Chapter 3
On the Possibility of Rice Green Revolution in Irrigated and Rainfed Areas in Tanzania: An Assessment of Management Training and Credit Programs

Yuko Nakano, Kei Kajisa, and Keijiro Otsuka

Abstract In order to develop a strategy for a rice Green Revolution in sub-Saharan Africa, this study investigates the determinants of the adoption of new technologies and their impact on productivity of rice cultivation. We analyzed two kinds of data sets collected in Tanzania: a nationally representative cross-sectional data and a 3-year panel data of irrigated farmers in one district. We found that not only irrigation but also agronomic practices taught by training play key roles in increasing the adoption of modern technologies and the productivity of rice farming.

Keywords Rice production • Tanzania • Adoption of new technology • Impact on productivity • Agronomic practices • Training

3.1 Introduction

Food insecurity and poverty are long-lasting and persistent problems faced by developing countries in general and in sub-Saharan Africa (SSA) in particular. Among major cereals, rice is most rapidly growing in consumption in SSA (Balasubramanian et al. 2007; Seck et al. 2010; Otsuka and Kijima 2010). The development and diffusion of fertilizer-responsive, high-yielding modern varieties

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Y. Nakano
Faculty of Humanities and Social Sciences, University of Tsukuba,
1-1-1 Tennodai, Tsukuba 305-8571, Japan

K. Kajisa
School of International Politics, Economics, and Communication, Aoyama Gakuin
University, 4-4-25 Shibuya-ku, Tokyo, Japan

K. Otsuka (✉)
National Graduate Institute for Policy Studies,
Roppongi, Minato-ku 7-22-1, 106-8677 Tokyo, Japan
e-mail: otsuka@grips.ac.jp

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(MVs) is widely acknowledged to play a fundamental role in fostering a rice Green Revolution, which had a significant impact on improving agriculture productivity and reducing poverty in Asian countries (David and Otsuka 1994; Evenson and Gollin 2003a). It is believed that the diffusion of MVs that led to the Green Revolution in Asia could have a similar impact on the productivity and the livelihoods of poor African farmers (Otsuka 2006; World Bank 2007).

Several studies have examined the determinants of the adoption of Green Revolution technologies in SSA, including MVs and chemical fertilizer (Adekambi et al. 2009; Diagne 2006; Kajisa and Payongayong 2011; Kijima et al. 2011; Otsuka and Larson 2013b). However, relatively less attention has been paid to the determinants of the adoption of improved agronomic practices such as bunding, leveling, and transplanting in rows. Bunding refers to piling soil around plots for storing water, leveling is making the paddy field flat for the even distribution of water, and transplanting in rows is used to control the plant density and make space for manual weeding (Becker and Johnson 2001; Raes et al. 2007). Many of these techniques had already been practiced in Asia when the Green Revolution started in the 1960s (David and Otsuka 1994; Chap. 5), so their importance is not widely recognized.

To develop a strategy for a Green Revolution in SSA, this study investigates the determinants of the adoption of rice cultivation technologies, including not only MVs and fertilizer but also the improved agronomic practices, and the productivity of rice farming in Tanzania. In particular, we focus on the impacts of irrigation, credit use, and access to extension or training services on technology adoption and the productivity of rice farming, because our field observations and emerging empirical studies point to these as important factors of technology adoption (Ali et al. 2014; Birkhaeuser et al. 1991; Carter 1989; David and Otsuka 1994; Feder et al. 1985; Foster and Rosenzweig 2010; Gine and Klonner 2005; Miyata and Sawada 2007; Moser and Barrett 2006).

To examine these issues, we use two data sets collected by the authors. One set contains cross-sectional data of 760 households in 2009 in three major rice-growing regions in Tanzania: Morogoro, Mbeya, and Shinyanga regions. We call these data extensive survey (ES) data. Another one, called case study (CS) data, is a 3-year panel data of 208 farmers in an irrigation scheme in Kilosa district, Morogoro region in Tanzania, from 2010 to 2012. At our case study site, Japan International Cooperation Agency (JICA) conducted training on basic rice cultivation technologies including the use of MVs and chemical fertilizer, bunding, leveling, and transplanting in rows in 2009. By combining recall data collected in 2010, we constructed a panel data on the rice cultivation before and after the training to evaluate its impact on technology adoption and productivity.

The extensive survey data are suitable to grasp the current status of the adoption of technologies in the country as a whole. In fact, our extensive survey is the first attempt to collect detailed information on rice farming in the major rice-growing regions of Tanzania. ES data is thus able to provide a nationally representative view of Tanzania's rice sector, beyond the snapshots of particular places provided by existing case studies (Meertens et al. 1999; Ngailo et al. 2007). On the other hand, by using the CS data set we can take advantage of panel data to control for the effects of unobservable household characteristics on estimating the impact of training on the adoption of technologies and the productivity of rice farming in irrigated areas.

The rest of the paper is organized as follows. Section 3.2 explains the data set. In Sect. 3.3, we investigate the determinants of the adoption of rice Green Revolution technologies by using the ES data set. We analyze the impact of JICA training on the adoption of technologies and paddy yield in an irrigation scheme by using the CS data set in Sect. 3.4. The paper ends with the conclusions in Sect. 3.5.

3.2 The Study Sites and Data

In Tanzania, rice is mainly cultivated in three agroecological zones: the Eastern Zone, Southern Highland Zone, and Lake Zone. To construct a nationally representative data set on rice, we covered all three zones in the extensive survey (ES). We chose one representative region from each zone: Morogoro from the Eastern Zone, Mbeya from the Southern Highland Zone, and Shinyanga from the Lake Zone (Fig. 3.1). The sample regions produce nearly 40 % of the rice grown in the country (United Republic of Tanzania 2009). Thus, we may be able to regard our survey as nationally representative in terms of rice production. In each region, we have selected two major rice-growing districts based on the amount of rice produced: Kilombero and Mvomero in the Morogoro region; Kyela and Mbarali in the Mbeya region; and Shinyanga rural and Kahama in the Shinyanga region.

In our sample area, most of the rice is grown under irrigated or rain-fed lowland conditions, and upland rice cultivation is rarely observed. Therefore we chose the sample villages by stratified random sampling on the basis of the number of rice-growing villages under irrigated and rain-fed conditions. For this purpose, we relied on the agricultural census in 2002–2003 in each region. In total, we selected 76 villages in 6 districts as our sample. In each village, we randomly sampled 10 households and generated a total of 760 sample households. The survey was conducted from September 2009 to January 2010. We collected two levels of data: village and household. The former was collected by group interviews with key village informants, and the latter by individual interviews. During the interviews, farmers were asked to identify the most important rice plot and were questioned in detail about the rice cultivation practices. We hereafter call this the sample plot. Figure 3.1 shows the irrigation status of the sample plots. For our analyses, we dropped 64 households that grew no rice either because they had no plots suitable for rice cultivation or because their plots received insufficient rainfall or irrigation water in 2009. We also dropped 24 outliers, which exhibit unrealistic values in the key variables and, hence, our effective sample became 672 households.

The case study surveys were conducted in the Ilonga irrigation scheme in Kilosa district, Morogoro region, Tanzania. The Ilonga irrigation scheme is approximately 15 km away from Kilosa, the nearest town. During the main season (i.e., October to

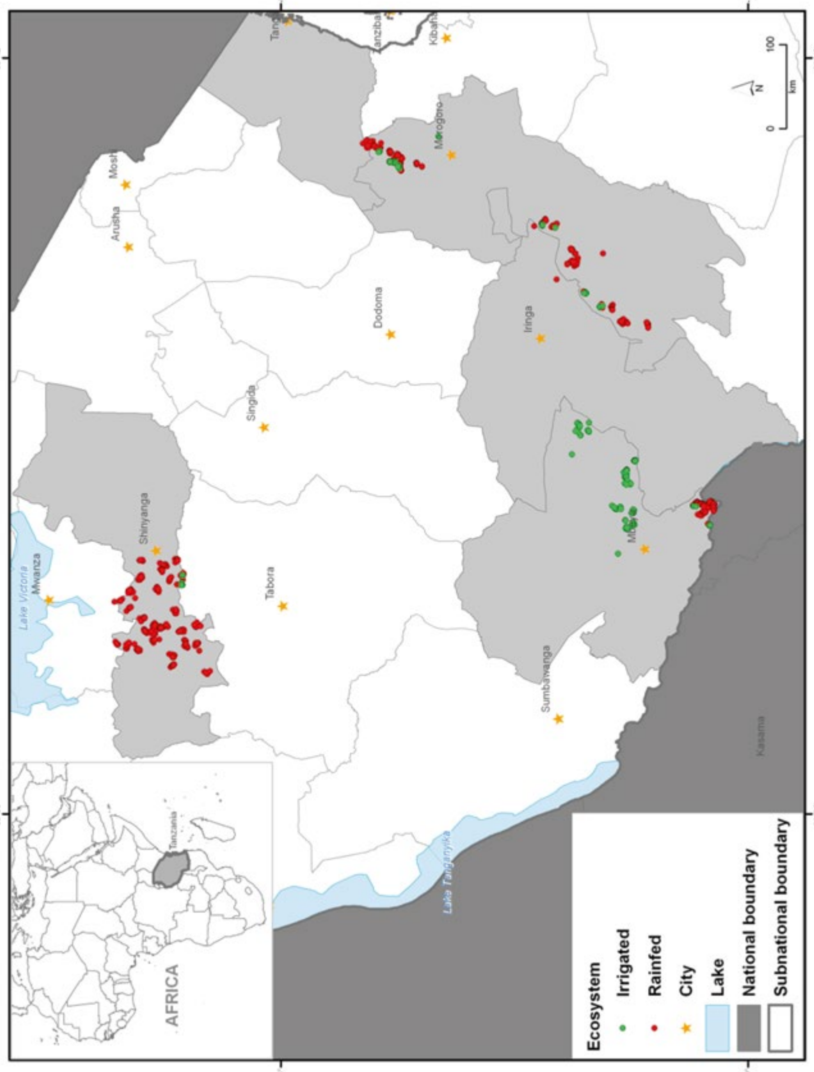

Fig. 3.1 Regions covered by extensive survey and location of the sample plots in Tanzania, by irrigation status

June) at the study site, farmers grow rice in irrigated plots and other crops, such as maize, beans, and vegetables, in upland plots. During the short cultivation season from July to September, some farmers grow vegetables in the irrigation scheme.

In the irrigation scheme, JICA conducted training on basic rice cultivation technologies including agronomic practices during the main season of 2008–2009, which will be denoted as 2009 hereafter. It was called TANRICE training, and the contents of the training included the use of modern varieties and chemical fertilizer, improved bund construction, plot leveling, and transplanting in rows. Note that an improved bund is compacted with soil more firmly than an ordinary bund so that it can store water in the plot more effectively.

JICA first trained 20 farmers at the nearby training center for 12 days before the cultivation season of 2009 started. These directly trained farmers are called key farmers.[1] Second, during the main season in 2009, 3 days of training were conducted at the demonstration plot in the Ilonga irrigation scheme during the nursery preparation, transplanting, and harvesting stages. The key farmers were supposed to invite five farmers each to this short training. These farmers, called intermediary farmers, learned technologies primarily from key farmers. The key and intermediary farmers were expected to be responsible for training other farmers who were not directly trained in TANRICE training, called ordinary farmers hereafter. The main issue in our analyses is the difference in technology adoption and productivity among the three groups of farmers.

The first interview was conducted from September to December 2010. A total of 208 farmers were interviewed on their rice cultivation practices in their most important rice plot, which we hereafter call the sample plot, in the main season of 2010. In the first survey, we also collected recall data for the main seasons of 2008, which is before TANRICE training. In the second round of interview, we revisited the same households in 2012 and asked about rice cultivation on the sample plot during the 2012 main season. After dropping the households which had unrealistic values in key variables, and those who did not cultivate rice on their sample plot, the number of sample households became 171 in 2008, 202 in 2010, and 167 in 2012.[2] For cross sectional analyses, we use these data sets. To construct panel data, we omit those household who did not grow rice in any single year from 2008 to 2012 and construct a balanced panel data set of 121 households over 3 years, generating a total sample size of 363.

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[1] Key farmers were self-selected during all-village meetings on the basis of criteria such as age, ability to read and write, gender (to achieve a balance), residency in the Ilonga irrigation scheme, and active rice farming.

[2] Note that the number of sample households in 2010 is larger than in 2009 and 2008, because we use recall data for 2009 and 2008, which is collected during the survey conducted in 2010.

3.3 Technology Adoption and Productivity in Extensive Survey

3.3.1 Descriptive Analyses and Hypotheses

This subsection investigates the determinants of technology adoption by using the ES data set. The set of technologies examined in this study can be classified into two categories: modern inputs and improved agronomic practices. Modern inputs include fertilizer-responsive high-yielding MVs and chemical fertilizers, while improved practices include bund construction and leveling of plots for better water management as well as transplanting in rows for better crop management. We will begin our analysis of the adoption of these technologies by developing hypotheses based on a literature review and field observations.

Prior studies in Asia have suggested that the adoption of MVs began under favorable agro-ecological conditions, such as in irrigated areas, and gradually diffused to less favorable areas (David and Otsuka 1994). Table 3.1 compares the adoption of modern inputs and improved practices by irrigation and credit status (classification explained below). The share of irrigated plots in the entire sample is 22.7 % (152 out of 669 observations). The overall average yield is 1.8 tons per hectare under rain-fed conditions and 3.7 tons per hectare under irrigated conditions, for an overall average

Table 3.1 Paddy yield, modern input use, and improved practices in the sample rice plots, by credit and irrigation status in extensive survey sites in Tanzania

	Rain-fed				Irrigated			
	Average	Credit user	Non-credit-needing farmer	Credit constrained	Average	Credit user	Non-credit-needing farmer	Credit constrained
Paddy yield (tons per hectare)	1.8	1.9	1.7	1.8	3.7	3.4	4.4**	3.6
Paddy yield (tons per hectare) for top 25 % of farmers	3.7				5.9			
Plots using modern varieties (%)	7.2	4.2*	3.4	8.4	28.7	15.2**	27.3	33.9
Chemical fertilizer use (kg per hectare)	6.7	7.3	3.1	7.1	32.2	47.8*	29.9	27.5
Bunded plots (%)	48.9	55.4	49.2	47.7	88.8	94.1*	95.8*	85.1
Leveled plots (%)	54.7	58.1	55.9	53.9	77.0	79.4	87.5*	73.4
Plots transplanted in rows (%)	5.2	4.1	5.1	5.1	28.9	29.4	29.2	28.7
Observations	517	74	59	384	152	34	24	94

***, **, and * indicate significance at 1, 5, and 10 %, respectively, in *t*-tests comparing between credit-constrained farmers and either of the other two categories of 2.2 tons per hectare.[3, 4] The paddy yields among the top 25 % of high-yielding farmers average 5.9 tons per hectare in irrigated areas and 3.7 tons per hectare under rain-fed conditions. These figures indicate high potential for productive rice cultivation in Tanzania despite the current low average yields, particularly in rain-fed areas. Realizing this potential is critical for achieving a rice Green Revolution.

We first explore the application of modern inputs, by irrigation status, within our dataset. The average area of land planted with MVs is just 7.2 % in rain-fed areas and 28.7 % in irrigated areas. This finding is consistent with the experience of the Asian Green Revolution, during which the adoption of MVs began in irrigated areas (David and Otsuka 1994). Irrigation water and chemical fertilizers are complements, so that in irrigated areas farmers generally use at least moderate amounts of fertilizers (an average of 32.2 kg per hectare). However, the level of chemical fertilizer used typically falls far short of that recommended by agronomists (125–250 kg of urea per hectare). Improved agronomic practices are more widely adopted in irrigated areas than in rain-fed areas. Among them, transplanting in rows, a common practice in Asia that facilitates weeding and harvesting, remains uncommon in Tanzania. In irrigated areas, only 28.9 % of farmers adopted transplanting in rows; this was even less common on rain-fed land. Overall, the descriptive analysis indicates that the adoption of new technology is lower in rain-fed areas. This is likely because the returns from the adoption of new technologies are lower under rain-fed conditions than under irrigated conditions. For example, bunding and leveling result in higher yields particularly with better control of water in the field. These observations lead us to the following hypothesis:

Hypothesis 1 Farmers with irrigated plots achieve higher productivity and profit by applying more modern inputs and adopting improved agronomic practices more frequently than farmers with rain-fed plots.

Next, we explore the role of credit in financing the cost of cultivation, as previous studies have identified inadequate credit access as a major constraint on the adoption of agricultural technology (Feder et al. 1985; Carter 1989; Gine and Klonner 2005; Moser and Barrett 2006; Miyata and Sawada 2007; Foster and Rosenzweig 2010; Ali et al. 2014). In rice farming, unless farmers have sufficient funds on hand, they must finance up-front costs by borrowing money from formal or informal sources. In Tanzania, formal sources available in rural areas are microfinance organizations, i.e., Savings and Credit Cooperative Society (SACCOs). SACCOs is a cooperative that provides credit based on the members' share capital or deposits and

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[3] Our data shows a higher proportion of irrigated plots amongst the sample plots than the other plots cultivated by sample farmers. The average paddy yield for the sample plots is 2.2 tons per hectare while that for the other plots is 1.8 tons per hectare. The adoption rate of MVs is also statistically higher for the sample plots than for the other plots. This suggests that our analysis shows the best practices of the representative rice farmers.

[4] In the household interviews, we asked the farmers to report their harvest in terms of the number of bags, which we then converted into kilograms. To compute the yield, the total harvest was divided by the size of plot reported in the interview.

is regulated by the Cooperative Societies Act. Available data from 2001 show that there are 646 SACCOs registered in Tanzania, of which 395 can be classified as rural SACCOs (Randhawa and Gallardo 2003). Many informal sources also exist, such as moneylenders, relatives, and friends, but they are less important than SACCOs. Informal arrangements between input dealers and farmers in which the latter pay the costs of modern inputs after harvest are also rare.

During our interviews, we asked farmers whether they used credit for rice cultivation on the sample plot or for any other purpose, including rice cultivation on other plots. If their responses indicated no use of credit, we asked why they did not use credit. On the basis of this information, we classified farmers' credit status into three categories: (a) farmers using credit for any purpose, including rice cultivation on the sample plot (credit user) (b) farmers who do not use credit because they do not need it (non-credit-needing farmer), and (c) farmers who do not use credit, even though they need it (credit-constrained farmer).

In Table 3.1, we show the results of *t*-tests comparing credit-constrained farmers with either one of the other two categories in rain-fed and irrigated areas. Our comparison among rain-fed farmers indicates that there is little difference in the adoption of technologies among credit users, non-credit-needing farmers, and credit-constrained farmers. Since the returns from the use of new technologies and improved practices are low under rain-fed conditions, the incentive to adopt them does not seem to change with credit access.

Turning to irrigated areas, a clear difference between the three categories can be observed for some technologies. Credit users apply larger amounts of chemical fertilizers than farmers in the other credit categories: in irrigated areas, they use 47.8 kg of fertilizer per hectare, whereas credit-constrained farmers use only 27.5 kg. However, the adoption rate of MVs is not higher for credit users than for credit-constrained farmers. To adopt MVs, farmers must buy seeds when they initially adopt varieties, but thereafter they can self-produce the seeds several times before the performance declines significantly. Hence, credit access may have a limited impact on the adoption of MVs. Compared with credit-constrained farmers, 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 %) or transplanting in rows (29.2 % and 28.7 %) between these two groups.

In order to examine differences in factor use among the different groups of farmers, we show factor payments in the cultivation of the sample plots by credit and irrigation status in Table 3.2. We define income as the value of gross output minus paid-out costs of current inputs, hired labor, and rental costs of machinery and draft animals. Profit is defined as income minus imputed costs of family labor and owned capital, evaluated at the village average wage and rental rate, which can be interpreted as the return to land and management ability. The lower part of Table 3.2 shows the costs of labor and capital for land preparation, including leveling and transplanting.

Average paid-out costs for labor are higher for credit users than for credit-constrained farmers in both rain-fed and irrigated areas. In rain-fed areas, credit users pay USD 120.6 per hectare and credit constrained farmers USD 97.7 per

Table 3.2 Factor payments (USD per hectare) and costs of labor and capital (USD per hectare) for land preparation by credit and irrigation status in extensive survey sites in Tanzania[a]

	Rain-fed			Irrigated		
	Credit user	Non-credit-needing	Credit constrained	Credit user	Non-credit needing	Credit constrained
Revenue	636.3	614.4	596.5	1195.2	1533.4*	1303.6
Current input costs	14.2	9.7	16.8	59.7**	21.7	24.0
Total labor costs	314.1*	318.6	383.3	476.0**	544.6	651.4
Paid-out labor cost	120.6*	84.4	97.7	233.8*	239.6	200.7
Imputed family labor cost	193.5**	234.3	285.6	242.2**	305.1	450.8
Total capital costs	79.7**	83.1***	65.6	121.2**	106.3	88.2
Paid-out capital cost	41.3	37.6	35.2	105.9***	41.3	45.9
Imputed capital cost	38.4*	45.5***	30.4	15.4**	65.0*	42.3
Income	460.1	482.8	446.8	795.8**	1230.8*	1033.0
Profit	228.2*	203.0	130.8	538.3	860.7**	540.0
Labor costs for land preparation						
Paid-out cost	14.7*	7.5**	22.6	68.7	67.0	67.5
Imputed cost	37.5**	44.1	66.5	50.9*	82.5	94.6
Labor costs for transplanting						
Paid-out cost	13.0	6.6	8.6	59.0**	64.3**	42.6
Imputed cost	26.6	18.4	26.1	55.7	83.2	87.5
Animal or machinery costs for land preparation						
Paid-out cost	31.8	29.1	30.5	76.7***	21.9	34.2
Imputed cost	37.0**	42.4***	28.1	10.6**	58.3*	37.1
Observations	74	59	384	34	24	94

***, **, and * indicate significance at 1, 5, and 10 %, respectively, in *t*-test comparing between credit-constrained farmers and either of the other two categories

[a] The exchange rate used is USD 1 = TZS 1,320.3

hectare, while in irrigated areas credit users pay USD 233.80 per hectare and credit-constrained farmers USD 200.7 per hectare. The average paid-out costs for renting machinery or animals are also significantly higher for the credit users (USD 105.9 per hectare) than for credit-constrained farmers (USD 45.9 per hectare) in irrigated areas. When we compare the machinery or animal rental costs by activity, credit users in irrigated areas on average spend more to hire machinery or animals for land preparation, including plot leveling. Paid-out costs for hiring labor for transplanting is also higher for the credit users than the credit-constrained farmers. These results suggest that, for certain activities, credit users are more inclined to adopt new technologies or management practices by hiring machinery, animals, and labor.

In terms of revenue, income, and profit, however, we do not observe large differences between credit users and credit-constrained farmers in either rain-fed or irrigated areas. This is likely because credit users do not necessarily use the full package of complementary modern inputs and improved production practices. For example, increasing chemical fertilizer application may not result in higher yields if farmers do not adopt MVs or do not apply the fertilizer at the right times. Therefore, in addition to credit access, farmers must have sufficient knowledge of new technologies in order for increased input use to effectively enhance paddy yields and profits from rice farming (Abdulai and Huffmann 2005). Based on these observations, the second hypothesis is postulated as:

Hypothesis 2 While credit access facilitates the adoption of technologies that require cash, such as chemical fertilizer and hired labor for labor-intensive agronomic practices, especially in irrigated areas, it is not clear whether it significantly improves the paddy yield and profitability of rice farming.

The existing literature (for example, Birkhaeuser et al. 1991) suggests that the access to extension and training can be another critical determinant of the adoption of technology and productivity of rice farming. In Tanzania each ward, which consists of several villages, has an extension officer. This extension officer is based in one of the village offices and provides extension services to surrounding villages in the ward. According to the report of World Bank in 2004, 5,835 extension officers are deployed to cover a total of 10,470 villages (World Bank 2004).[5] Furthermore, Japan International Cooperate Agency (JICA) has established Kilimanjaro Agricultural Training Canter (KATC) in 1994. Since its establishment, KATC has provided training on irrigated rice cultivation not only to extension officers but also to farmers in other irrigation schemes. For example, 1,008 farmers and extension officers were trained in KATC from 1994 to 1999 (IDCJ 2004). More than 5,000 farmers in other irrigation schemes were trained from 2007 to 2011 with the support of JICA (2011). The fact that the training targeted irrigated areas suggests that the extension services are widely available in Tanzania especially in irrigated area. Furthermore, according to JICA experts, a package of effective yield enhancing rice cultivation technologies has been already established in irrigated area, where agro-ecological conditions are relatively homogeneous, whereas such package is not yet well developed in rain-fed area, where agro-ecological conditions greatly varies depending on the areas. These observations lead us to postulate the following third hypothesis:

Hypothesis 3 Access to extension services enhances the adoption of improved technologies and improves the productivity and profitability of rice farming especially in irrigated areas.

Table 3.3 compares paddy yield, modern input use, and improved practices of farmers in villages with and without extension offices in rain-fed and irrigated areas. Note that 77 % of farmers with irrigated plots (117 out of 152) have access to an extension office within their villages, while 48 % of farmers in rain-fed areas (248 out of 517) do, supporting our observations that extension services are widely

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[5] Note that the government extension officers are not necessarily specialized in rice cultivation.

Table 3.3 Paddy yield, input use, and improved practices in the sample rice plots, by access to extension services and irrigation status in extensive survey sites in Tanzania

	Rain-fed		Irrigated	
	No extension office	With extension office	No extension office	With extension office
Paddy yield (tons per hectare)	1.7	1.9*	3.0	3.8***
Plots using modern varieties (%)	4.4	10.2***	17.1	32.2***
Chemical fertilizer use (kg per hectare)	2.5	11.3***	10.5	38.7**
Bunded plots (%)	46.5	51.6***	82.9	90.6
Leveled plots (%)	55.4	54.0	85.7	74.4*
Plots transplanted in rows (%)	5.2	5.2	31.4	28.2
Observations	269	248	35	117

***, **, and * indicate significance at 1, 5, and 10 %, respectively, in *t*-test comparing between farmers in villages with and without extension offices

available especially in irrigated area in Tanzania. Farmers in villages with an extension office achieve higher paddy yields in both rain-fed and irrigated areas. Furthermore, rates of adopting MVs and chemical fertilizer in both rain-fed and irrigated areas are significantly higher for farmers in villages with an extension office than those in villages without one. Farmers in villages with extension offices more frequently adopt bund construction in rain-fed areas and plot leveling in irrigated areas than those in villages without extension offices. These results suggest that access to extension services is important for enhancing technology adoption as well as improving the productivity of rice farming, which is consistent with the existing literature (for example, Birkhaeuser et al. 1991).

3.3.2 Methodology in the Extensive Survey Study

This sub-section investigates the determinants of technology adoption and rice yield by using regression analyses. The dependent variables in the technology adoption models are the adoption of MVs (dummy variable equal to 1 if adopted), the use of chemical fertilizer (kilograms per hectare), and the adoption of bund construction, leveling of plots, and transplanting in rows (separate dummy variables for each practice which is equal to 1 if the practice was adopted). We also estimate the determinants of rice yield and profitability. Although it would be ideal to endogenize and examine the impacts of each of these technologies and management practices on the productivity and profitability of rice farming, it is infeasible to do so both due to a lack of several instrumental variables and the complementarity of modern inputs and improved management practices. Therefore, in the productivity models, we use the same set of explanatory variables as in the estimation of technology adoption functions in which the dependent variables are paddy yield (tons per hectare), gross output value (100 USD per hectare), total costs (100 USD per hectare), and profit from rice farming (100 USD per hectare).

Since credit use depends on a farmer's choices, we estimate models using both OLS and IV methods. In the OLS model, we estimate the reduced-form model by including the presence of SACCOs in the village. We interpret that credit has a positive impact on the adoption of technologies or on rice productivity when we observe a positive coefficient for SACCOs because the existence of SACCOs significantly increases credit use by farmers, though the regression results on credit use are not shown here. Since our descriptive analysis suggested that the impact of credit on technology adoption differs between irrigated and rain-fed areas, we also include an interaction term between the existence of SACCOs and the irrigated plot dummy. In the IV model, we include a dummy variable for being a credit-constrained farmer; as this is a potentially endogenous variable, it was instrumented by the dummy variable for the existence of SACCOs.[6]

In our field interviews, we did not find strong evidence that the establishment of SACCOs is strongly associated with rice cultivation potential. Rather, the aim of SACCOs is to meet diverse 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 interpret credit as having a positive impact on the adoption of rice technologies and on the productivity of rice farming when we observe a negative coefficient on the credit-constrained farmer variable. In order to examine our third hypothesis, we include the distance to the nearest extension office and its interaction term with the irrigated plot dummy. We interpret a negative coefficient on the distance to the nearest extension office as indicating a positive impact of access to extension services on the adoption of technologies and productivity of rice farming.

In order to capture the effects of characteristics of the sample plots, we include the size of the plot (in hectares) and a dummy variable for whether the plot is irrigated. We also include the total area of other lowland plots (in hectares) and the total area of upland plots (in hectares) to capture the effect of a household's land endowment. The number of cows and bulls owned and the value of the household's assets (in million TZS) are also included to capture the influences of animal ownership and physical asset endowments.[7] To assess the impact of human capital endowments, we use the number of adult household members over 15 years of age, the average years of schooling for adult household members, a dummy variable for a female-headed household, and the age of the household head.

3.3.3 Technology Adoption in Extensive Survey Study

Table 3.4 shows regression results for the adoption of MVs and chemical fertilizer use. The first-stage *F*-test is highly significant, indicating that our estimated IV models are valid in models (2) and (4). Since the first stage regression is common

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[6] The first stage regression is available in Nakano et al. (2014).

[7] In upland areas, farmers grow maize, beans, cassava, sunflowers, and other crops for both consumption and sale.

Table 3.4 Determinants of adoption of MVs and chemical fertilizer use (kg per hectare) in extensive survey sites in Tanzania (district-level fixed-effect model)

	(1)	(2)	(3)	(4)
	MV	MV	Chemical fertilizer	Chemical fertilizer
	OLS	IV	OLS	IV
SACCOs	0.037		−3.109	
	(0.385)		(0.490)	
Irrigated * SACCOs	−0.050		54.978**	
	(0.557)		(0.025)	
Credit constrained		−0.139		−75.167
		(0.523)		(0.163)
Distance to the nearest extension office (km)	−0.001	−0.000	0.083	0.489
	(0.723)	(0.864)	(0.680)	(0.309)
Irrigated * distance to the nearest extension office (km)	−0.028**	−0.027**	−2.427	−2.110
	(0.023)	(0.029)	(0.438)	(0.374)
Distance to the district capital (km)	−0.001**	−0.001**	−0.242***	−0.209**
	(0.043)	(0.048)	(0.005)	(0.037)
Irrigated plot	0.514***	0.487***	−5.691	5.857
	(0.000)	(0.000)	(0.667)	(0.681)
Size of the plot (ha)	−0.019**	−0.020**	−2.211*	−4.453**
	(0.014)	(0.025)	(0.065)	(0.031)
Size of other plots owned in lowland areas, excluding the sample plot (ha)	0.001	0.003	−0.836	−0.584
	(0.829)	(0.616)	(0.186)	(0.533)
Size of plots owned in upland areas (ha)	−0.010**	−0.014**	−0.334	−2.376
	(0.012)	(0.026)	(0.514)	(0.134)
Number of cows and bulls owned	−0.000	−0.000	0.130	0.208
	(0.682)	(0.894)	(0.314)	(0.261)
Household assets (million TZS)	−0.008	−0.011	1.055	−0.629
	(0.489)	(0.358)	(0.694)	(0.873)
Number of adults (age≥15)	0.009	0.007	−1.414	−1.733
	(0.118)	(0.218)	(0.111)	(0.192)
Average years of schooling of adult household members	−0.002	−0.002	1.209	1.747
	(0.609)	(0.671)	(0.123)	(0.145)
Female household head	−0.047	−0.059	4.957	3.584
	(0.209)	(0.128)	(0.246)	(0.572)
Age of household head	−0.000	0.000	−0.088	0.330
	(0.704)	(0.893)	(0.572)	(0.356)
Constant	0.403***	0.503***	42.545**	85.296**
	(0.000)	(0.000)	(0.012)	(0.022)
Observations	669	669	669	669
R-squared	0.410		0.264	
First stage *F*		10.393		10.393
[*p*-value]		(0.002)		(0.002)
Endogeneity test		0.421		1.996
[*p*-value]		(0.519)		(0.162)

The numbers in parentheses are robust *p*-values

***, **, and * indicate significance at 1, 5, and 10 %, respectively for all IV models, the validity of the first stage results holds for all the other IV models shown in Tables 3.5 and 3.6 as well. In some cases, an endogeneity test does not reject the null hypotheses that the credit-constrained farmer variable is exogenous. In these cases, however, we still rely on the results of the IV models because results from the OLS models in which we treat being a credit-constrained farmer as an exogenous dependent variable are consistent with those from the IV models.[8]

Neither the existence of SACCOs nor being a credit-constrained farmer has a significant impact on adoption of MVs in either model (1) or (2). These results indicate that there is no serious credit-related constraint on the adoption of MVs, which does not require a large amount of cash or credit. On the other hand, the interaction term between the existence of SACCOs and the irrigated plot dummy has a positive and significant effect on chemical fertilizer use in model (3). Furthermore, being a credit-constrained farmer has a negative effect on chemical fertilizer use in model (4), though the estimated coefficient is not statistically significant. These results suggest a positive impact of credit access on chemical fertilizer use in irrigated plots, supporting our second hypothesis. Another important finding regarding the adoption of MVs is that the interaction term between the distance to the nearest extension office and the irrigated plot dummy has a negative and significant impact on the adoption of MVs in both models (1) and (2), suggesting that better access to extension services enhances the adoption of MVs especially in irrigated areas.

In all models, the distance from the district capital has a negative and significant impact on the adoption of MVs and chemical fertilizer use. A possible explanation of this result is transportation costs, which reduce output prices and increase input prices. In fact, our data indicates that the ratio of urea price to output price per kg 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; this difference is statistically significant.

As would be expected from the descriptive analysis, results from both models (1) and (2) show that MVs are used more commonly on irrigated plots. This is consistent with our first hypothesis and with experiences in Asian countries, where farmers in irrigated areas adopted MVs more quickly and widely than farmers in rain-fed areas (David and Otsuka 1994). It is important to note that plot size has negative coefficient in all models (1) to (4). These results suggest that small-scale farmers are more likely to adopt MVs and chemical fertilizer, even though plot size is imperfectly correlated with total farm size.[9] Furthermore, household assets and the total area of other plots in lowland or upland areas have no positive impact on the adoption of MVs or chemical fertilizer use, suggesting that adoption of MVs and the use of chemical fertilizers are not influenced by wealth.

Table 3.5 shows the results of regressions analyzing the adoption of improved management practices, namely bund construction, plot leveling, and transplanting in rows. In models (1) and (2), neither the existence of SACCOs nor being a credit-constrained farmer has a significant effect on the adoption of bund construction.

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[8] These estimation results are not shown here.

[9] The correlation coefficient between plot size and total landholding is 0.58.

Table 3.5 Determinants of the adoption of bund construction, plot leveling, and transplanting in rows in extensive survey sites in Tanzania (district-level fixed-effect model)

	(1)	(2)	(3)	(4)	(5)	(6)
	Bund	Bund	Leveling	Leveling	Transplanting in rows	Transplanting in rows
	OLS	IV	OLS	IV	OLS	IV
SACCOs	0.034		0.055*		0.009	
	(0.335)		(0.089)		(0.795)	
Irrigated * SACCOs	−0.045		0.044		0.336**	
	(0.592)		(0.609)		(0.025)	
Credit constrained		−0.128		−0.413**		−0.629*
		(0.530)		(0.043)		(0.086)
Distance to the nearest extension office (km)	−0.000	0.000	−0.002	−0.001	−0.000	0.002
	(0.940)	(0.950)	(0.380)	(0.701)	(0.714)	(0.412)
Irrigated * distance to the nearest extension office (km)	−0.000	0.001	0.018	0.021	0.007	0.011
	(0.984)	(0.937)	(0.156)	(0.187)	(0.682)	(0.498)
Distance to the district capital (km)	−0.001**	−0.001**	0.000	0.000	−0.001**	−0.001
	(0.015)	(0.026)	(0.818)	(0.676)	(0.027)	(0.206)
Irrigated plot	0.581***	0.556***	0.329***	0.310***	0.102	0.159
	(0.000)	(0.000)	(0.000)	(0.000)	(0.209)	(0.102)
Size of the plot (ha)	−0.009	−0.010	−0.020	−0.027*	−0.023***	−0.039***
	(0.189)	(0.238)	(0.131)	(0.054)	(0.000)	(0.005)
Size of other plots owned in lowland areas, excluding the sample plot (ha)	0.004	0.005	−0.011	−0.008	0.011*	0.014*
	(0.565)	(0.426)	(0.245)	(0.434)	(0.096)	(0.072)
Size of plots owned in upland areas (ha)	−0.003	−0.007	−0.005	−0.016*	0.005	−0.012
	(0.511)	(0.345)	(0.480)	(0.094)	(0.293)	(0.343)
Number of cows and bulls owned	0.000	0.000	0.002*	0.002*	0.000	0.001
	(0.827)	(0.733)	(0.099)	(0.093)	(0.956)	(0.646)
Household assets (million TZS)	−0.015	−0.018	0.027*	0.017	−0.004	−0.018
	(0.121)	(0.106)	(0.062)	(0.325)	(0.815)	(0.332)
Number of adults (age≥15)	0.009	0.008	−0.012	−0.015	−0.010	−0.014
	(0.261)	(0.331)	(0.288)	(0.228)	(0.144)	(0.172)
Average years of schooling of adult household members	−0.004	−0.004	−0.000	0.001	0.011*	0.015
	(0.469)	(0.518)	(0.966)	(0.899)	(0.071)	(0.114)
Female household head	−0.036	−0.047	−0.078*	−0.103**	−0.020	−0.040
	(0.330)	(0.225)	(0.072)	(0.032)	(0.505)	(0.438)

(continued)

Table 3.5 (continued)

	(1)	(2)	(3)	(4)	(5)	(6)
	Bund	Bund	Leveling	Leveling	Transplanting in rows	Transplanting in rows
	OLS	IV	OLS	IV	OLS	IV
Age of household head	–0.001	–0.000	–0.000	0.001	0.002	0.005**
	(0.452)	(0.807)	(0.731)	(0.456)	(0.166)	(0.049)
Constant	0.259***	0.351**	0.291**	0.561***	0.067	0.442*
	(0.007)	(0.012)	(0.019)	(0.001)	(0.315)	(0.081)
Observations	669	669	669	669	669	669
R-squared	0.680		0.354		0.214	
First stage *F*		10.393		10.393		10.393
[*p*-value]		(0.002)		(0.002)		(0.002)
Endogeneity test		0.422		5.422		4.389
[*p*-value]		(0.518)		(0.023)		(0.040)

The numbers in parentheses are robust *p*-values

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

Hence, credit does not seem to be important for the adoption of bunding. On the other hand, the existence of SACCOs in model (3) and its interaction term with the irrigated plot dummy in model (5) have positive and significant effects on the adoption of plot leveling and transplanting in rows, respectively. Furthermore, the coefficient on being a credit-constrained farmer is negative and significant in models (4) and (6). Since plot leveling and transplanting in rows are labor-intensive activities, this result may imply that farmers with good access to credit are able to hire more agricultural labor, machinery, or animals than credit-constrained farmers, as indicated in Table 3.2.

The number of cows and bulls owned has a positive and significant effect on the adoption of plot leveling, which is consistent with the fact that animal traction is used for this activity. The dummy variable for female-headed households has a negative effect on the adoption of plot leveling in models (3) and (4). Furthermore, the size of the plot has a negative effect on the adoption of plot leveling and transplanting in rows in models (4) to (6). These results suggest that inadequate endowments of family labor and/or animal traction power may be constraints to adopting plot leveling and transplanting in rows. Note that the coefficient on the number of cows and bulls owned would be insignificant if the machinery or animal rental market were perfect. Thus, this result suggests that the draft animal market is imperfect in the study areas, which may hinder the adoption of plot leveling. The coefficient on the irrigated plot dummy is positive in all models, indicating that farmers have a higher incentive to adopt these improved practices on irrigated plots, supporting our first hypothesis.

Table 3.6 shows results from the regressions examining the determinants of paddy yield (tons per hectare), gross output value (100 USD per hectare), total costs (100 USD per hectare), and profit from rice farming (100 USD per hectare). The

Table 3.6 Determinants of paddy yield (tons per hectare), gross output value, total costs, and profit of rice farming (100 USD per hectare) in extensive survey sites in Tanzania (district-level fixed-effect model)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Yield	Yield	Gross output value	Gross output value	Total costs	Total costs	Profit	Profit
	OLS	IV	OLS	IV	OLS	IV	OLS	IV
SACCOs	0.181		1.024		–0.250		1.274	
	(0.459)		(0.298)		(0.536)		(0.223)	
Irrigated * SACCOs	–0.156		–0.887		0.152		–1.039	
	(0.706)		(0.582)		(0.853)		(0.493)	
Credit constrained		–0.841		–4.740		1.268		–6.008
		(0.457)		(0.351)		(0.555)		(0.270)
Distance to the nearest extension office (km)	–0.006	–0.004	–0.035	–0.024	–0.029	–0.032	–0.006	0.008
	(0.494)	(0.681)	(0.176)	(0.465)	(0.264)	(0.238)	(0.813)	(0.822)
Irrigated * distance to the nearest extension office (km)	–0.087**	–0.079*	–0.277**	–0.234	0.127	0.116	–0.404**	–0.350
	(0.024)	(0.069)	(0.027)	(0.181)	(0.315)	(0.368)	(0.029)	(0.132)
Distance to the district capital (km)	0.001	0.001	–0.006	–0.005	–0.004	–0.004	–0.002	–0.001
	(0.715)	(0.702)	(0.373)	(0.529)	(0.395)	(0.346)	(0.724)	(0.875)
Irrigated plot	1.665***	1.549***	5.601***	4.946***	1.937**	2.085***	3.664***	2.861***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.044)	(0.009)	(0.001)	(0.008)
Size of the plot (ha)	–0.197***	–0.207***	–0.713***	–0.773***	–0.473***	–0.456***	–0.240*	–0.317*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.075)	(0.061)
Size of other plots owned in lowland areas, excluding the sample plot (ha)	–0.022	–0.012	–0.056	–0.002	–0.194***	–0.208***	0.138	0.206
	(0.445)	(0.717)	(0.577)	(0.989)	(0.006)	(0.003)	(0.272)	(0.201)
Size of plots owned in upland areas (ha)	–0.018	–0.039	–0.079	–0.201	–0.074	–0.042	–0.004	–0.160
	(0.496)	(0.254)	(0.422)	(0.208)	(0.149)	(0.485)	(0.967)	(0.349)

(continued)

Table 3.6 (continued)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Yield	Yield	Gross output value	Gross output value	Total costs	Total costs	Profit	Profit
	OLS	IV	OLS	IV	OLS	IV	OLS	IV
Number of cows and bulls owned	0.016***	0.017***	0.061***	0.066***	0.013	0.012	0.048**	0.054**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.284)	(0.335)	(0.023)	(0.012)
Household assets (million TZS)	0.042	0.023	0.094	–0.016	–0.130	–0.101	0.224	0.085
	(0.483)	(0.719)	(0.673)	(0.952)	(0.349)	(0.451)	(0.377)	(0.767)
Number of adults (age≥15)	–0.040	–0.047	–0.124	–0.165	0.379***	0.389***	–0.503***	–0.555***
	(0.212)	(0.163)	(0.239)	(0.151)	(0.001)	(0.001)	(0.003)	(0.001)
Average years of schooling of adult household members	0.039	0.041	0.077	0.091	–0.066	–0.070	0.143	0.161
	(0.146)	(0.133)	(0.385)	(0.365)	(0.404)	(0.361)	(0.151)	(0.146)
Female household head	–0.091	–0.159	–0.317	–0.699	–0.330	–0.233	0.013	–0.466
	(0.618)	(0.406)	(0.626)	(0.365)	(0.482)	(0.611)	(0.987)	(0.578)
Age of household head	–0.007	–0.003	–0.026	–0.005	0.016	0.011	–0.042**	–0.016
	(0.177)	(0.687)	(0.153)	(0.880)	(0.127)	(0.485)	(0.031)	(0.634)
Constant	2.586***	3.169***	8.551***	11.838***	5.399***	4.532***	3.152**	7.307**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.005)	(0.041)	(0.037)
Observations	669	669	669	669	669	669	669	669
R-squared	0.326	0.283	0.351	0.225	0.224	0.220	0.195	0.039
First stage F		10.393		10.393		10.393		10.393
[p-value]		(0.002)		(0.002)		(0.002)		(0.002)
Endogeneity test		0.434		0.861		0.12232		1.075
[p-value]		(0.512)		(0.356)		(0.728)		(0.303)

The numbers in parentheses are robust p-values

***, **, and * indicate significance at 1, 5, and 10 %, respectively most important finding is that there is no evidence that better access to credit improves the productivity and profitability of rice farming. Being a credit-constrained farmer has no significant impact on paddy yield, gross output value, or rice farming profits, suggesting that non-credit-constrained farmers do not necessarily gain higher revenues or productivity compared to credit-constrained farmers.

On the other hand, the coefficient on the interaction term between the distance to the nearest extension office and the irrigated plot dummy is negative for paddy yield, gross output value and profit per hectare. These results suggest that access to extension services may be an important determinant of paddy yield and rice farming profits, especially in irrigated areas. This finding indicates that in order to shift the production function upward, it is necessary for a farmer to have knowledge of modern inputs and improved production practices in irrigated areas. This finding is consistent with the view of Japanese rice production experts dispatched to Tanzania by the Japan International Cooperation Agency, who concluded that thorough management of paddy fields is indispensable for realizing a rice Green Revolution in Tanzania.

The coefficient on the irrigated plot dummy variable was positive in all of the models. According to our estimation results, paddy yield increases by 1.5–1.7 tons per hectare and profit increases by 286–366 USD per hectare if the plot is irrigated. This result supports our first hypothesis that irrigation is critically important for enhancing paddy yields and the productivity of rice farming. The size of the sample plot significantly decreases paddy yield and profit, which is consistent with the 'inverse relationship' between farm size and agricultural productivity (Otsuka 2007; Larson et al. 2014). The number of cows and bulls owned has a positive and significant impact on yield, gross output value, and profit, suggesting that farmers can increase paddy yield and profit by using owned animals for traction, which enables farmers to adopt plot leveling.

3.4 Impact of TANRICE Training in Case Study

3.4.1 Descriptive Analyses and Hypotheses

This section examines the impact of TANRICE training on the adoption of technologies and productivity of rice farming by using the CS data set. Table 3.7 presents paddy yield and technology adoption by key, intermediary, and ordinary farmers from 2008 to 2012. We also show the results of *t*-tests comparisons between ordinary and key farmers and between ordinary and intermediary farmers in each year. Note that the TANRICE training was conducted during the cultivation season of 2009, and the recall data for 2008 were collected during the survey in 2010.

As shown in the table, even prior to TANRICE training, key farmers achieved slightly higher yield than ordinary farmers. Thus, farmers showing superior performance would have been selected as the key farmers. However, the difference of yields between key and ordinary farmers is merely 0.5 ton per hectare and there was

Table 3.7 Paddy yield and technology adoption by the training status in case study sites in Tanzania from 2008 to 2012[a]

	Key farmers		
Variables	2008	2010	2012
Paddy yield (t/ha)	3.1*	4.8***	4.7**
Chemical fertilizer use (kg/ha)	63.4	137.7***	131.3***
Share of plots using modern varieties	46.2*	65.8***	66.7***
Share of plots with improved bund	15.4**	31.3***	15.4
Share of levelled plots	46.2	81.3	76.9
Share of households who adopted transplanting in rows	23.1	93.8***	92.3***
Observations	13	16	13

	Intermediary farmers		
Variables	2008	2010	2012
Paddy yield (t/ha)	2.5	2.8	3.9
Chemical fertilizer use (kg/ha)	22.2**	79.1	95.2
Share of plots using modern varieties	30.4	40.8**	49.5**
Share of plots with improved bund	13.0*	22.6***	33.3***
Share of levelled plots	43.5**	74.2	62.5
Share of households who adopted transplanting in rows	13.0	64.5***	58.3**
Observations	23	31	24

	Ordinary farmers		
Variables	2008	2010	2012
Paddy yield (t/ha)	2.6	2.5	3.7
Chemical fertilizer use (kg/ha)	46.5	69.7	83.2
Share of plots using modern varieties	26.7	25.7	32.9
Share of plots with improved bund	3.0	7.7	11.5
Share of levelled plots	54.8	69.0	66.9
Share of households who adopted transplanting in rows	11.1	25.8	36.9
Observations	135	155	130

***, **, and * indicate significance at 1, 5, and 10 %, respectively, in *t*-tests comparing between ordinary farmers and key farmers and between ordinary farmers and intermediary farmers in each year

[a] Recall data for 2008 and 2009 collected in the survey in 2010 are used

no statistically significant difference between intermediary and ordinary farmers in 2008. The key farmers' paddy yield increased soon after the training from 3.1 tons per hectare in 2008 to 4.8 tons per hectare in 2010; this is because of the high rate of new technology adoption by the key farmers. After the TANRICE training, the adoption rate of modern varieties, improved bund construction, plot leveling, and transplanting in rows by key farmers increased rapidly and remained high until 2012. As a result, key farmers achieved higher yields than ordinary farmers by about 2 tons per hectare in 2010, a difference which is statistically highly significant. Remarkably, however, the yield gap declined to only 1 ton per hectare in 2012.

Soon after the training, intermediary farmers started adopting new technologies including modern varieties and improved bund, and transplanting in rows, and the difference in the adoption rate of these technologies between intermediary and ordinary farmers started increasing. However, the increase in the paddy yield of the intermediary farmers, from 2.5 tons per hectare in 2008 to 3.9 tons per hectare in 2012, was not as quick as that of the key farmers. Furthermore, the difference in paddy yield between ordinary and intermediary farmers is insignificant.

The paddy yield of ordinary farmers increased from 2.6 tons per hectare in 2008 to 3.7 tons per hectare in 2012. This increase can also be attributed to an increase in the application of chemical fertilizer and the adoption of improved agronomic practices among ordinary farmers, although the change was neither rapid nor drastic compared with the key and intermediary farmers. Yet, the difference between intermediary and ordinary farmers became considerably smaller in 2012, which indicates that the ordinary farmers caught up with intermediary farmers to a significant extent. These results suggest that technologies taught in TANRICE training diffuse slowly from key farmers to intermediary and ordinary farmers. These observations lead us to hypothesize that:

Hypothesis 4 The adoption of technologies and the paddy yield of key farmers increase soon after the training and the gap between key and other farmers widened significantly initially, but adoption and yield gap between them became gradually smaller.

Hypothesis 5 While the key farmers are high performers from the beginning, so that their performance is always higher than other farmers, *net* difference among the key, intermediary, and ordinary farmers has become smaller and possibly disappeared in the longer run, even though it was large during the training and subsequent short periods.

3.4.2 Methodology in the Case Study

In order to examine these hypotheses, we estimate the impact of TANRICE training on the adoption of rice cultivation technologies and paddy yield by using regression analyses. We employ two methods: the first are average treatment effect (ATE) models and the second are difference-in-difference methods (Imbens and Wooldridge 2007; Wooldridge 2010). In both models, the dependent variables are paddy yield (t/ha) and the sets of technology adoption variables including the dummy variable which takes one if a farmer adopts MVs or chemical fertilizer (kg/ha), and dummy variables which take one if improved bund construction, leveling of plots, and transplanting in rows are adopted respectively.

Let y_1 denote an outcome of interest of a household with training, and y_0 the outcome of the same household without training. Let the variable w be a binary treatment indicator, where $w=1$ denotes receiving training and $w=0$ otherwise.

Average treatment effect (ATE) can be defined as:

$$ATE = E\left(y_1 - y_0\right), \tag{3.1}$$

which is the expected effect of treatment on a randomly drawn person from the population. A fundamental problem here is that we cannot observe both y_1 and y_0 as an individual cannot be in both states.

Let x denote the vector of observable household characteristics and p(x) the probability of receiving training $p\left(x\right)=p\left(w=1 \mid \mathrm{x}\right)$. By using inverse probability weight 1/p(x), ATE can be defined as

$$ATE = E\left\{\frac{\left[(w-p\left(x\right)y\right]}{p\left(x\right)\left[1-p\left(x\right)\right]}\right\}.$$

Thus, by estimating the probability of receiving treatment, we can estimate ATE. Since our treatment status has two categories (being key or intermediary farmers), we use a multinominal-logit model to estimate *p*(*x*) (for more technical detail, see StataCorp 2013 and Wooldridge 2010). We include the age of household head, its squared term, female headed household dummy, number of adult household members, number of adult household members squared, size of sample plot, size of owned plots in upland areas, size of owned plots in lowland areas, and value of household assets as independent variables in our estimation.

The problem of ATE estimation, however, is that we need to assume ignorability in mean:

$$E\left(y_0 \mid x,w\right)=E\left(y_0 \mid x\right)\text{and}E\left(y_1 \mid x,w\right)=E\left(y_1 \mid x\right).$$

This assumption implies that if we can observe enough information (contained in x) that determines treatment, then the outcome might be mean independent of w, conditional on x (Wooldridge 2010).

Since this is a strong assumption and is not directly testable, we also estimate a difference-in-difference model by utilizing the panel feature of our data set for a robustness check (Imbens and Wooldridge 2007). Namely, we estimate the following model by controlling household fixed effect (FE).

$$y_{it} = \lambda_t + \tau w_{it} + c_i + u_{it}, \mathrm{t} = 1, \ldots \mathrm{T},$$

The advantage of this model is that we can control time-invariant unobservable household characteristics, denoted here as c_i, which might affect program participation. In order to estimate the year-specific impact of being key or intermediary farmers, we include interaction terms of year dummy and training status dummy variables which take one if a farmer is a key farmer or intermediary farmer respectively in w_{it}. The base category is all the farmers in 2008, which is before TANRICE training. We also control year dummies in λ_t, which capture the general trend in outcome variables. Thus, the interaction terms of key or intermediary farmer dummy and year dummy would capture the difference in the growth of outcome variables between key and intermediary farmers and general trends including ordinary farmers, after taking into account the innate differences in farmers' traits.

3.4.3 Regression Results

Table 3.8 shows the estimation results for the average treatment effect of being key and intermediary farmers in each year.[10] We also show the potential outcome means of ordinary farmers. Before TANRICE training in 2008, there was hardly any significant difference between key or intermediary farmers and ordinary farmers in the paddy yields and the adoption of technologies except that key farm-

Table 3.8 Average Treatment Effect (ATE) of training in case study sites in Tanzania from 2008 to 2012

	(1)	(2)	(3)	(4)	(5)	(6)
	Yield (t/ha)	MV	Chemical fertilizer use (kg/ha)	Improved bund	Leveling	Transplanting in rows
2008						
Key farmer (ATE)	0.384	0.061	5.238	0.076	–0.196*	0.117
	(0.183)	(0.478)	(0.669)	(0.157)	(0.098)	(0.201)
Intermediary farmer (ATE)	–0.003	–0.064	–19.889**	0.130	–0.153	–0.009
	(0.987)	(0.352)	(0.032)	(0.117)	(0.148)	(0.879)
Potential outcome means						
Ordinary farmer	2.564***	0.271***	46.934***	0.026**	0.546***	0.116***
	(0.000)	(0.000)	(0.000)	(0.038)	(0.000)	(0.000)
2010						
Key farmer (ATE)	2.498***	0.522***	76.616***	0.150*	0.120	0.683***
	(0.000)	(0.000)	(0.001)	(0.070)	(0.268)	(0.000)
Intermediary farmer (ATE)	0.524*	0.166*	11.860	0.155**	0.090	0.371***
	(0.074)	(0.082)	(0.204)	(0.046)	(0.266)	(0.000)
Potential outcome means						
Ordinary farmer	2.483***	0.325***	69.342***	0.075***	0.686***	0.258***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
2012						
Key farmer (ATE)	1.403***	0.290**	39.337***	–0.002	0.174**	0.575***
	(0.002)	(0.027)	(0.001)	(0.976)	(0.032)	(0.000)
Intermediary farmer (ATE)	0.726	0.185*	12.737	0.197**	–0.015	0.253**
	(0.155)	(0.050)	(0.397)	(0.031)	(0.869)	(0.012)
Potential outcome means						
Ordinary farmer	3.631***	0.424***	83.602***	0.117***	0.674***	0.371***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

The numbers in parentheses are robust *p*-values

***, **, and * indicate significance at 1, 5, and 10 %, respectively for ATE of being key and intermediary farmers and potential outcome means for ordinary farmers

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[10] Multi-nominal logit estimation of probability of being key or intermediary farmers is available for readers upon request.

ers adopt plot leveling slightly less often than ordinary farmers and intermediary farmers apply less chemical fertilizer than ordinary farmers. Soon after the training, however, the adoption rates of improved technologies by key farmers including MVs, chemical fertilizer, and transplanting in rows become higher than those by ordinary farmers. As a result, the paddy yield of key farmers is higher than that of ordinary farmers by 2.5 tons per hectare in 2010. These results support the first part of Hypothesis 4 that the adoption of technologies and paddy yield by key farmers increases soon after the training and the gap between key and other farmers would widen at first.

However, as time goes on, the difference in paddy yield between key and ordinary farmers become smaller in 2012. The paddy yield of key farmers is significantly higher than that of ordinary farmers but only by 1.4 tons per hectare in 2012. Moreover, the potential outcome means of paddy yield of ordinary farmers steadily increases from 2.6 tons per hectare in 2008 to 3.6 tons per hectare in 2012. We also observe steady increase in the adoption of all the technologies by ordinary farmers. Intermediary farmers achieve a slightly higher yield than ordinary farmers in 2010, though the overall difference between intermediary and ordinary farmers in paddy yield and technology adoption is not as large as that between key and ordinary farmers. These results support the second part of Hypothesis 4 that the difference between key and other farmers become smaller as time goes on after the training.

Table 3.9 shows the estimation results of difference-in-difference models. The year dummy has a positive and significant coefficient in the adoption of chemical fertilizer, plot leveling, and transplanting in rows in 2010 and 2012, suggesting that the adoption of these technologies increases steadily after the training for all the farmers. The adoption of other technologies, including MVs and improved bund construction, also increases in 2012.

Note that the coefficient of year dummy on paddy yield is significant only in 2012, suggesting that the paddy yield for all the farmers started increasing in 2012. On the other hand, the interaction term of key farmer dummy and year dummy has a positive and significant coefficient on yield in 2010, implying that key farmers' technology adoption and paddy yield both increase soon after the training. A more significant finding is the absence of the significant yield effects of the interaction term between the key farmer dummy and 2012 dummy, even though the interaction term is significant in the fertilizer use and transplanting in rows. These results are consistent with Hypothesis 5 that after taking into account the innate difference, the impacts of direct training become nil in the long run. While the intermediary farmers catch up with the key farmers earlier than ordinary farmers, the interaction term of intermediary farmer dummy and year dummy has no positive and significant coefficient on yield, suggesting that there is little difference between ordinary and intermediary farmers by 2012. These findings are consistent with the Hypothesis 5 that the *net* difference in the performance among the key, intermediary, and ordinary farmers has disappeared in 2012.

Table 3.9 Difference-in-difference estimators of the impact of training in case study sites in Tanzania from 2008 to 2012

	(1) Paddy yield (t/ha)	(2) MVs	(3) Chemical fertilizer use (kg/ha)	(4) Improved bund	(5) Plot leveling	(6) Transplanting in rows
Key farmer *2010	1.587***	0.262	76.403***	0.070	0.170	0.625***
	[0.009]	[0.150]	[0.001]	[0.592]	[0.407]	[0.000]
Key farmer *2012	−0.264	0.090	48.790**	−0.203	0.180	0.422**
	[0.660]	[0.622]	[0.033]	[0.122]	[0.380]	[0.014]
Intermediary farmer *2010	0.173	0.143	21.430	−0.041	0.194	0.347**
	[0.725]	[0.338]	[0.253]	[0.704]	[0.250]	[0.013]
Intermediary farmer *2012	−0.403	0.153	16.244	−0.020	0.061	0.041
	[0.413]	[0.305]	[0.386]	[0.849]	[0.716]	[0.770]
Year 2010	0.082	0.071	16.617**	0.041	0.163***	0.153***
	[0.636]	[0.176]	[0.013]	[0.283]	[0.006]	[0.002]
Year 2012	1.110***	0.133**	33.016***	0.092**	0.153**	0.245***
	[0.000]	[0.012]	[0.000]	[0.016]	[0.011]	[0.000]
Constant	2.540***	0.248***	42.317***	0.058**	0.504***	0.099***
	[0.000]	[0.000]	[0.000]	[0.017]	[0.000]	[0.002]
Observations	363	363	363	363	363	363
R-squared	0.207	0.059	0.190	0.040	0.073	0.221
Number of household	121	121	121	121	121	121

The numbers in parentheses are robust *p*-values
***, **, and * indicate significance at 1, 5, and 10 %, respectively

3.5 Conclusions

Using two unique data sets collected in Tanzania, our paper analyzed the current status of rice cultivation and identified the factors underlying the adoption of new rice cultivation technologies such as MVs, chemical fertilizers, and improved agronomic practices. Overall, the adoption rates of these technologies are not high, but have been gradually increasing.

Statistical analyses of our extensive data set reveal that credit does not strongly enhance the adoption of MVs, which can be self-produced for several seasons after the initial purchase. Meanwhile, improvement in credit access may be important for the adoption of chemical fertilizer, which requires cash for purchase, though the statistical significance is not high. We also found a positive impact of credit on the adoption of plot leveling and transplanting in rows, which suggests that credit access may allow labor-constrained farmers to rely on hired labor to adopt these labor-intensive agronomic practices. In short, improvement in credit access selectively enhances technology adoption. Nonetheless, there is no indication that improved credit access has any significant impacts on yield or the profitability of rice farming. This can be taken to imply that it is not increased input use that critically determines the efficiency of rice farming in Tanzania.

In contrast, we observed positive and highly significant impacts of access to extension services on the adoption of MVs and paddy yield and profit per hectare, especially in irrigated areas in ES study sites. Recently, more policy emphasis has been placed on the improvement of access to input such as chemical fertilizer and improved seeds by means of fertilizer and seed subsidies. However, our results suggest that improving access to extension services is critically important to enhance the productivity of rice cultivation in Tanzania, especially in irrigated areas.

Consistent with the results of extensive survey, we found a positive and significant impact of JICA training on the adoption of technology and productivity of rice cultivation in an irrigated area of CS study sites. The technologies taught by JICA gradually diffused from directly trained key farmers to other farmers, and increased paddy yields, suggesting the effectiveness of the farmer-to-farmer extension mechanism. In fact, the net difference in the performance among the key, intermediary, and ordinary farmers largely disappeared by 2012, strongly indicating the efficient dissemination of new technologies and management practices from the key farmers to other farmers. Overall, our findings strongly indicate that in order to shift the production function upward, it is necessary for a farmer to have not only access to credit but also sufficient knowledge on appropriate rice cultivation practices.

Our results also suggest the importance of irrigation for the adoption of technologies and productivity of rice farming. New technologies are more widely adopted in irrigated areas than in rain-fed areas. Furthermore, farmers in irrigated areas achieve much higher paddy yield and profit than those in rain-fed areas. Does this imply that the irrigation is prerequisite for the rice Green Revolution? This is a critically important question in view of the fact that rain-fed areas account for the majority of paddy fields not only in Tanzania but also in other countries in SSA. If irrigation is such a key factor, the rice Green Revolution in SSA will not be realized in the near future. According to studies by De Graft-Johnson et al. in Northern Ghana (Chap. 5), Kijima et al. in Eastern Uganda (Chap. 3), and our on-going study in Tanzania, rice yield can be increased significantly even under rain-fed conditions, if a package of modern inputs and improved management practices is adopted. Since this study as well as Nakano et al. (2013) strongly indicates that a rice Green Revolution has been almost realized in irrigated areas, the question of how to realize a rice Green Revolution in rain-fed areas as well is a major remaining issue in SSA for food security and poverty reduction.

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