). However, given that its mean value is merely 2.9 years, its impact may not be large enough to affect farming practices.

5. The determinants of yield

Descriptive Analysis

Table 5 shows land use, rice technologies, and household- and village-level characteristics of the sample of 197 rice farmers by rice yield group, where the average yield ranges from 294 kg/ha for the bottom group, to 809 kg/ha for the middle, and to 2,200 kg/ha for the top. Two variables on land use shed light on two key issues of land productivity. First, the size of the cultivated area shows an inverse relationship with yield. This feature is commonly observed in South Asia partly because factor markets are distorted and large landholders have to manage their farms by themselves even when renting out is a better option (Otsuka 2007). Since Mozambique used to follow a socialist system, the private ownership of farm land has not yet been fully established and doubt still exists on the credibility of official land titling. Under such circumstances, land rental transactions could be inactive, resulting in an inverse relationship.

Second, in order to identify the households already facing their land limit for rice cultivation, we generate a dummy variable that takes the value one when the proportion of the rice area is 100%. The table indicates a high yield is more likely to be observed when land is already fully utilized and the size of the cultivated area is small, implying that, even in Mozambique's rainfed areas, some farmers may have already entered into the stage of land intensification through land productivity improvement.

Being consistent with this conjecture, the adoption of a modern variety (ITA 312) is observed only among the top yield group.[2] Furthermore, the adoption rate increases from 0.03 to 0.11 if we limit the sample of this group to the full land utilizing farmers, which we may regard as an intensification effort. Meanwhile, there is no clear pattern in the adoption of local varieties. The use of other modern inputs such as chemical fertilizer and other chemicals is zero for all, indicating the use of these inputs is not yet an available option for productivity improvement. The table also shows the level of adoption of improved practices recommended by local agronomists (i.e., the construction of bunds, flatness of plots (as a result of leveling), transplanting (against direct seeding), timely seeding/transplanting, and the number of seedlings per hill) does not show a clear association of them with the

2. ITA 312 was developed by the International Institute of Tropical Agriculture (IITA) in Nigeria. It has the yield potential of 5 to 6 t/ha in farmers' fields.

yield.[3] Regarding power use, the use of draft animals for land preparation looks positively associated with the yield, although the use of tractors does not have any association presumably due to the inappropriate size of that technology as we have discussed in the previous section.

The table also shows household- and village-level characteristics. Among them, it is reasonable to observe that the participation in agricultural training, rice price (at a village market), and the existence of draft animal rental markets are positively associated with the rice yield. A positive association of rice price with the yield is an interesting contrast to the case of rice area expansion for which price has no impact. This implies that the area expansion is strictly constrained by the labor endowment of the household (highly significant in the regression analysis) even when the rice price is attractive for more expansion, while the intensification constraint may be less strict and thus there is room to proceed along that path when the price becomes more attractive.

Regression Analysis

We estimate a kind of reduced form yield function that can be expressed as a function of a household's resource endowment (exogenous at least in the short-term). A key explanatory variable is either the proportion of rice area or the full cultivation dummy to capture the emergence of the Boserupian process. Since these variables are possibly endogenous, we use the instrumental variable approach where the explanatory variables in the quadratic model of our rice area function are used for identifying instrumental variables (IVs). Table 6 shows the estimation results with village fixed effects. As additional explanatory variables, we include household characteristics used in the previous model. The diagnostic tests support the use of IV.

First of all, the IV result with a full land utilization dummy has a positive and significant coefficient, indicating the emergence of intensification for farmers facing rice land limits, although the result is not robust across the models. Secondly, a negative and significant coefficient of the size of cultivated area indicates a very strong inverse relationship. It also shows that the owning of draft animals is important for productivity improvement, although we cannot deny a reverse causality.

Having identified who achieves high yields, we now explore how

3. Timely seeding / transplanting is crucial in Mozambique in order to avoid yield loss due to cold weather in winter.

they achieve high yields. To explore this issue, we estimate a structural form of yield function. However, the estimation of this form entails the endogeneity problem of explanatory variables. Although one possible solution is the use of the IV method, we were not able to find appropriate identifying IVs as most of the variables that affect input and technology adoption also affect the yield directly. Therefore, we use this form simply to draw implications about associations among the yield, the input levels and the technology adoption. In order to supplement this approach, we also estimate a reduced-form yield function, which can be expressed as a function of a household's resource endowment (exogenous at least in the short-term) and village-level variables (exogenous to a household). In addition, the reduced-form technology adoption function will be estimated for the technologies that were identified as influential in the structural form estimation. Combining all the results, we discuss what factors encourage/constrain technology adoption and how they eventually determine the yield.

The structural form regression results (Table 7) show that those who achieve high yield tend to use modern rice technologies such as a high yielding variety (ITA 312) and animal power. Although the causality issue between adoption and yield still remains, this may imply the Boserupian process is emerging with the adoption of modern technologies.

Table 8 shows the estimation results of the reduced form regressions with district fixed effects or village fixed effects. The result shows that the adoption of ITA 312 is positively influenced by the age of the household head and the existence of a credit market in the village. The former may capture the effect of experience in farming. The existence of a credit market would help the cash-constrained farmers who would like to purchase seeds from the markets. Moving now to the next adoption function, the use of draft animals for land preparation is promoted when a farmer owns more draft animals. Moving now to the yield function, among the significant determinants in previous functions, the number of owned draft animals is still statistically significant. In the yield function, the rice price becomes highly significant, although it does not affect any adoption. The price effect may be directly related to farmers' efforts to realize more careful farm management for higher earnings as rice is a cash crop in Mozambique.

6. Conclusion

About 90% of the rice area is under rainfed lowland ecology in Mozambique (Seck et al. 2010). Observing increasing rice consumption in the country, this paper investigated the potential of and constraints on rainfed lowland rice farming in Mozambique, using data from Zambézia and Sofala provinces. The data show that the potential is not fully exploited as only 41% of the cultivable lowland is used for rice. Our regression analysis indicates that the lack of power is the predominant constraint to rice area expansion. There are few landless people in the country to supplement the lack of manpower of farming households. Besides, under rainfed conditions, the labor demand peaks coincide with the rainfall pattern and hence it is difficult to rely on exchange or hired labor among the rice farmers. Hence, the development of the labor markets cannot be an effective solution. The alternative is to seek a substitution of animal or machine power for manpower. In fact, our regression analysis shows that the existence of animal rental markets could contribute to an increase in the rice area proportion. Statistical evidence is not found on mechanization. However, this does not necessarily mean the ineffectiveness of mechanization because our result relies on data where four-wheeled tractors are commonly used. Two-wheeled tractors are more commonly used in other rice-producing countries. Taking this into account, it is worth considering the potential of small-scale mechanization as a way to relax the constraint of the lack of power.

Our analysis also shows that some farmers are already approaching their rice land limit and moving from an extensification stage toward an intensification stage (i.e., Boserupian process). The intensification has high potential for production increases as indicated by an average yield of 2.5 t/ha among the top 25% of farmers in the rainfed area where the yield of about 2 t/ha is still an attractive yield. The intensification process has just started and thus the evidence is still limited to clearly identify the determinants and constraints. Nevertheless, according to our analysis, the use of modern varieties and draft animals seems to contribute to a yield increase. In this regard, firstly, it is worth devoting efforts to developing modern varieties that fit the country's rainfed agro-climatic conditions. Secondly, to tackle the lack of power, it is worth investigating further the role of draft animals and small-scale mechanization for intensification. As found in the case study of the Chokwe irrigation scheme, modern inputs such as chemical fertilizer would be important factors for yield increase even in the rainfed area if the irrigation conditions were as reliable as in the areas with modern irrigation systems (Kajisa and Payongayong 2011). We also find that a price signal is an important stimulus for intensification. The reduction of marketing margins through the development of a rice marketing system could contribute to the production increase through intensification. Investigation into the rice marketing system is beyond the scope of this paper, which we will leave for our future research.

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Table 1: Area of rice production in 2005 and agro-ecology by province

Province	Area of rice production in 2005 (000ha)	Proportion (%)	Predominant agro-ecology in major rice provinces
Niassa	5.9	2	
Cebo Delgado	38.2	14	Rainfed lowlands/Uplands
Nampula	28.1	10	Rainfed lowlands/Uplands
Zambézia	158.2	57	Rainfed lowlands
Tete	1.6	1	
Manica	3.2	1	
Sofala	24.9	9	Rainfed lowlands
Inhambane	6.0	2	Rainfed lowlands/Uplands
Gaza	11.8	4	Irrigated
Maputo	0.4	0	Rainfed lowlands
Total	278.3	100	

Source: TIA 2005 for area and proportion. Zandamela et al. (1994) referred in Agrifood Consulting International (2005) for agro-ecology.

Table 2: Summary statistics on rice farming and household characteristics in rainfed lowland areas in Zambézia and Sofala in 2008

Variable	Mean	Std. Dev.
Features of rice farming		
Paddy yield (kg/ha)	1095	1019
Paddy yield of top 25% (t/ha)	2500	1044
Land holding size – total (ha.)	1.60	1.34
Land holding size – lowland (ha.)	0.76	0.85
Proportion of rice area (%)	41	29
Share of modern variety (%)	1	10
Chemical fertilizer use (kg/ha)	0.00	
Use of other chemicals (kg/ha)	0.00	
Share of plot w/bund (%)	45	50
Share of transplanting farmers	29	45
Share of HHs using machinery for land prep. (%)	3	16
Share of HHs using animals for land prep. (%)	2	14
Household characteristics		
HH size	5.23	2.26
No. of working members	2.23	0.87
Age of HH head	39.08	12.26
Proportion of female-headed HHs	0.26	0.44
Average schooling years	2.92	1.95
Obs.	197	

Table 3: Household- and village-level characteristics by proportion of rice area

	No rice	<Median*	>Median*
Prop. of rice area (%)	0.0	18	64
HH-level characteristics			
Landholding (Lowland) (ha)	0.38	1.00	0.53
No. of working members/ha	3.54	1.42	3.94
Ave. educ. (years)	2.44	2.71	3.15
No. of tractors owned	0.00	0.00	0.00
No. of draft animals owned	0.00	0.00	0.06
Head age (years)	41.6	39.3	38.6
Female head (dummy)	0.31	0.23	0.28
No. of non-ag. income earners	0.45	0.56	0.38
Ag. training participation (dummy)	0.0	0.02	0.002
Village-level characteristics			
Rice price (milled eq.) (MT/kg)	13.4	13.4	13.3
Road access (paved) (dummy)	0.19	0.31	0.27
Road access (non-seasonal) (dummy)	0.78	0.91	0.81
Seed market access (dummy)	0.61	0.63	0.69
Fertilizer market access (dummy)	0.00	0.02	0.04
Credit access (traders) (dummy)	0.10	0.05	0.06
Draft animal rental mkt. (incl. non-rice) (dummy)	0.06	0.04	0.08
Tractor rental mkt. (incl. non-rice) (dummy)	0.29	0.12	0.20
Obs.	51	95	102

Median=33

Table 4: Estimation results of the determinants of rice area

	Dependent var.: rice cultivated area (ha.)			
	Tobit and district fixed effects		Tobit and village fixed effects	
	Linear	Quadratic	Linear	Quadratic
HH-level determinants				
Landholding (Lowland)	0.0730	0.0441	0.0324	-0.0418
	(0.0502)	(0.119)	(0.0513)	(0.117)
Lowland area size sq.		0.00963		0.0241
		(0.0319)		(0.0309)
No. of working age members	0.141***	-0.122	0.155***	-0.151
	(0.0487)	(0.138)	(0.0504)	(0.135)
No. of working age members sq.		0.0364*		0.0424**
		(0.0198)		(0.0195)
Ave. educ.	0.00868	0.0220	0.00131	-0.0244
	(0.0224)	(0.0564)	(0.0228)	(0.0571)
Ave. educ. Sq.		-0.00151		0.00431
		(0.00829)		(0.00830)
Head age	0.00237	0.0416***	0.00296	0.0524***
	(0.00314)	(0.0154)	(0.00314)	(0.0156)
Head age sq.		-0.000438**		-0.000561***
		(0.000171)		(0.000176)
Female head	-0.00771	-0.0622	0.0175	-0.0294
	(0.0916)	(0.0928)	(0.0970)	(0.0961)
Prop. of ag. training participation	-0.157	-0.701	-0.0643	-0.202
	(0.518)	(1.905)	(0.502)	(1.843)
Prop. of ag. training participation sq.		0.476		0.0627
		(2.113)		(2.045)
No. of draft animals	0.00216	-0.0151	0.0441	0.0264
	(0.0980)	(0.0960)	(0.0959)	(0.0929)
Village-level determinants				
Rice price (village mkt.)	-0.0124	0.0356		
	(0.0135)	(0.109)		
Rice price sq.		-0.00146		
		(0.00358)		
Av. proportion of non-ag. workers	0.0848	-0.653		
	(0.161)	(0.663)		
Av. proportion of non-ag. workers sq.		0.738		
		(0.622)		
Road access (paved)	-0.142	-0.187		
	(0.189)	(0.250)		
Road access (non-seasonal)	-0.110	-0.159		
	(0.146)	(0.146)		
Seed market access	0.0460	0.0580		
	(0.105)	(0.105)		
Fertilizer market access	0.729**	0.0840		
	(0.341)	(0.640)		
Credit access (trader)	-0.244	-0.254		
	(0.192)	(0.195)		
Animal rental mkt.	0.420*	0.519**		
	(0.233)	(0.233)		
Machine rental mkt.	0.106	0.134		
	(0.177)	(0.222)		
Constant	-0.146	-0.816	-0.106	-0.584
	(0.335)	(0.896)	(0.249)	(0.384)
Pesuido R squared	0.095	0.119	0.147	0.181
Observations	248	248	248	248

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
51 left-censored obs. at 0.

Table 5: Land use, rice technologies and household- and village-level characteristics by three rice yield groups

	Bottom	Middle	Top
Paddy Yield (kg/ha)	294	809	2200
Land use			
Cultivated area in the sample parcel (ha)	0.48	0.37	0.23
Full utilization of land for rice (dummy)	0.15	0.05	0.14
Modern Inputs			
Use of modern variety (dummy)			
ITA312	0.00	0.00	0.03
Use of local variety (dummy)			
Chupa	0.00	0.02	0.03
Nene	0.18	0.15	0.08
Cabo	0.14	0.09	0.14
Manda	0.03	0.02	0.06
Chemical fertilizer (kg/ha)	0.0	0.0	0.0
Use of herbicide/insecticide (%)	0.0	0.0	0.0
Improved Practice			
Plot w/bund (dummy)	0.52	0.41	0.43
Flat plot (dummy)	0.83	0.89	0.86
Transplanting (dummy)	0.27	0.32	0.28
Direct seeding month (Month-week)	Nov. 4th	Nov. 4th	Nov. 4th
Transplanting month (Month-week)	Jan. 2nd	Jan. 2nd	Jan. 2nd
No. of seedlings per hill	2.2	1.9	2.1
Power use			
Animal use for land prep. (dummy)	0.00	0.02	0.05
Tractor use for land prep. (dummy)	0.02	0.05	0.02
HH-level characteristics			
Lowland area size (ha)	0.58	0.77	0.93
No. of working age members/ha	3.8	2.2	2.3
Ave. educ. (years)	2.9	2.9	2.9
No. of tractors owned	0.0	0.0	0.0
No. of draft animals owned	0.0	0.0	0.1
Head age (years)	37.9	38.7	40.7
Female head (dummy)	0.32	0.23	0.23
No. of non-ag. income earners	0.53	0.36	0.51
Ag. training participation (dummy)	0.00	0.004	0.023
Village-level characteristics			
Rice price (milled eq.) (MT/kg)	12.4	13.0	14.7
Road access (paved) (dummy)	0.30	0.21	0.35
Road access (non seasonal) (dummy)	0.79	0.90	0.87
Seed market access (dummy)	0.55	0.70	0.75
Fertilizer market access (dummy)	0.02	0.02	0.06
Credit access (traders) (dummy)	0.06	0.06	0.05
Draft animal rental mkt. (incl. non-rice) (dummy)	0.00	0.08	0.11
Tractor rental mkt. (incl. non-rice) (dummy)	0.21	0.09	0.17
Obs.	66	66	65

Table 6: Estimation results of paddy yield function

	Dependent var.: paddy yield (kg/ha)			
			Village Fixed Effect	
	OLS	IV	OLS	IV
Proportion of rice area [a]	312.4	1,214		
	(294.2)	(1,037)		
Full land utilization (dummy) [a]			415.2	1,272*
			(264.0)	(763.5)
Cultivated area [a]	-642.3***	-1,392***	-643.2***	-1,022***
	(196.1)	(433.4)	(190.5)	(304.8)
Landholding (lowland)	84.43	196.4	79.37	145.3
	(96.30)	(144.0)	(92.25)	(97.87)
No. of working age member/ha	11.45**	3.890	10.88**	5.897
	(5.258)	(6.338)	(5.257)	(5.512)
Ave. educ.	58.47	47.04	57.95	48.64
	(41.10)	(40.80)	(40.85)	(38.60)
Head age	8.262	11.16*	8.859	11.61**
	(6.104)	(5.970)	(6.098)	(5.812)
Female head	-68.96	-83.11	-57.18	-24.80
	(181.3)	(179.1)	(180.8)	(182.2)
Ag. training participation	859.8	944.7	784.9	709.9
	(855.9)	(821.8)	(850.9)	(787.4)
No. of draft animals /ha.	125.5**	111.5**	137.8***	155.1***
	(49.83)	(48.00)	(49.93)	(49.69)
Constant	414.3	388.5	531.8	662.7
	(491.0)	(594.1)	(474.8)	(471.2)
Endogeneity test (Durbin)	4.86		4.42	
	[0.09]		[0.11]	
Endogeneity test (Wu-Hausman)	1.95		1.77	
	[0.15]		[0.17]	
First-stage F for prop. rice area or full cult.		3.09		2.33
		[0.00]		[0.03]
First-stage F for cultivated area		10.11		10.11
		[0.00]		[0.00]
Overidentification test (Sargan)		6.64		5.61
		[0.24]		[0.34]
Overidentification test (Basmann)		5.27		4.42
		[0.38]		[0.50]
Observations	197	197	197	197
R-squared	0.370	0.332	0.375	0.331

a) possible endogenous variable. Identifying IVs are the explanatory variables in the quadratic village fixed effect model in Table 4
Standard errors in parentheses; p-values in brackets
*** p<0.01, ** p<0.05, * p<0.1

Table 7: Estimation results of paddy yield function (structural form)

	Dependent var.: paddy yield (kg/ha)		
	Village Fixed Effect		
	OLS	OLS	OLS
Proportion of rice area	101.6		
	(284.8)		
Full land utilization (dummy)		245.9	
		(265.3)	
Cultivated area	-708.5***	-721.6***	
	(185.1)	(181.0)	
Plot with bund	148.7	144.8	95.67
	(155.2)	(154.9)	(161.0)
Use of ITA 312	2,317***	2,240***	2,447***
	(721.6)	(716.3)	(731.7)
Use of Chupa	623.4	545.8	680.8
	(582.1)	(587.7)	(605.4)
Use of Nene	-249.7	-270.9	-223.2
	(236.7)	(237.4)	(246.4)
Use of Cabo	-187.2	-213.7	-60.91
	(254.4)	(255.6)	(262.6)
Use of Mamia	-92.12	-99.29	-52.51
	(284.4)	(283.4)	(295.6)
Use of Manda	641.0	662.1	920.7*
	(461.2)	(459.0)	(470.2)
Use of tractor for land preparation	-284.3	-252.1	-523.6
	(478.6)	(479.0)	(494.3)
Use of animal for land preparation	1,006*	1,020*	952.4*
	(519.9)	(518.3)	(540.8)
Transplanting (against direct seeding)	-77.21	-88.80	-111.2
	(185.2)	(184.6)	(192.4)
Constant	1,262***	1,294***	1,054***
	(177.0)	(144.1)	(135.1)
Observations	197	197	197
R-squared	0.377	0.380	0.316

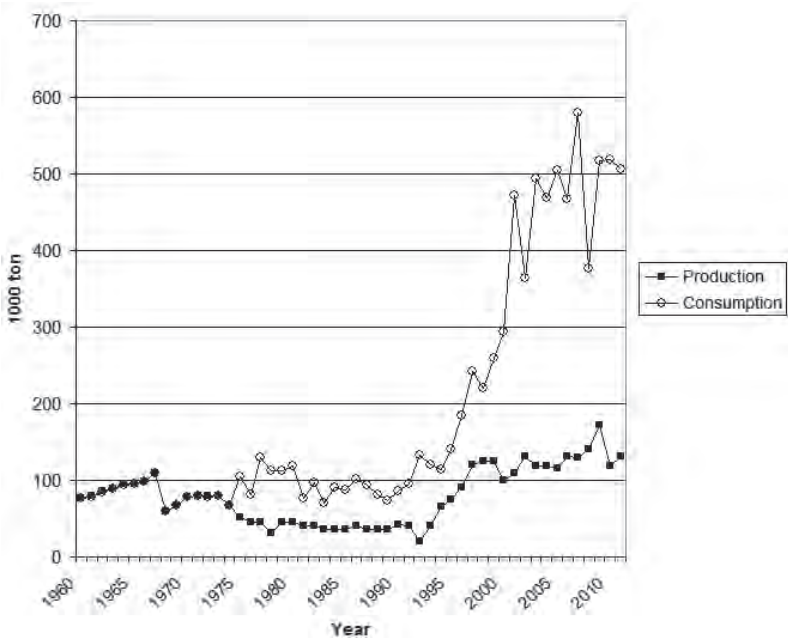
Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 8: Estimation results of paddy yield function and technology adoption function (reduced form)

VARIABLES	Use of ITA 312 (dummy)		Use of animal (dummy)		Yield (kg/ha)	
	District Fixed Effects	Village Fixed Effects	District Fixed Effects	Village Fixed Effects	District Fixed Effects	Village Fixed Effects
HH-level variables						
Landholding (Lowland)	-0.0107	-0.0108	-0.00384	-0.00480	71.31	36.77
	(0.00952)	(0.0102)	(0.0112)	(0.0123)	(89.44)	(93.12)
No. of working age members/ha	0.000258	0.000106	-0.000350	-0.000427	17.54***	17.91***
	(0.000505)	(0.000549)	(0.000594)	(0.000662)	(4.739)	(5.006)
Ave. educ.	0.000412	-0.000198	0.00164	0.00345	33.79	62.22
	(0.00432)	(0.00461)	(0.00508)	(0.00556)	(40.57)	(42.03)
Head age	0.00147**	0.00151**	-0.000733	-0.000840	3.609	5.926
	(0.000637)	(0.000682)	(0.000750)	(0.000824)	(5.988)	(6.227)
Female head	-0.00996	-0.0273	-0.0331	-0.0484**	32.47	-20.16
	(0.0180)	(0.0202)	(0.0212)	(0.0244)	(169.2)	(184.2)
Ag. training participation	-0.0222	-0.0119	0.00463	-0.000823	717.0	876.3
	(0.0945)	(0.0962)	(0.111)	(0.116)	(888.0)	(877.4)
No. of draft animals/ha	-0.000235	0.000448	0.0404***	0.0417***	113.4**	134.4***
	(0.00545)	(0.00560)	(0.00641)	(0.00676)	(51.18)	(51.08)
Village-level variables						
Rice price (village mkt.)	6.68e-05		-0.00124		68.36***	
	(0.00272)		(0.00320)		(25.55)	
Av. proportion of non-ag. workers	-0.0178		0.0141		-275.8	
	(0.0322)		(0.0379)		(302.8)	
Road access (paved)	-0.0105		0.0158		617.6*	
	(0.0378)		(0.0444)		(354.8)	
Road access (non-seasonal)	0.00418		-0.0132		423.8	
	(0.0299)		(0.0352)		(280.8)	
Seed market access	-0.0122		0.0151		86.03	
	(0.0212)		(0.0250)		(199.4)	
Fertilizer market access	0.0306		-0.0355		253.7	
	(0.0674)		(0.0793)		(632.7)	
Credit access (trader)	0.0765*		-0.0101		-99.17	
	(0.0403)		(0.0474)		(378.2)	
Animal rental mkt.	0.00605		0.0819		245.1	
	(0.0482)		(0.0567)		(452.9)	
Machine rental mkt.	-0.0150		-0.0195		-353.2	
	(0.0360)		(0.0424)		(338.1)	
Constant	-0.0293	-0.0343	0.0627	0.0607	-805.0	401.2
	(0.0536)	(0.0339)	(0.0631)	(0.0410)	(503.5)	(309.5)
Observations	197	197	197	197	197	197
R-squared	0.099	0.168	0.369	0.387	0.227	0.327

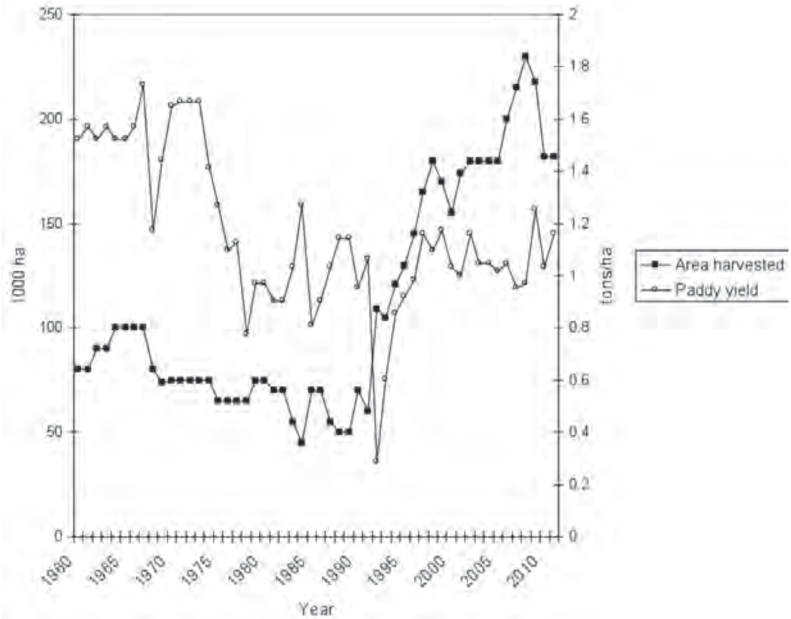
Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Figure 1: Production and consumption of rice (milled) in Mozambique from 1960 to 2011



Source: USDA PS&D Online downloaded from http://worldfood.apionet.or.jp/index-e.html.

Figure 2: Area harvested and paddy yield in Mozambique from 1960 to 2011



Source: USDA PS&D Online downloaded from http://worldfood.apionet.or.jp/index-e.html.

Figure 3: Map of survey province and districts 1960 to 2011

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