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In Pursuit of an African Green Revolution

Views from Rice and Maize Farmers' Fields

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In Pursuit of an African Green Revolution

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Foreword

The future of Africa's growth relies greatly on the performance of the agricultural sector, as the African Union declared the year 2014 the African Year of Agriculture and Food Security, marking the 10th Anniversary of the adoption of the Comprehensive Africa Agriculture Development Programme (CAADP). Agricultural development has been essential for poverty reduction and food security in sub-Saharan Africa, and one of the major cereal crops that has great potential for achieving these goals is rice. Based on this understanding, the Japan International Cooperation Agency (JICA), together with other donors, research institutions, and relevant organizations, launched the Coalition for African Rice Development (CARD) initiative at the Fourth Tokyo International Conference on African Development in May 2008.

In parallel to CARD, the JICA Research Institute (JICA-RI) has been conducting a research project to empirically analyze how the CARD initiative serves to increase rice productivity per unit of land and reduce poverty. The project has been headed by Professor Keijiro Otsuka, National Graduate Institute for Policy Studies (GRIPS), since 2009. In collaboration with Dr. Donald Larson of the World Bank, this book project pays due attention to the strategy to boost the production of maize, another most important crop in Africa. Interestingly, we learned that findings from rice and maize studies are highly complementary.

In concluding, I would like to express my sincere gratitude to Dr. Otsuka, for his strong initiative in leading the research project of JICA-RI, and to Dr. Larson, for making this volume possible as a result of their invaluable collaboration. I hope this book will prove to be useful both for researchers and practitioners who are "in pursuit of an African Green Revolution."

JICA-RI
Tokyo, Japan
April 2015

Ichiro Tambo

Preface

As we argue in Chap. 1, growth in agriculture offers the best hope for reducing poverty among this generation of the rural poor. In sub-Saharan Africa, this means boosting the productivity of the millions of small farms that occupy most of the sub-continent's arable land (Lowder et al. 2014). This emphasis should not distract from the importance of helping rural household members prepare to work outside of agriculture, where average incomes are higher. However, it is a recognition that the process of structural transformation, which leads eventually to a smaller share of workers employed in a more productive agricultural sector, takes time.

There is a sobering consensus about the importance of smallholder agriculture. There is also broad agreement about an approach that emphasizes developing and disseminating new technologies that increase the yields of key smallholder food crops, an approach that is a common element in the development strategies promoted by African governments, multilateral development organizations, and development-focused NGOs (Larson et al. 2014).

The approach draws heavily on Asia's Green Revolution experience (Otsuka and Larson 2013). Like sub-Saharan Africa and unlike other regions, Asia's agriculture is based on small-scale family farming. Further, Asia's success, which proved that small scale need not preclude sustained productivity gains, came after an extended period of declining farm size, declining per capita cereal crop production, and widespread hunger (Hazell 2009).

Looking back across six decades, it is important to recall that Asia's Green Revolution was not initiated by innovative government policies or by improvements in infrastructure, marketing systems, and land rights institutions. It began precisely because of the advent of high-yielding modern varieties of rice and wheat, initially developed for temperate climates and subsequently adapted for tropical Asia. The new seeds were particularly high-yielding under irrigated conditions and with ample applications of chemical fertilizer. Thus, the advent of new varieties induced irrigation investments, credit programs to finance inputs, and improvements in marketing systems in subsequent periods. Overall, the Asian experience strongly suggested that the development and dissemination of improved technologies appropriate for sub-Saharan Africa were the prerequisite for an African Green Revolution. It also motivates the continued strategic emphasis of African policy makers on new staple-crop technologies.

Hayami and Ruttan (1985) argue that the essence of the Asian Green Revolution is the technology transfer from the temperate zone, such as Japan, to the tropical zone countries in Southeast and South Asia, by means of scientific research. Historically Japan has been making serious efforts to develop fertilizer-responsive, high-yielding rice varieties since the late nineteenth century. It is understandable that such technology transfer from temperate zone to tropics is far from simple. But is it also difficult to transfer technology from tropical Asia to tropical sub-Saharan Africa?

Our earlier book identified lowland rice as the most promising crop for the African Green Revolution because of the high potential benefits of transferring rice technology directly from tropical Asia to sub-Saharan Africa (Otsuka and Larson 2013). This volume illustrates how this process has already begun in selected areas and documents the consequences by using “views from farmers’ fields,” that is, by analyzing carefully collected data of farm households in Mozambique, Tanzania, Uganda, Ghana, and Senegal.

Taken together, the chapters address several questions. First, has the Green Revolution taken place in irrigated rice fields in sub-Saharan Africa, where production environments are similar to those in Asia? Second, is it possible to realize significant productivity gains for rice in the rain-fed areas of sub-Saharan Africa, which comprise the dominant production environment? Third, how effective are the management training programs designed to raise the productivity of small-scale family rice farms? To the extent that the answers to these questions are affirmative, we would like to ask whether the time is ripe for a Rice Green Revolution in sub-Saharan Africa. If it is, then the next question to ask is how best to speed the dissemination of improved rice technologies.

It is clear that rice is not the most important staple crop in Africa; however, it is growing in importance. In addition, we believe that the success of rice serves as a model for a series of Green Revolutions in other food crops.

Other chapters in this volume examine whether the strategy to realize a Green Revolution in maize is working in Kenya and Uganda, again based on “views from farmers’ fields.” The study in Uganda suggests that standard approaches based solely on new maize varieties have not fared well. However, the study from Kenya illustrates how farmers in the densely populated highlands in Kenya have developed an innovative system based on high-yielding hybrid maize varieties, organic and chemical fertilizers, and cross-bred stall-fed cows. While the component parts of this system have been supported by basic research, to the best of our knowledge, the system itself is indigenous, illustrating the important practical role of farmers in creating new innovations.

In short, this volume reports recent development of rice and maize farming in sub-Saharan Africa, which we hope proves useful in designing effective strategies to realize a Green Revolution there. In the process of our collaborative research leading to this volume, we have benefitted greatly from comments by collaborators, colleagues, and other researchers interested in the African Green Revolution. In

particular, we would like to thank Aliou Diagne, Amadou Abdoulaye Fall, Koichi Futakuchi, Yukinori Ito, T. Kilic, Masanori Kurisu, Yukichi Mano, Takahiro Nakamura, Timothy Njagi, Nobuaki Oizumi, Ellen Payongayong, Dick Sserunkuuma, Nobuhito Sekiya, Aya Suzuki, Takuji Tsusaka, Kazushi Takahashi, Maiko Takeuchi, Masato Tamura, Motonori Tomitaka, Takashi Yamano, and Robert Zeigler. We also thank Yasuko Maeshima for her patient preparation of the manuscript.

This volume is a result of a research project being conducted at the Japan International Cooperation Agency (JICA) Research Institute to empirically analyze how best the Coalition for African Rice Development (CARD) initiative can serve to increase rice productivity and reduce poverty in sub-Saharan Africa. CARD, which aims at doubling rice production from 2008 to 2018, was jointly launched by JICA and the Alliance for the Green Revolution in Africa (AGRA) at the 4th Tokyo International Conference on African Development (TICAD) meeting in 2008. We would like to thank the JICA Research Institute for the intellectual and financial support it has provided for this project. We are also grateful for the financial support provided to maize research in Kenya by the Global Center of Excellence Program and the GRIPS Emerging State Project of the Japan Society for the Promotion of Science (JSPS KAKENHI Grant Number 25101002) and the generous support of the donor-funded Knowledge for Change Program hosted by the World Bank.

Tokyo, Japan — Keijiro Otsuka
Washington, DC, USA — Donald F. Larson

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Keijiro Otsuka is a professor of development economics at the National Graduate Institute for Policy Studies (GRIPS) in Tokyo. After receiving a Ph.D. in economics from the University Chicago in 1979 and working for the Economic Growth Center of Yale University as a postdoctoral fellow for 1 year, he served as an associate professor and a professor of economics at the Tokyo Metropolitan University until 2001, when he joined GRIPS, where he served as the director of the International Development Studies Program from 2003 to 2011.

He was visiting scientist at the International Rice Research Institute (1986–1989), visiting research fellow at the International Food Policy Research Institute (1993–1998), and lead researcher at the World Bank (2011–2012). He was formerly chairman of the board of trustees of the International Rice Research Institute (2004–2007) and president of the International Association of Agricultural Economists (2009–2012). Currently he is chairman of the Oversight Committee of the Global Rice Science Partnership and an adviser to the Coalition for African Rice Development.

He has been working extensively on the Green Revolution, land tenancy, property rights and natural resource management, cluster-based industrial development, and the poverty dynamics in Asia and sub-Saharan Africa. His studies are primarily survey-based with comparative perspectives between Asia and sub-Saharan Africa. He has conducted numerous surveys in Japan, Taiwan, China, Vietnam, Indonesia, Thailand, India, Nepal, Ghana, Côte d'Ivoire, Ethiopia, Kenya, Uganda, Tanzania, and Malawi.

He received the Purple Ribbon Medal from the Japanese government in 2010 and was selected as an Honorary Life Member of the International Association of Agricultural Economists in 2012, Fellow of the Agricultural and Applied Economics Association (formerly the American Agricultural Economics Association) in 2013, and a Distinguished Fellow of the African Association of Agricultural Economists in 2013. He is the author or coauthor of 113 articles in refereed international journals of development economics, agricultural economics, and environmental economics and the coauthor or coeditor of 21 books (plus 8 Japanese books). Currently he is an editorial board member of *Economic Development and Cultural Change*, *Agricultural Economics*, and the *Asian Development Review*.

Donald F. Larson is a Senior Economist in the Development Research Group at the World Bank. He holds a PH.D. in agricultural and resource economics from the University of Maryland, as well as degrees in economics from Virginia Tech and the College of William and Mary. Don has written on a range of topics with a focus on rural development, natural resource management, food security, carbon markets and trade. With colleagues he has authored or edited six books, and has published in a diverse range of scholarly journals, including the *Journal of Development Economics*, *Journal of Environmental Economics and Management*, *Annales d'Economie et Statistique*, *The Journal of Futures Markets* and the *World Bank Economic Review*. He has worked with governments on policy issues in Africa, Asia, Europe, the Caribbean, Latin America and the South Pacific. Don was also part of a World Bank team that launched the first climate-finance fund, the Prototype Carbon Fund, in 1999.

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Chapter 1

Introduction: Why an African Green Revolution Is Needed and Why It Must Include Small Farms

Donald F. Larson and Keijiro Otsuka

Abstract This book explores recent experiences in the effort to bring about a Green Revolution in Sub-Saharan Africa (SSA). It focuses on rice and maize, which are promising and strategic smallholder crops. This chapter sets out the stage for the statistical analyses presented in later chapters by clarifying the importance of Green Revolution, identifying emerging challenges, and suggesting an effective strategy towards an African Green Revolution. Three major conclusions are derived. First, a rice Green Revolution is possible based primarily on the transfer and adaptation of technology and management practices from Asia, a process that is already begun in some places. Second, a maize Green Revolution is possible based on the establishment of new productive farming systems; however the relevant experience is limited in comparison to the new rice technologies. Third, not only "improved technologies" but also "improved management practices" are the keys to Green Revolution in SSA.

Keywords African Green Revolution • Asian Green Revolution • Rice farming • Maize farming • Modern inputs • Production management

1.1 Introduction

The goal of boosting productivity on smallholder farms is a central pillar in the rural development strategy of most African governments – a strategy backed by multilateral and bilateral aid agencies and the broader community of non-government organizations. There are many compelling reasons why this is so, among which the pressing need to poverty reduction is central.

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In 2008, there were 300 million poor living in Sub-Saharan Africa (SSA) with most depending on agriculture for a portion of their income. Worldwide, the number of rural poor has fallen in recent decades, driven by large income gains in East Asia and steady gains in most regions. In contrast, the number of rural poor in SSA is rising, up from nearly 200 million in 1990. Most of the very poor, those trying to survive on $0.75 per day, live in rural Africa (International Fund for Agricultural Development 2011, p. 48).

This book explores recent experiences in the effort to bring about a Green Revolution in SSA, a process which we believe is essential to reducing persistent poverty in Sub-Saharan Africa. It focuses on rice and maize, which are promising and strategic smallholder crops. This opening chapter sets out the stage for statistical analyses to be carried out on rice farming in Chaps. 2, 3, 4, 5, and 6 and on maize farming on Chaps. 7 and 8 by clarifying the importance of Green Revolution in poverty reduction and food security in SSA, identifying emerging challenges in this region, and contemplating effective strategy towards an African Green Revolution. The remaining chapters are based on careful inquiries into outcomes from farmers' fields, where a number of innovative changes have been actually taking place.

1.2 Green Revolutions and the Rural Poor

There are several potential pathways out of poverty for rural households, although none is easy. Family members from poor households often leave rural areas, migrating to cities or to other countries to earn incomes outside of agriculture. And in rural areas, farming families often engage in non-farm activities to supplement their incomes. Still, in the aggregate, the pace of sectoral migration – the shift of labor from agriculture to other sectors – is slow and the transformation of labor markets takes decades to achieve (Larson and Mundlak 1997). In many African countries, it is a process that is far from complete. According to Food and Agriculture Organization (2015), SSA's population is expected to remain primarily rural through 2033 and the absolute number of people living in rural areas will continue to climb through 2050.

In contrast, technological transformations in agriculture can occur in a single generation. During Asia's Green Revolution, new seeds and new farming practices spread quickly, especially among rice and wheat farmers in Asia (David and Otsuka 1994; Evenson and Gollin 2003a; Larson et al. 2010). As a consequence, rural incomes grew directly from on-farm productivity gains. Rural communities benefited as well, as businesses linked to agriculture grew; a second round of nonfarm employment added to rural incomes as well. At the household level, enhanced productivity and greater farm income also helped families prepare for jobs outside of agriculture, as farming families were able to invest in the health and education of their children. Indeed, Otsuka et al. (2008) find that, in Asia, increased farm income led to increased investment in schooling of children, who later contributed to the development of nonfarm sectors by supplying the educated labor.

Said differently, experience suggests that productivity growth in agriculture can be a powerful catalyst for poverty reduction and economic growth, working across several channels of welfare enhancing changes. The process is well documented in a variety of country studies in poor and middle income countries.[1] What's more, there is little evidence that growth in other sectors matters nearly as much.[2] For these reasons, Asia's experience suggests that agriculture offers the best hope for this generation of rural poor in Africa.

1.3 Green Revolutions, Food Security and the Urban Poor

Despite the many changes brought about by Asia's Green Revolution, sector productivity in Asia is still driven by what happens on small farms, and the same is true in SSA. In East Asia, South Asia and SSA, 95 % of the farms are less than 5 ha and these farms occupy most of the farmland in these regions (Lowder et al. 2014). Still, as Asia's Green Revolution proved, the small scale of farms in Africa need not stand in the way of technology adoption and productivity gains. Evenson (2003, p. 450) estimates that by 1998, about 82 % of the area in Asia planted to major crops used improved seeds. In Latin America, where farms are larger, adoption rates were similar for wheat, a significant export crop; however rates were lower overall, with 62 % of the land planted to modern varieties by 1998.

Only in Africa did the spread of the new technologies stall. By 1998, only 27 % of farmland in SSA was planted to modern varieties. Adoption rates improved subsequently, but remained well below rates on Asia's small farms. By 2005, the adoption of new varieties were 45 % for maize, 26 % for rice, and 15 % for sorghum (Binswanger-Mkhize and McCalla 2010; Pingali 2012). Even today, Sub-Saharan Africa is a mosaic of experiences, with innovations occurring in some places, but without a sweeping revolution.

Still, the 20th Century Green Revolution was broadly successful outside of Africa, and this had global consequences for food supplies. Research suggests that during the first Green Revolution, productivity gains from improvements in crop germplasm boosted global agricultural productivity by 1 % per year for wheat, 0.8 % for rice and 0.7 % for maize (Evenson and Gollin 2003a; Pingali 2012). From 1961 to 2001, world maize, rice and wheat yields grew annually at 2.1, 1.9 and

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[1] For example, Ravallion and Datt (1996) link growth in agriculture to significant declines in poverty in India, and Anríquez and López (2007) find the same holds true for middle-income Chile.

[2] For example, Thirtle et al. (2003) estimate that a 1 % gain in crop yields reduces the number of people living under poverty by 6.25 million while productivity gains in industry and services have little effect on poverty rates. Using a cross-country panel, Bravo-Ortega and Lederman (2009) found that the effects of boosting agricultural labor productivity were 2.9 times more effective at reducing poverty than productivity gains in other sectors. Christiaensen et al. (2011) found that agriculture mattered most for the very poor, but non-agricultural growth was important for the near-poor. The cited studies about poverty in India and Chile also found that economic growth outside of agriculture had significant consequences for poverty levels.

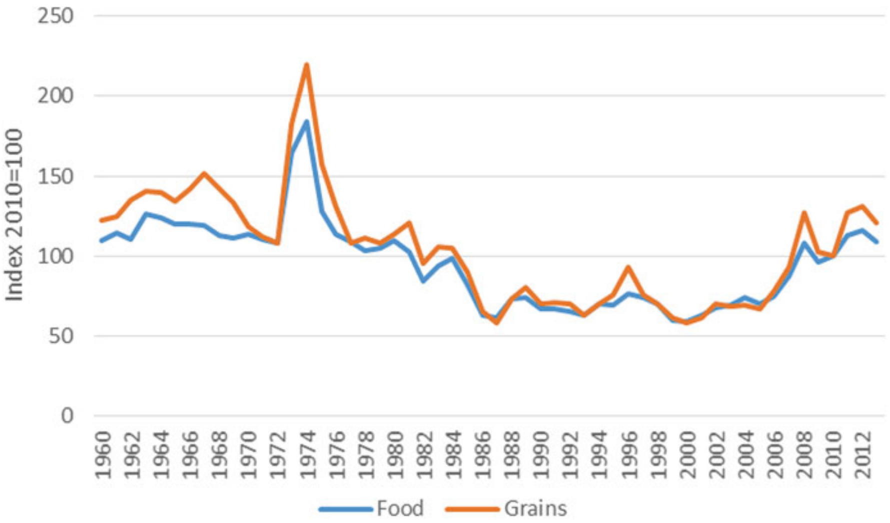

Fig. 1.1 Real food and grain prices (Source: World Bank Pink Sheet 2015)

2.3 %, well above the 1.8 % growth in population (Food and Agriculture Organization 2015). In Asia, rice yields grew by 2 % annually and maize and wheat yields grew by more than 3 % per annum.

Despite a historic set of price spikes in the mid-1970s, real cereal prices fell during this time, as did food prices in general (Fig. 1.1). All consumers benefited and poor consumers benefited the most, since poor household spend a greater share of their income on food. The aggregate effect was a final round of poverty reduction as the urban poor became more food secure (Ravallion et al. 2007).

1.4 Emerging Challenges

Since 2000, the global experience with food prices has changed. Real cereal prices, which declined at an annualized rate of 2.4 % from 1961 to 2000, rose on average by 6.8 % per year between 2000 and 2013; real food prices, which had declined by 2 %, rose by 5.5 % (World Bank Pink Sheet 2015). Additionally, the period was punctuated with sharp price spikes with harsh consequences for the poor, especially the urban poor.[3]

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[3] A large literature of global, regional and country studies have emerged documenting the consequences of the 2008 price spike and the prolonged raise from 2010 to 2012. See, for example, the global study by Ivanic and Martin (2008), the regional study by Larson et al. (2014a, b), and country studies for Brazil (Ferreira et al. 2013), Ethiopia (Kumar and Quisumbing 2013), Indonesia (Warr and Yusuf 2014), Mexico (Valero-Gil and Valero 2008), and the Philippines (Fujii 2013).

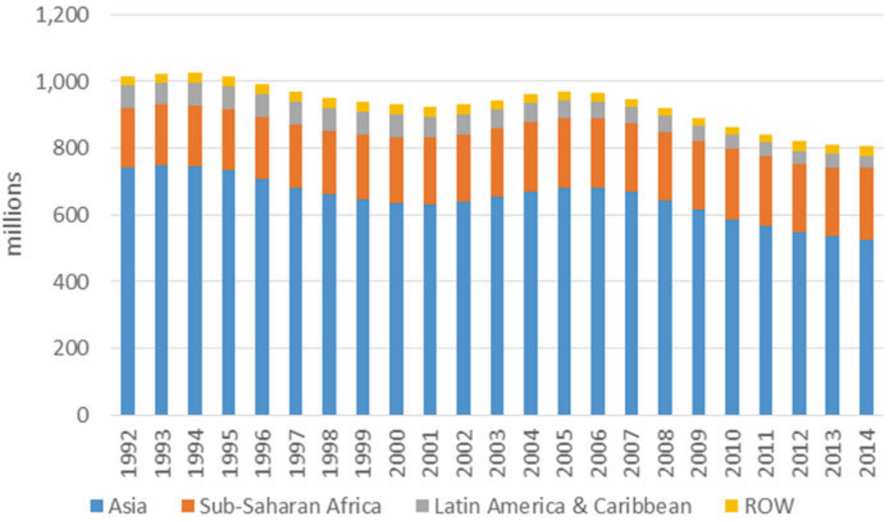

Fig. 1.2 Number of people undernourished (Source: FAO 2015). Note: Reported values are moving 3-year averages

As the Green Revolution enters its sixth decade, the pace of cereal yield gains has slowed (to 1.7 % per year for 2000–2013), but so has population (at 1.2 % for the same period). Income gains, especially in the fast growing economies of Asia, have helped the near poor achieve food security. In addition, better fashioned safety nets have helped the poor endure intermittent price and income shocks, and sustain better access to food (Wodon and Zaman 2010). As a consequence, Food and Agriculture Organization (2015) estimates that the number of malnourished has fallen since 2000, despite rising food prices (Fig. 1.2).

Still, there are concerns that food security gains will be harder to maintain going forward. Even though, on average, cereal yields continue to improve, there are signs that productivity growth has stagnated in many areas, leaving fewer opportunities for future global gains (Ray et al. 2012). What's more, Otsuka (2013) argues that the transition to labor-saving mechanization, needed in the face of rising real wages in many high performing countries in Asia, may undercut future productivity gains. As a consequence, many Asian countries, including such very large countries as China, India, and Indonesia may become importers of food grains, following the paths taken by Japan, South Korea, and Taiwan.

In addition, while the Green Revolution significantly reduced rates of deforestation, poorly managed water and pesticide use that accompanied the Green Revolution have done damage over time (Pinstrup-Andersen and Hazell 1985; Pingali and Rosegrant 1994; Stevenson et al. 2013.) As a consequence, degraded resources will limit growth in some places in the near term. Further ahead are the uncertain consequences of climate change on food production and prices (Intergovernmental Panel on Climate Change 2014).

Table 1.1 Changes in food supplies, calories and protein, 2000–2011

	Per capita		Total	
	Calories	Protein	Calories	Protein
Asia	6.4 %	9.5 %	20.4 %	23.9 %
Sub-Saharan Africa	8.6 %	11.5 %	44.4 %	48.3 %
World	5.2 %	7.1 %	19.8 %	21.9 %

Source: FAO (2015) and authors' calculations

At the same time, the future demand for food will place added demand on already constrained global resources. Food and Agriculture Organization (2015) estimates that farmers will need to feed an additional 2.32 billion people by 2050, an additional 1.36 billion of which will live in SSA.[4] What's more, in some ways, the tremendous strides taken in recent decades to reduce hunger have made future success harder to achieve. With improved incomes, households have diversified their diets beyond staple foods like maize, rice and wheat, and have increased their intake of animal proteins. This has had a profound impact on food systems and will continue to do so in the future, as the demand for animal feed competes with food crops for land (Delgado et al. 2001). This point is illustrated by Table 1.1, which lists the overall change in calorie and protein consumption from 2000 to 2013. Globally, growth in per capita protein intake exceeded the growth in calorie intake, and the same was true in Asia and in SSA. Rates of change were higher in Africa, where incomes are beginning to catch up. Overall, rates were significantly higher in SSA, because population growth rates are higher there as well.

The conversion of sugar, palm oil, grains and other agricultural commodities to biofuels will place added pressure on agricultural resources as well. A joint forecast by FAO and the OECD (OECD 2015) forecasts ethanol production will increase by 4 % annually from 2013 to 2023 and biodiesel production will increase by 4.3 % annual during the same period.

1.5 Toward an African Green Revolution

As discussed, boosting productivity on smallholder farms in Africa is vitally important for the 300 million poor living in rural Africa, since it offers their best opportunity for escaping poverty. This is reason enough for governments and the development community to act. However, looking ahead, it becomes clear why Africa's success is important for the rest of the world as well.

According to Food and Agriculture Organization (2015), about 20 % of all agricultural land is in SSA, and the World Bank (2015) estimates that about 9 % of

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[4] FAO estimates the 2014 world population at 7.23 billion and projects the 2050 population at 9.55 billion. The corresponding numbers for SSA are 1.35 billion and 2.71 billion.

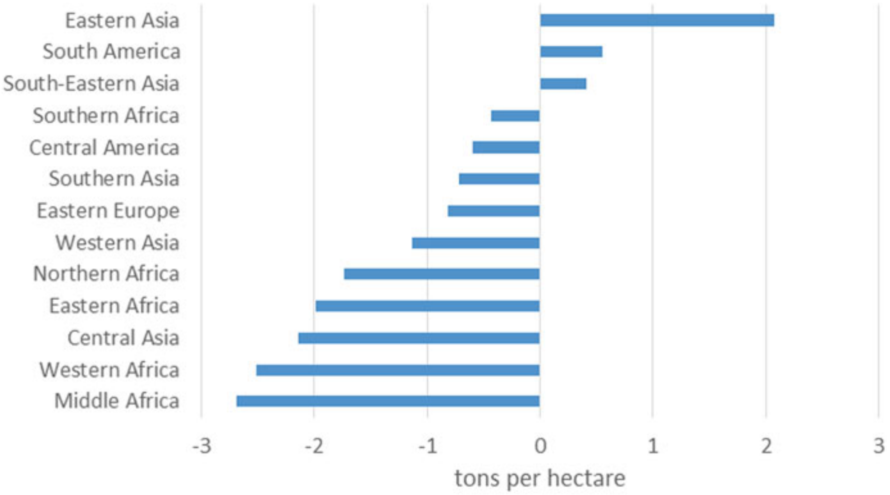

Fig. 1.3 Average cereal yield gap by developing region, 2011–2013 average (Source: FAO 2015 and authors' calculations). Note: The gap is regional average minus world average

renewable freshwater resources are in Africa. In addition, water resources in Africa, while limited, are under less pressure than water resources generally. In 2013, about 9 % of global freshwater resources were withdrawn from rivers, lakes and underground aquifers, while 3 % of SSA's resources were used. In addition, about 17 % of the World's rural population lives in Africa, where many families are experienced farmers. Still, food production in SSA is low relative to its natural resources. In 2011 SSA produced roughly 6 % of the world's food supply, when weighted by calories. And productivity remains low in SSA across a variety of measures. For example, cereal yields in SSA averaged about 1.4 tons per hectare for 2011–2013 compared to a global average of 3.7 tons (Food and Agriculture Organization 2015).

With natural resources already burdened, closing yield gaps around the globe through sustainable intensification is a necessary step to meet future food needs.[5] In turn, for staple cereals, the largest regional gaps are in SSA. As shown in Fig. 1.3, cereal yields are above global averages in Eastern and South-Eastern Asia and in South America, while yield gaps are evident in Eastern Europe and Central Asia and all of Africa.

There are places in Africa where agricultural land remains relatively abundant, and there is room to farm on a larger scale (Deininger and Byerlee 2012).[6] However, as discussed, most of the land that is currently farmed in SSA is farmed by smallholder families. And there is little evidence of land consolidation. Consequently,

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[5] See Godfray et al. (2010) for a good discussion of why sustainable intensification is needed.

[6] Even in areas in Africa where large-scale farming is feasible, hurdles remain due to poor property rights, especially for communal lands, and inefficient and opaque land markets.

for now, closing the yield gap means bringing better technologies to the smallholder farms that occupy most of Africa's arable land.

Nevertheless, there are important reasons why Africa's Green Revolution will be different from Asia's (Otsuka and Larson 2013a). Chief among them are the diverse agro-climatic conditions and the related diversity in the staple crops that are the foundation of African diets. This basic starting point means that a larger portfolio of new crop technologies, adapted to succeed under a wider range of soils and climates, along with a robust way of disseminating a more complex set of technical knowledge to a dispersed set of farmers, are all needed to produce significant national and global impacts on poverty and food security. Still, Asia's Green Revolution began with just a handful of crops, and it is likely that Africa's will as well.

As Evenson and Gollin (2003b) pointed out, the foundation for Asia's early success was a large stock of improved germplasm from temperate zones that served as a blueprint for varietal improvements: wheat varieties from North America, Europe and Japan, and rice cultivars derived from Taiwanese and Japanese semi-dwarfs. Matched with the large share of wheat or rice in Asian diets and similarities in growing conditions, the technologies spread quickly with large effects on farming households and on food prices. In contrast, the germplasm suitable for transfer for other crops was limited when the Green Revolution began. International breading programs for sorghum, millet, barley, lentils, potatoes and cassava, crops that are important in Africa, did not begin until the 1970s, and rice programs for Africa did not start until the 1980s. Although considerable progress would be made by the close of the twentieth century, this meant a slow start to Africa's Green Revolution.

As pointed out in our earlier volume, *An African Green Revolution*: *Finding Ways to Boost Productivity on Small Farms* (Otsuka and Larson 2013b), significant technical progress has been made for two of Africa's primary staple crops, maize and rice (Estudillo and Otsuka 2013; Diagne et al. 2013a; Kijima and Otsuka 2013; Smale et al. 2013). For these crops, we concluded that Africa's Green Revolution was already underway in some communities, even though the overall consequences were hard to see.

Now, even in the aggregate, there are signs that the gap in cereal yields is beginning to close. Figure 1.4 shows annualized growth rates in yields in Africa, Asia and the World for two periods. The first, 1961–2000, covers the 20th Century Green Revolution, while the second period, 2000–2013, looks at the available data for the time since. During the first period cereal yield gains in Asia outpaced those in SSA by a wide margin. Since then, yield growth rates have slowed somewhat, as have average world rates. However, growth rates in SSA have accelerated. The figure shows considerable differences among the regions for both periods, with the largest yield gains occurring in Southern Africa. Keeping in mind that yield improvements in Asia have been sustained for six decades, it is clear that the yield gap between Asia and SSA remains large. However, the recent differential growth rates of crop yields do suggest that the gap between Asia and parts of Africa have begun to close. It is obvious that it is worth inquiring what has been happening on farmers' fields in SSA.

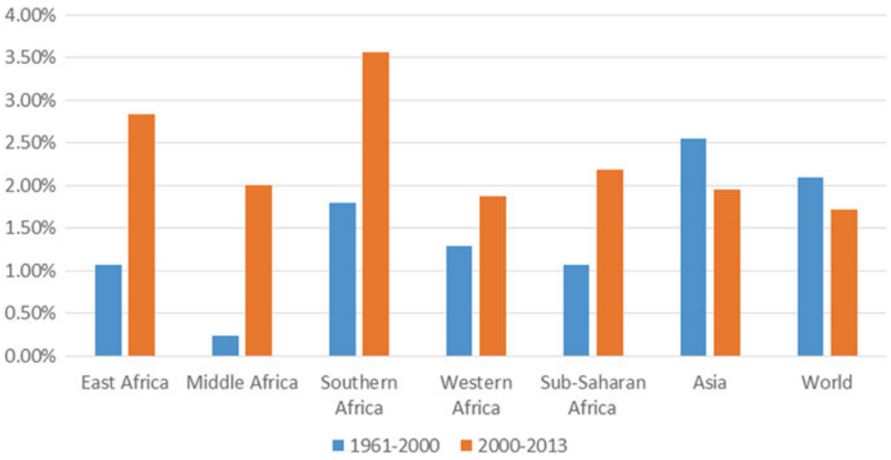

Fig. 1.4 Annualized rates of growth for cereals, Asia, Africa and the World (Source: FAO 2015 and authors' calculations). Note: **Eastern Africa** includes: Burundi, Comoros, Djibouti, Kenya, Madagascar, Malawi, Mauritius, Mozambique, Eritrea, Zimbabwe, Réunion, Rwanda, Somalia, United Republic of Tanzania, Uganda, Ethiopia, and Zambia. **Middle Africa** includes: Angola, Cameroon, Central African Republic, Chad, Congo, Gabon, Sao Tome and Principe, and the Democratic Republic of the Congo. **Southern Africa** includes Botswana, Lesotho, Namibia, South Africa, and Swaziland. **Western Africa** includes: Cabo Verde, Benin, Gambia, Ghana, Guinea, Côte d'Ivoire, Liberia, Mali, Mauritania, Niger, Nigeria, Guinea-Bissau, Senegal, Sierra Leone, Togo, and Burkina Faso

1.6 The Remaining Chapters

Lowland rice is a unique crop in a number of ways. First, it is the most sustainable major staple, as soil submergence helps control weeds, alters biological nitrogen fixation and soil chemical processes leading to increased supply of soil nitrogen and phosphorus, and maintain soil organic matter (Ladha and Reddy 2003; Buresh 2015). Second, in the context of SSA, the demand has been growing most rapidly among major crops and its consumption per capita doubled over the last three decades or so (Otsuka and Larson 2013b). Third, although production has been increasing rapidly due primarily to area expansion, the demand growth exceeded the production growth, thereby leading to growing imports from Asia (Fig. 1.5). Fourth, rice yield began growing since the beginning of this century in SSA, suggesting that technological changes have gradually taken place in some places. Fifth, unlike upland crops, this crop is management intensive, meaning that such agronomic practices as bunding, leveling, and straight-row transplanting, are critically important for yield growth. Such agronomic practices are commonly adopted in Asia but not in SSA and, hence, there is significant room for the improvement of rice yield in SSA by introducing such practices.

Significantly, we find that an African Rice Revolution based largely on Asian practices has already begun in many irrigated areas, including the Senegal River

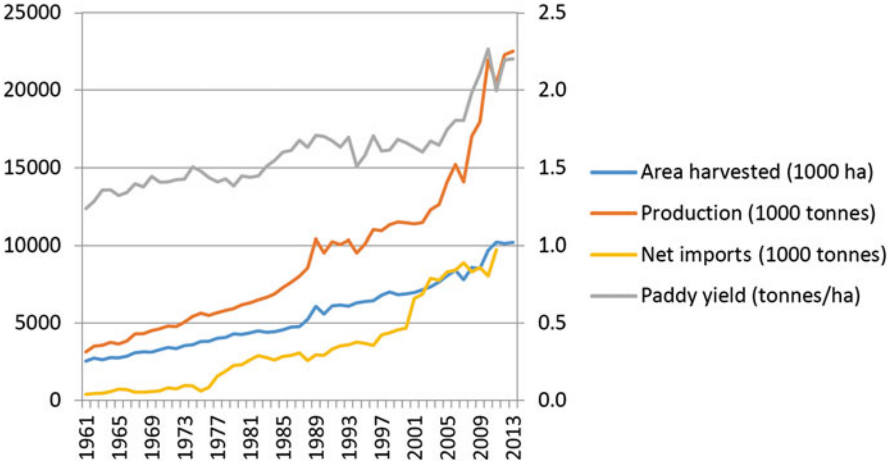

Fig. 1.5 Rice in SSA: area, production, imports, and yield

Valley (Chap. 6) and some areas in Tanzania (Chap. 3). In these areas, farmers use Asian-type modern varieties, chemical fertilizer, and improved management practices. The resulting yields match, and sometimes exceed typical yields found on irrigated farms in Asia. Further, we find that the same technological package significantly increases the productivity and profitability of rice farming in rainfed areas as well, e.g., Tanzania (Chap. 3), Uganda (Chap. 4), and Ghana (Chap. 5). We also find evidence that management training, when done well, can boost productivity on smallholder farms (Chaps. 2, 3, 4, and 5). In contrast, yield of rainfed rice farming is exceedingly low in Mozambique, where management training has seldom been offered (Chap. 2). This suggests that African governments can accelerate the pace of Africa's Rice Revolution by strengthening extension capacity.

The story for maize is wholly different as revolutionary high maize yields are seldom observed in SSA. More typical is the experience reported for Uganda in Chap. 8, where most farmers use local varieties, apply little chemical fertilizer, and obtain very low yields. However, a different approach is found in the highly populated highlands of Kenya (Chap. 7). Here a number of farmers have adopted high-yielding hybrid maize varieties and chemical fertilizer, as was the case in the Asian Green Revolution, apply manure produced by cows in stalls fed by feed crops grown on crop fields, as was the case during the British Agricultural Revolution, and keep improved cows, or cross-breeds from European cows and local stock, as was the case of Indian White Revolution. While these indigenous innovations have increased production and farm income in the highlands of Kenya, they have not receive public sector support, or garnered the attention of research centers, including those associated with the Consultative Group on International Agricultural Research. Obviously, for further yield growth, farmers must know how many cross-bred cows, what kind of feed crops and hybrid seeds, how much manure or compost, and what kind of chemical fertilizer are appropriate for one hectare of land. In other words, we must recognize that in all likelihood, productive maize-based farming systems in Africa are management intensive, whose dissemination requires both research and extension.

We argue in the concluding chapter that while rice in Africa has benefited from an Asian Green Revolution strategy that emphasizes modern seeds, inputs and focused management knowledge transfers from Asia to SSA, the success of Africa's maize Revolution will require a different farming system approach based on hybrid maize, chemical and organic fertilizers, and stall-fed cross-bred cows.

Chapter 2
On the Determinants of Low Productivity of Rice Farming in Mozambique: Pathways to Intensification

Kei Kajisa

Abstract This chapter analyzes a rice farmer panel data set that was collected in 2007/2008 and 2011 in Mozambique. We found that in a rainfed area, farmers expanded their cultivated area as local paddy prices increased in parallel with international rice price trends. However, the average yield decreased as the farmers were approaching to marginal land of their land frontier. To improve yield for further production increases, the production mode must shift from extensification to intensification through the introduction of land-saving technologies, such as irrigation development. A lesson learnt from the Chokwe Irrigation Scheme, the largest scheme of the country, is useful for this aim. A key lesson is that assuring water access is crucially important because timely water application directly increases output and also increases the returns to chemical fertilizer use. In Chokwe, a recent increase in the real price of modern inputs, such as fertilizer and tractors, saw farmers substitute family labor for modern inputs, that is, a return to traditional farming. To recapture the momentum of modernization, our analyses suggest that training and market access are important because those farmers who received a management training program did not give up using animal traction. Additionally, those who had access to rice buyers kept using chemical fertilizer.

Keywords Rice farming • Mozambique • Irrigation • Modern inputs • Rice production management training

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2.1 Introduction

Rice consumption in Mozambique has increased rapidly from 86 thousand tons in 1990 to 519 thousand tons in 2010, at an annual growth rate of 8.6 % (USDA 2011). The growth rate of rice consumption has been faster than the three other major cereals: maize (5.5 %), wheat (7.4 %), and sorghum (4.7 %) (United States Department of Agriculture 2011). Initially, local rice production stagnated, resulting in a rapid increase in rice imports. Although it has started rising since 2008, local rice production is still one third of consumption. Faced with an increase in rice prices on the world market, it is crucially important for the country to design effective strategies to accelerate the ongoing trend of rice sector development. For example, under the initiative of the Coalition for African Rice Development (CARD), the country has drafted a national development strategy report emphasizing the modernization of the rice sector (CARD 2011).

However, it is not yet clear what strategies will push through the intensification. A first step toward a strategy for development is a clear understanding of the constraints on the current production mode, which will help find ways to achieve intensification of rice farming. A major reason for difficulties in this task is the lack of detailed and representative data on rice. The International Rice Research Institute (IRRI) conducted a household survey in irrigated and rainfed areas in 2007/2008 and 2011 to construct a panel data set on rice farmers. Although national level general surveys of farmers had been carried out, this was the first data set designed specifically for rice.

Utilizing this data set, we begin by exploring what occurred in the rice sector between the two periods in the irrigated and rainfed areas. We then aim to identify what the constraints to an increase in rice production are. In the irrigated area, modern varieties and chemical fertilizer are moderately used, achieving the paddy yield of about 2 tons per hectare. Hence, we try to identify the constraints that were placed on intensification, which has to some extent already taken place. Meanwhile, the rainfed areas that have followed a traditional style with no application of modern inputs, have achieved a paddy yield of around 1 ton per hectare. Boserup (1965) argues that the modernization of agriculture starts once farmers reach the frontier of arable land and when the relative cost of extensification becomes more expensive than that of intensification. In line with this, our analysis of the rainfed areas focuses on the examination of the extensification process and possible pathways to intensification.

The organization of this chapter is as follows. After providing a brief overview of rice consumption and production in Mozambique in Sect. 2.2, Sect. 2.3 explains the nature of data used in this study and Sect. 2.4 examines changes in production and technology in study sites from 2007/2008 to 2011. While Sect. 2.5 explains the estimation methodology, Sect. 2.6 discusses the determinants of rice cultivation and the performance in the Chokwe irrigation scheme and Sect. 2.7 examines rice production performance in the rainfed area. Section 2.8 analyzes the impact of rice cultivation on household welfare. Finally Sect. 2.9 concludes this chapter by considering pathways to intensification in rice farming in Mozambique.

2.2 Rice in Mozambique

As a result of an increase in urbanization and the convenience of preparing rice meals, Mozambique, like other African countries, has seen a shift in consumer preference for rice (Hossain 2006). Demand for rice in Mozambique has, therefore, been rapidly increasing. In response to this increase, production grew initially at 12.1 % annually between 1993 and 1998, but then stagnated until 2008. The growth of production between 1993 and 1998 was largely attributed to area expansion resulting from the resettlement of rural populations after the peace agreement in 1992, rather than to an increase in yield (Zandamela 2008). Therefore, as shown in Fig. 2.1, the paddy yield had been around 1 ton per hectare in this period. Once resettlement was completed, production growth lost its momentum in the period from the end of the 1990s to the early 2000s. Growth resumed in 2008 when the international commodity markets, including rice, suffered a price surge. However, the increase in rice production is still reliant on area expansion, keeping the paddy yield at around 1 ton per hectare throughout the period (Fig. 2.1).

Rice in Mozambique is produced mostly under rainfed lowland ecology (Table 2.1), where the farmers follow traditional cultivation practices. Among rainfed lowland areas, Zambézia (57 %) is the dominant area, followed by Cebo Delgado

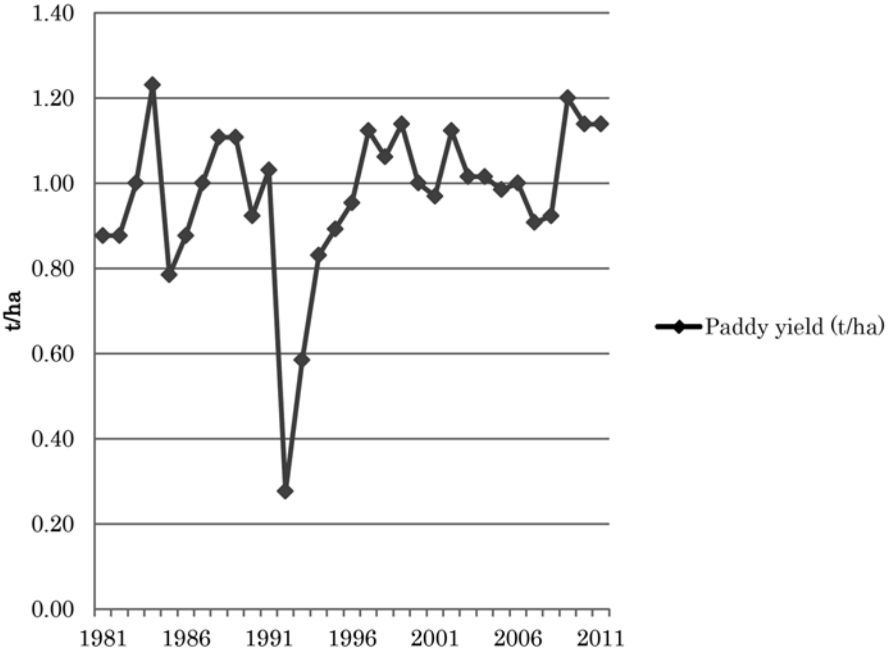

Fig. 2.1 Paddy yield in Mozambique from 1981 to 2011 (Source: USDA PS&D Online downloaded from http://worldfood.apionet.or.jp/index-e.html)

Table 2.1 Area of rice production in 2005 and agro-ecology by province in Mozambique

Province	Area of rice production in 2005 (000 ha)	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 and Agrifood Consulting International (2005) for agro-ecology

(14 %), Nampula (10 %), and Sofala (9 %). Irrigated areas are concentrated in Gaza where the largest irrigation scheme in the country, the Chokwe irrigation scheme, is located. Chokwe is located about 220 km north of the capital, Maputo, in an area considered to be the most favorable in terms of its agro-ecological and economic conditions. However, due to a lack of rehabilitation investment and proper management of the system since its construction during the Portuguese colonial period, irrigation water from the scheme (which supplies water by a gravity system and is managed by the state) is limited and unreliable. Even worse, the system was severely damaged by the catastrophic Limpopo river floods in 2000, and has not yet fully recovered. As a result, only 4,000 ha out of 26,000 ha of planned command area are irrigated. We have therefore looked at a wide variation in access to water as well as the extent of modernization within the irrigation scheme.

2.3 Data

The International Rice Research Institute (IRRI) conducted three household surveys in order to collect two-period panel data both in irrigated and in rainfed areas. The first survey, in 2007, was conducted on the Chokwe irrigation scheme in Gaza (Fig. 2.2). For this survey we randomly sampled small and medium-size farmers stratified by tertiary canal, and excluded commercial plantations with a land area larger than 8 ha. After data cleaning 441 of the 451 sample farmers remained. Our sample included farmers who received a rice production management training form Japan International Cooperation Agency (JICA) that was implemented in two water user groups between March 2007 and March 2010. The contents of the program included the training on modern farming practices such as seed selection, seedling

Fig. 2.2 Location of survey districts (Source: IRRI Social Science Division)

preparation, transplanting, fertilizer use, water management, and animal traction. Additionally, the introduction of rice-related businesses, such as a micro finance program for rice farmers and a rice milling service, were also included.

The second 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 data set covering all provinces. We chose Zambézia and Sofala as the provinces representing a rainfed sample. Based on the TIA08 survey, 33 villages in 9 districts, out of 151 villages in 17 districts in these provinces, were identified as rice growing villages. TIA08 sampled around 8 households in each village, generating a sample of 270 farmers in 33 villages. IRRI additionally conducted a detailed rice survey of these sample farmers.

The third round of surveys, conducted in 2011, was undertaken simultaneously in both the irrigated and the rainfed areas. We added a number of detailed questions on rice, the importance of which was recognized after the analysis of the previous round of surveys. The survey team tried their best to identify the sample farmers in the previous round, and collected data from 323 farmers in Chokwe and 212 farmers in Zambézia and Sofala. The attrition rate of each site was 27 % and 21 %, respectively.

2.4 Changes Between 2007/2008 and 2011

This section reviews the changes in production and technologies between the two time periods in each agro-ecological site. Table 2.2 shows the changes in rice production, technology, and water access conditions. The figures for the variables that were not asked in the 2007/2008 round of the survey are missing from the tables. We report not only the changes in the survey plots but also those of the aggregated rice plots, including non-survey plots.[1] This is particularly important for rainfed areas as they have multiple rice plots and expansion of the area is occurring.[2] A contrast is observed in the aggregated cultivated area between the irrigated and the rainfed areas: the former almost fully utilized the entire lowland and thus experienced little change in the size of cultivated area from 1.12 to 1.20 ha; in contrast, the latter increased the size from 0.86 to 1.04 ha (using upper limit figure).

In the irrigated area, paddy production and the yield of the survey parcel went down (from 2.19 tons to 1.9 tons for production and from 2.04 tons per hectare to 1.56 tons per hectare for yield), indicating a declining performance.[3] However, at the JICA training sites the decline was smaller than the others and the gap between the average at the JICA site and the overall average became wider; the ratio changed from 2.64/2.04 = 1.15 to 2.32/1.56 = 1.48. The farmers in the training sites seemed to be able to mitigate adverse effects more effectively. In the rainfed area, although rice cultivation became more active in that the cultivated area of survey parcel expanded from 0.36 to 0.43 ha, it was associated with small yield decline (from 1.00 ton per hectare to 0.80 ton per hectare) and little change in production (from 0.29

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[1] The survey plot is the plot recognized as the most important one by the interviewed household, for which we collected detailed input and output data.

[2] Note that the cultivated area of non-survey plots is based on farmers self-claim and we asked this type of question in different manners for double checking purposes. That being said, we received a wide range of answers as reported in the table. For the survey plot we measured the size with a GPS device.

[3] We compute the yield based on farmers' recall of their harvest. Usually, they reported the harvest in terms of container they used (e.g., bags). We convert their answer to kilograms using a converter. For example, the most common container for rice is a 50 kg bag, which is converted to 38 kg of paddy rice (24 % depreciation).

Table 2.2 Changes in rice production, technology, weather, and irrigation conditions in Mozambique from 2007/2008 to 2011

	Chokwe		Zambézia and Sofala	
	2007	2011	2008	2011
Rice production—aggregated over all rice plots				
Land holding (lowland) (ha.)	1.84	1.80	1.92	1.40
Rice cultivated area (ha.)	1.12	1.20	0.50–0.86	0.60–1.04
Rice production—survey plot				
Rice cultivated area (ha.)	1.12	1.20	0.36	0.43
Paddy production (t)	2.19	1.90	0.29	0.25
Paddy yield (t/ha)	2.04	1.56	1.00	0.80
Paddy yield of JICA training sites (sub-sample) (t/ha)	2.67	2.32		
Rice technology and practice				
Plot with bund (%)	68	98	45	47
Plot subdivided by bund (%)		94		41
Bund height (cm)		28.80		38.75
Bund construction in survey year (%)		97		61
Major variety (name and %)	TIA312, 61 %	TIA312, 74 %	Nene, 16 %	Mamia, 22 %
Transplanting (%)	77	74	28	23
Weather and irrigation				
Drought experienced farmers (%)	53	19	74	65
Flood experienced farmers (%)	3	58	26	12
Insufficient water experienced farmers (%)	14	9		
Too much water experienced farmers (%)	7	13		

tons to 0.25 tons). The possible reasons for these features in irrigated and rainfed areas will be explored later, together with other summary statistics.

The middle part of Table 2.2 shows the adoption of new rice varieties and improved management practices (such as bund construction and transplanting as opposed to direct seeding) which did not change much in either area. In this period, these technologies were not the factors underlying the observed production changes.

The data on weather and irrigation in the irrigated area shows that the farmers suffered drought and irrigation water shortage in 2007, while flood and too much water was the problem in 2011. As we will discover later, water access is the crucial determinant for rice production performance. The fact that the proportion of farmers who claimed insufficient water (14 % in 2007) was lower than that of drought experience (53 % in 2007) in the irrigated area indicates that to some extent, the irrigation system mitigated the impact of weather shocks on water access. The same applies in the case of floods and too much water in 2011. Nevertheless, we will find out later that the scheme can make further improvements on irrigation performance. In the rainfed area, as indicated by the experiences of drought or flooding, weather shocks were more rampant than in Chokwe, which is located in a better agro-ecological zone.

Table 2.3 Changes in price, inputs, income, and profits in Mozambique from 2007/2008 to 2011

	Chokwe		Zambézia and Sofala	
	2007	2011	2008	2011
Price				
Paddy price (MT/kg)	3.97	6.36	6.67	10.83
Wage rate (av. all ag labor works) (MT/day)	45.60	84.50	31.68	44.61
Price of nitrogen (MT/kg)	30.40	57.10		
Tractor rental cost (MT/ha)	1,432	2,800[a]		
Real wage rate (in paddy)	11.80	13.40	5.27	4.40
Real nitrogen price (in paddy)	7.84	9.04		
Real tractor rental cost (in paddy)	369	440		
Input				
Fertilizer (NPK) amount (kg/ha)	21.00	9.63	0.00	0.00
Fertilizer payment, at the time of purchase		0.78		
Fertilizer payment, after harvest		0.14		
Animal use (%)	45	1	1	0
Tractor use (%)	55	0	0	0
Thresher use (%)	7	0	1	0
Family labor input excl. bird scaring (days/ha)	50	94	159	119
Hired labor input excl. bird scaring (days/ha)	34	33	16	16
Income and profit				
Rice income per ha. (MT/ha)	3,771	3,871	5,703	6,770
Rice profit per ha. (MT/ha)	269	−2,173	453	1,797
Total rice income from the survey plot (MT)	3,322	4,992	2,677	6,358

[a]Obtained from secondary source

Table 2.3 shows the changes in prices, inputs, income, and profit between the two periods. We start with a review of the irrigated area. Reflecting the trend in the international rice market, the paddy price at a local market increased over the period. More importantly, however, the wage rate of agricultural labor, the nitrogen price, and tractor rental cost increased at a faster pace, resulting in an increase in the real price of these inputs (the nominal price of the input divided by the paddy price) and the decline in the profitability of rice production. It is worth noting that, for example, on the international markets the fertilizer price increased but at a slower pace than that of rice.[4] Accordingly, a faster increase in input prices must stem from domestic factors. As we will see later, the high input prices seem to be a reason for the stagnation of modernization. An investigation of the domestic input market structure would be an important agenda for future research.

The levels of real input prices (the price divided by the paddy price) have been very high in comparison with those in Asia. For example, from the 1960s to the

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[4] For example, FOB price of Thai rice (A1 Super grade) increased from 272 USD/ton to 466 USD/ton by 71 % from 2007 to 2011, while Arabian Gulf FOB price of urea increased from 310 USD/ton to 400 USD/ton (29 %) in the same period.

2000s the real price of nitrogen in the Philippines was between 2 and 3 with a few exceptional years. The corresponding figure in Mozambique was 7.84 in 2007 and 9.04 in 2011. In this regard, the already high real price of fertilizer in 2007 rose even higher in 2011. This must be the main reason why the low NPK use at 21.00 kg/ha (recommended level of nitrogen, 50 kg/ha) was further reduced to 9.63 kg/ha in 2011. The real rental cost of tractors increased from 369 to 440 and we suspect that a similar increase in prices was seen for animal and threshing machine rental. Accordingly the figures show the disappearance of the use of animals, tractors, and threshing machines, although animal use survived to a small extent. As a substitute for these power sources, family labor input increased remarkably. The use of hired labor, however, changed little presumably due to an increase in the real wage rate. Because of this substitution strategy, the farmers reduced the paid-out cost and ensured slightly higher levels of income, even though they gave up the yield gain (see the lower part of Table 2.3).

An interesting feature observed in 2011 was the emergence of an informal credit arrangement for fertilizer transactions. Amongst fertilizer users the dominant mode of payment was cash at the time of purchase (78 %). Meanwhile, 14 % of users paid for the fertilizer after the harvest. This proportion is higher than for similar arrangements for seed (4 %) or machine/animal (2 %) transactions (not shown in the table). This kind of arrangement is very common in Asia where rice millers or buyers also deal in fertilizer. Thus the access to credit was not the critical bottleneck for the progress of the Green Revolution in Asia (David and Otsuka 1994). Meanwhile, the number of millers and buyers in Africa is limited and they do not usually deal in fertilizer. It is alleged that in Africa credit constraints may not easily be solved. However, our case may indicate that such arrangement can emerge. This is most likely because the production risk is lower and payment after harvest is more credible in the irrigated area.

In the rainfed area, as a net importer of rice, the rice price at local markets became higher than that in the irrigated area (6.67 in 2008 and 10.83 in 2011), reflecting the remoteness of the villages in the rainfed area. Although the nominal wage rate was also higher in the rainfed area, the real wage rate became slightly lower in 2011 due to a faster increase in rice prices, implying an increase in profitability. These changes in the markets could be a significant stimulus to the production increase.

Regarding input use, rice production in the rainfed area relied mostly on family labor with little use of animals or machines and no use of fertilizer in 2008. In 2011 animals, machines and fertilizer were not used at all. Only 9–12 % of the total labor input was hired labor. Under such a production mode the paid-out cost account for only a small portion of total cost and the revenue becomes almost equal to the income. Therefore, despite very low yield, farmers still earn a substantial amount of income. Note that, taking advantage of the rice price increase, the income per hectare increased from 5,703 to 6,770 MT/ha and the total income from 2,677 to 6,358 MT in the rainfed area.

In Table 2.4, we review the conditions of output and factor markets. Even in the irrigated area the number of rice millers and buyers was low. The activeness of a labor market is approximated by the proportion of hired labor. Because landless house-

Table 2.4 Changes in output, labor, and land markets in Mozambique from 2007/2008 to 2011

	Chokwe		Zambézia and Sofala	
	2007	2011	2008	2011
Output market				
Rice miller (number)		0.22		0.05
Rice buyer (number)		0.44		0.17
Labor market				
Proportion of hired labor (%)	33	22	9	12
Exchange labor for crop establishment[a] (%)			9	
Hired labor for crop establishment[a] (%)			26	
Exchange labor for harvesting[a] (%)			14	
Hired labor for harvesting[a] (%)			26	
Land transaction				
How land obtained (%)				
From traditional/formal authority		56	6	8
From relative		5	22	17
Rent-in or borrow		12	10	8
Occupied		2	22	24
Purchased		0	14	20
Inherited		23	26	24
Others		0	0	0
Proportion of rented-in plot of all rice plots (%)		2	12	5

[a] Data are from the village level questionnaire

holds are not common -a remarkable difference between Mozambique and Asia – hired labor is not the major source of power.[5] With regard to the land rental market, only 2 % of rice plots in the irrigated area were rented by the farmers in 2011. In the rainfed areas the figures were 12 % in 2008 and 5 % in 2011. In summary, both the agricultural labor and the land rental markets were very thin in Mozambique.

Lastly we examine the changes in household characteristics (Table 2.5). Among human capital and other asset endowments, the number of working age household members changed little in both areas. The average number of years of schooling increased slightly. In the rainfed area the number of cattle increased. With regard to welfare, the figures from the irrigated area show that households experienced an improvement in their asset position. Non-agricultural job opportunities did not improve considerably, as indicated by the rather declining proportions of salary or cash earners.

Summarizing the features discussed above, the changes in rice production have been schematically summarized in Fig. 2.3. The graph shows the production function of rice with only the land size dimension of input on the horizontal axis. The change in the rainfed area is characterized as an area expansion with little

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[5] For example, in the Philippines the proportion was 49 % in 1966 and 71 % in 1976 in Laguna, and 60 % in 1967 and 43 % in 1971 in Central Luzon. In Tamil Nadu, India, the proportion was 73 % in 1971.

Table 2.5 Changes in household characteristics in Mozambique from 2007/2008 to 2011

	Chokwe		Zambézia and Sofala	
Household characteristics	2007	2011	2008	2011
No. of working age members	4.1	3.7	2.2	2.5
Female-headed HH (%)	34	38	23	23
Head's schooling years	2.90	2.69	3.07	3.06
Average schooling years	4.03	4.44	3.02	3.32
Credit experience in survey year (% of farmers)	6	7	2	3
Extension service, received in survey year (% of farmers)	39	17	8	17
Value of asset (MT)	35,977	61,914		6,544
Cattle number	3.14	3.54	0.07	0.21
Proportion of salary earner in a family (%)	16	9	9	6
Proportion of cash earner in a family (%)	23	21	24	17

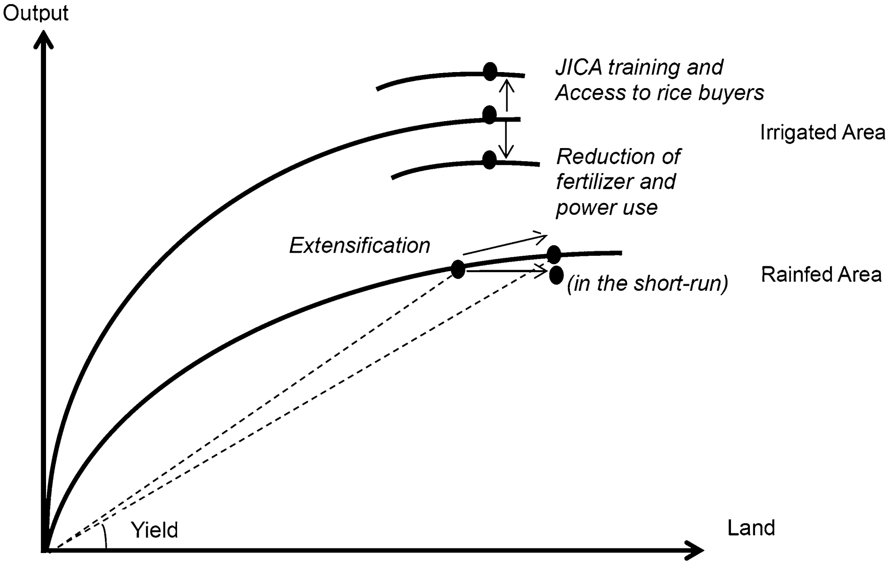

Fig. 2.3 The change in rice production due to land expansion in irrigated area and rainfed area

progress in technology adoption (no shift in the production curve). Hence, the expected outcome is a production increase with more land but at a lower yield. The main reason for change in this direction during our survey period could be the stimulus created by the sharp increase in the local rice price. In the expansion process, some farmers would have started rice cultivation in the lowland, which had not yet been used for rice. If this was the case, some lowland parcels may not have been fully prepared for rice cultivation in the survey year, particularly where the plot was in a remote area or where the environmental conditions of the plot were very severe.

Under such a transition process a newly expanded area might not be able to achieve its potential yield and farmers may even fail to harvest any rice crop. This situation could have resulted in, on average, an insignificant or a marginal increase in output (in the short-run) and may have made the low yield in the rainfed area even lower.

Meanwhile, in the irrigated area (the upper production function), as a result of the adverse effect of increases in the real price of fertilizer and machinery, the use of these inputs was reduced and, accordingly, land productivity declined. This situation resulted in a yield decline from 2008 to 2011. However, those farmers who were trained by JICA could mitigate these adverse and maintain a high yield. In the following sections we statistically examine these propositions.

2.5 Methodology

We have taken different estimation approaches between the irrigated and the rainfed areas. Table 2.6 shows the transition matrix of rice cultivation where the figures indicate the number of rice cultivators or non-cultivators in each survey round. The matrix of the irrigated area indicates that only 76 farmers cultivated rice in both years, while 56 did not and 52 started/resumed in 2011. Our field observations show that farmers make decisions of rice cultivation each year based on their expectations about water availability from irrigation as well as other constraints. If they decide not to cultivate rice, they either allow the land to lie fallow, or they cultivate vegetables or less-water demanding crops – usually at a small portion of the parcel. We therefore begin by estimating the determinants of rice cultivation by year. We then go on to estimate the determinants of rice production performance among the rice cultivators. The most important performance indicator in the irrigated area is yield. In addition, we estimate the determinants of the use of major inputs such as fertilizer, labor, animal power, and tractors.[6]

Table 2.6 Rice cultivator transition matrix in Mozambique

		2011		
Chokwe		Cultivator	Non-cultivator	Total
2007	Cultivator	76	56	132
	Non-cultivator	52	139	191
Total		128	195	323

		2011		
Zambézia and Sofala		Cultivator	Non-cultivator	Total
2008	Cultivator	195	15	210
	Non-cultivator	1	0	1
Total		196	15	211

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[6] The use of thresher in 2007 is not estimated because only 7 % of the farmers used it. Tractor use and thresher use in 2011 are not estimated because farmers used neither method at all.

In the rainfed areas, most of the farmers who cultivated rice in 2008 also cultivated rice in 2011 (195 out of 211 farmers). Additionally, our descriptive tables indicate that what occurred in the area was not a structural change associated with technology adoption but rather an adjustment of resource use with the same technology set. Therefore, taking advantage of the panel structure we apply household fixed effect models to estimate the determinants of rice production performance. To capture the extensification process, the main performance indicators in the rainfed area are: the area cultivated, the output, and the yield of the entire rice parcels including non-survey parcels. As it is related to the yield, we also estimate the size of the fallowed land area.

2.6 Analysis of the Chokwe Irrigation Scheme

2.6.1 Determinants of Rice Cultivation

We apply a Probit model to estimate the equation of a binary dependent variable which becomes one for a rice cultivator and zero otherwise. The explanatory variables include: (1) credit access (the dummy of credit use in the survey year); (2) extension service (the dummy of service received in the survey year); (3) labor endowment (the number of working-age household members, the average number of schooling years, a female headed household dummy, the proportion of salary earners); (4) land endowment (total landholdings); (5) power source endowment (the number of cattle owned); and (6) water access (downstream dummy, drought dummy, and flood dummy). In order to capture differential impacts of water access shocks in the irrigated area, we include interaction terms of the downstream dummy with the drought dummy or the flood dummy. Since access to credit and access to the extension service are possibly endogenous variables, we estimate additional models by replacing these two variables with the value of assets and travel time to the nearest town – assuming that they are given to the household for the short term at least.

Firstly, the results in Table 2.7 clearly indicate the importance of water access. In 2007 (a year of severe drought), the coefficient of the drought dummy is negative and highly significant but its interaction term with the downstream dummy is not so. Meanwhile, in 2011 when the drought was mild, only the downstream farmers who were affected by the drought (i.e., interaction term of drought and downstream) had to give up rice cultivation. This indicates that unless weather shocks are severe, an improvement in the capacity of a system and stricter water management would reduce the number of downstream farmers who have to give up their rice cultivation.

Another interesting finding is that credit was important in 2007 but not so in 2011. Possible reasons for this change will be discussed later in this chapter. Access to extension services was influential in both years, implying the usefulness of knowledge about modern rice production management in the irrigated area.

Table 2.7 Probit analysis of rice cultivation in 2007 and 2011, Chokwe irrigation scheme in Mozambique

	Dep. var.: Rice cultivation=1			
	2007		2011	
Credit use in survey year	1.409***		0.257	
	(2.817)		(0.804)	
Extension service received	0.437***		0.456**	
	(2.722)		(2.206)	
Value of assets		−4.82e-07		−4.86e-07
		(−0.413)		(−0.630)
Travel time to the nearest town		−0.00747**		−0.00240
		(−2.316)		(−0.938)
No of working age HH members	−0.00338	−0.0174	−0.0212	−0.0319
	(−0.0939)	(−0.474)	(−0.552)	(−0.819)
Ave. schooling years	−0.00507	0.00401	0.0404	0.0352
	(−0.130)	(0.0948)	(1.222)	(1.010)
Female-headed HH dummy	−0.0126	0.0327	0.0622	0.0649
	(−0.0759)	(0.193)	(0.375)	(0.396)
HH head age	−0.00658	−0.00569	−0.00329	−0.00270
	(−1.262)	(−1.021)	(−0.960)	(−0.789)
Total land holdings	0.101**	0.148***	0.155***	0.170***
	(2.449)	(3.700)	(3.813)	(4.218)
No of cattle, owned	−0.0194*	−0.0164	0.000870	0.00607
	(−1.670)	(−1.182)	(0.120)	(0.709)
Prop of salary earners	−1.213**	−1.376**	−0.178	−0.0562
	(−2.059)	(−2.305)	(−0.286)	(−0.0905)
Downstream dummy	−0.481	−0.647**	−0.105	−0.122
	(−1.555)	(−2.067)	(−0.310)	(−0.363)
Drought experience dummy	−0.458***	−0.533***	0.0113	0.0550
	(−2.606)	(−3.068)	(0.0515)	(0.254)
Drought*downstream	0.124	0.348	−0.950*	−0.961*
	(0.297)	(0.807)	(−1.776)	(−1.813)
Flood experience dummy	−0.104	−0.192	0.277	0.302*
	(−0.243)	(−0.456)	(1.629)	(1.780)
Flood*downstream[a]			0.534	0.556
			(1.257)	(1.314)
Constant	0.235	0.650	−0.790***	−0.641**
	(0.601)	(1.576)	(−2.781)	(−2.155)
Observations	323	303	323	321

The numbers in parentheses are *z*-statistics

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

[a] Not included in 2007 regression due to the drop of two observations by the perfect prediction by this variable

2.6.2 Determinants of Rice Production Performance

The composition of explanatory variables is slightly different from the previous model. Firstly, we replaced household-level water condition variables (the drought dummy and the flood dummy) with the plot-level ones (the insufficient water dummy and the too-much water dummy). Secondly, we included the dummy of those who received JICA training. Thirdly, in the second round of our survey we collected information about access to rice-related markets such as the number of accessible rice buyers, rice millers, and seed sellers. This information is included in the analysis of the 2011 data. As these variables are missing for some of the farmers, to check for robustness we also ran models without these new variables.

Table 2.8 shows the estimation results in 2007. They indicate that the farmers in the downstream area or those suffering from insufficient irrigation achieved a lower yield in the severe drought year. We would like to stress again the importance of access to water. In 2007, the use of chemical fertilizer was positively associated with credit use in a structural form or with the value of assets in the reduced form regression. This indicates the importance of having cash in hand in order to purchase the fertilizer. The negative influence of insufficient water on the use of chemical fertilizer indicates a complementary effect between the two. The number of working-age household members is significant in the total (i.e., the sum of family and hired) labor input function. This implies the existence of allocative inefficiency due to inactive factor markets, because if household with a shortage of labor were able to hire as much labor as they wished, the household level labor endowment would not have a significant effect on labor input. The likelihood that animals will be used increases among those who own more cattle. The access to credit looks to be important for tractor use; however, the result is not robust as the asset variable in the alternative model is not significant.

It is critically important to find that the JICA training dummy is significant in the structural form model in relation to total labor hours. This dummy is also significant in the reduced form yield function, indicating that the yield is about 0.7 tons per hectare higher at the training sites. This is presumably due to the implementation of more labor-intensive farming practices at the project sites. Note, however, that since this is the result for the year that the project started, we cannot yet be sure of the sustainability of this impact.

The results in 2011 are reported in Table 2.9. The corresponding results with the full sample excluding the newly collected variables are placed in the Appendix Table 2.11. Since the qualitative results are the same, our discussion relies on the results in Table 2.9. An important change from the 2007 results is that the impact of the JICA training becomes greater and more robust in 2011. First, the impact on yield became greater and the coefficients became significant both in structural and reduced forms. The model predicts that the trained groups can achieve a yield that is higher by about 1 ton per hectare. Second, this dummy is also significant in the animal use function, both in structural and reduced forms. This indicates that among other things the animal traction component was practically effective and was

Table 2.8 Determinants of paddy yield, fertilizer application, labor input, animal use, and tractor use in 2007, Chokwe irrigation scheme in Mozambique

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Variables	Paddy yield	Paddy yield	NPK amount	NPK amount	Total labor hrs	Total labor hrs	Animal use dummy	Animal use dummy	Tractor use dummy	Tractor use dummy
Credit use in survey year	–0.333		11.34*		28.86		–0.0697		0.241*	
	(–1.038)		(1.776)		(1.136)		(–0.517)		(1.878)	
Extension service, received	0.0602		–2.396		–20.96		–0.0226		0.0627	
	(0.268)		(–0.535)		(–1.176)		(–0.239)		(0.695)	
Value of assets		1.42e-06		0.000103***		0.000195		–6.52e-07		2.36e-07
		(0.805)		(3.067)		(1.358)		(–0.884)		(0.329)
Travel time to the nearest town		–0.00173		–0.000635		–0.440		–0.00182		–0.000590
		(–0.326)		(–0.00625)		(–1.019)		(–0.819)		(–0.272)
No of working age HH members	0.0388	0.0356	–1.250	–1.524	20.67***	21.35***	–0.00424	0.0103	0.0411*	0.0290
	(0.703)	(0.605)	(–1.138)	(–1.354)	(4.729)	(4.459)	(–0.183)	(0.420)	(1.857)	(1.208)
Ave. schooling years	0.108*	0.103	1.590	0.811	2.408	–2.097	–0.0495**	–0.0514*	0.0505**	0.0540**
	(1.849)	(1.574)	(1.363)	(0.651)	(0.519)	(–0.395)	(–2.013)	(–1.882)	(2.152)	(2.032)
Female-headed dummy	–0.0901	–0.0109	–2.312	0.660	–21.55	–15.28	–0.0832	–0.0536	0.00577	–0.0224
	(–0.388)	(–0.0453)	(–0.499)	(0.144)	(–1.171)	(–0.781)	(–0.853)	(–0.532)	(0.0619)	(–0.229)
HH Head age	–0.000849	0.00346	0.284*	0.427**	–0.882	–0.808	0.000322	0.000319	0.000247	0.00120
	(–0.105)	(0.385)	(1.758)	(2.478)	(–1.372)	(–1.102)	(0.0945)	(0.0845)	(0.0759)	(0.326)
Total land holdings	–0.00169	–0.0266	2.452**	3.050***	–2.881	–2.752	–0.0254	–0.0268	0.00892	0.0206
	(–0.0327)	(–0.526)	(2.376)	(3.156)	(–0.702)	(–0.670)	(–1.168)	(–1.267)	(0.429)	(1.002)
No of cattle owned	0.0324	0.0350*	–0.0152	–0.225	–1.924	–2.762*	0.0153*	0.0141*	0.000762	0.00112
	(1.626)	(1.774)	(–0.0384)	(–0.596)	(–1.218)	(–1.719)	(1.831)	(1.702)	(0.0953)	(0.140)
Prop of salary earners	–0.734	–0.477	2.952	–15.60	–30.67	–39.79	0.358	0.402	0.00643	–0.0847
	(–0.877)	(–0.540)	(0.177)	(–0.923)	(–0.462)	(–0.554)	(1.019)	(1.087)	(0.0191)	(–0.235)

Downstream dummy	−0.718*	−0.678*	−10.79	−10.21	41.35	43.15	0.184	0.230	−0.248*	−0.349**
	(−1.975)	(−1.804)	(−1.489)	(−1.420)	(1.435)	(1.411)	(1.204)	(1.460)	(−1.698)	(−2.277)
Insufficient irrigation	−0.830**	−0.844**	−16.93**	−12.33*	−4.885	2.658	0.121	0.117	0.0947	0.109
	(−2.510)	(−2.531)	(−2.569)	(−1.933)	(−0.186)	(0.0980)	(0.868)	(0.838)	(0.714)	(0.803)
Insufficient* downstream	0.345	0.214	−8.204	−8.533	−30.02	−28.18	−0.202	−0.276	0.520	0.645
	(0.354)	(0.220)	(−0.422)	(−0.459)	(−0.388)	(−0.356)	(−0.492)	(−0.678)	(1.328)	(1.627)
Too much irrigation water	−0.209	−0.0870	1.353	7.009	−36.18	−21.07	0.110	0.168	−0.296	−0.423**
	(−0.455)	(−0.182)	(0.148)	(0.765)	(−0.992)	(−0.541)	(0.571)	(0.840)	(−1.601)	(−2.165)
Too much*downstream	−1.062	−1.364	−6.097	−17.28	−31.07	−47.53	0.390	0.254	0.00462	0.160
	(−0.774)	(−0.974)	(−0.223)	(−0.645)	(−0.286)	(−0.417)	(0.676)	(0.434)	(0.00838)	(0.280)
JICA training WUG dummy	0.453	0.657*	−2.798	−3.762	46.36*	44.51	0.0993	0.00646	−0.190	−0.123
	(1.352)	(1.839)	(−0.419)	(−0.550)	(1.747)	(1.530)	(0.705)	(0.0432)	(−1.412)	(−0.847)
Constant	1.703***	1.495**	1.910	−5.957	61.77	73.63	0.633***	0.639***	0.123	0.172
	(3.280)	(2.577)	(0.185)	(−0.537)	(1.501)	(1.560)	(2.899)	(2.628)	(0.592)	(0.726)
Observations	132	125	132	125	132	125	132	125	132	125
R-squared	0.201	0.238	0.196	0.279	0.213	0.232	0.122	0.150	0.198	0.192

The numbers in parentheses are *t*-statistics
***, **, and * indicate significance at 1, 5, and 10 %, respectively

Table 2.9 Determinants of paddy yield, fertilizer application, labor input, and animal use in 2011, Chokwe irrigation scheme in Mozambique (sub-sample)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	Paddy yield	Paddy yield	NPK amount	NPK amount	Total labor hrs	Total labor hrs	Animal use dummy	Animal use dummy
Credit use in survey year	0.660		–3.631		83.79*		0.0845***	
	(1.490)		(–0.569)		(1.954)		(3.126)	
Extension service, received	0.000372		1.142		5.768		0.00449	
	(0.00115)		(0.244)		(0.184)		(0.227)	
Value of assets		2.49e-06		–1.42e-05		–0.000119		–2.87e-09
		(1.211)		(–0.481)		(–0.589)		(–0.0217)
Travel time to the nearest town		–0.00276		–0.0444		–0.619		6.24e-05
		(–0.469)		(–0.529)		(–1.081)		(0.166)
No of working age HH members	0.0393	0.00683	–1.152	–0.918	24.42***	21.72***	–0.00281	–0.00574
	(0.487)	(0.0818)	(–0.991)	(–0.764)	(3.125)	(2.651)	(–0.571)	(–1.066)
Ave. schooling years	0.0652	0.0697	0.837	0.990	–10.05*	–7.571	–0.000509	–0.000191
	(1.047)	(1.038)	(0.933)	(1.023)	(–1.667)	(–1.149)	(–0.134)	(–0.0442)
Female-headed dummy	–0.436*	–0.430*	–7.562**	–7.472**	–14.42	–19.30	–0.00950	–0.0133
	(–1.874)	(–1.808)	(–2.271)	(–2.201)	(–0.644)	(–0.834)	(–0.673)	(–0.878)
HH Head age	0.000529	0.00170	0.0703	0.0720	–0.596	–0.443	0.000113	0.000204
	(0.0855)	(0.274)	(0.789)	(0.807)	(–0.996)	(–0.728)	(0.299)	(0.511)
Total land holdings	–0.000352	0.00279	1.698*	1.575*	–22.11***	–19.96***	–0.00178	0.000451
	(–0.00558)	(0.0442)	(1.881)	(1.747)	(–3.642)	(–3.249)	(–0.465)	(0.112)
No of cattle owned	0.00821	–0.00736	–0.104	–0.0389	–0.214	0.00104	0.00107	0.000812
	(0.488)	(–0.374)	(–0.430)	(–0.137)	(–0.131)	(0.000539)	(1.044)	(0.640)
Prop of salary earners	1.273	1.352	–18.76	–18.32	191.5*	216.3*	0.245***	0.250***
	(1.133)	(1.154)	(–1.158)	(–1.086)	(1.759)	(1.882)	(3.569)	(3.317)

Downstream dummy[a]	−0.311	−0.351	−8.738	−9.743*	60.73	49.15	−0.00633	−0.00976
	(−0.798)	(−0.892)	(−1.554)	(−1.718)	(1.607)	(1.272)	(−0.266)	(−0.384)
Insufficient irrigation[a]	−0.0472	−0.0848	−7.864	−8.295	101.1**	84.09*	−0.00133	−0.0109
	(−0.103)	(−0.183)	(−1.190)	(−1.247)	(2.275)	(1.855)	(−0.0474)	(−0.367)
Too much irrigation water	−0.287	−0.252	−5.533	−6.150	−66.61	−75.05*	−0.0188	−0.0253
	(−0.609)	(−0.536)	(−0.836)	(−0.929)	(−1.496)	(−1.665)	(−0.668)	(−0.853)
Too much*downstream	−0.500	−0.222	7.645	8.657	−13.32	−0.311	0.0186	0.0219
	(−0.472)	(−0.206)	(0.503)	(0.560)	(−0.130)	(−0.00296)	(0.289)	(0.317)
JICA training WUG dummy	1.132***	0.913**	−2.118	−2.723	26.23	10.87	0.0631**	0.0590**
	(2.850)	(2.209)	(−0.370)	(−0.458)	(0.682)	(0.268)	(2.603)	(2.216)
Rice experience years	0.00440	0.00470	−0.0442	−0.0208	0.898	0.748	0.00113	0.000983
	(0.379)	(0.397)	(−0.264)	(−0.122)	(0.800)	(0.645)	(1.594)	(1.292)
No of accessible rice buyers	0.562***	0.599***	9.048***	8.967***	−5.159	−4.599	−0.0109	−0.0104
	(2.810)	(2.958)	(3.147)	(3.078)	(−0.267)	(−0.232)	(−0.897)	(−0.797)
No of accessible rice millers	0.691**	0.804**	−2.829	−2.596	25.21	26.08	−0.0226	−0.0208
	(2.141)	(2.374)	(−0.612)	(−0.537)	(0.811)	(0.792)	(−1.153)	(−0.960)
No of accessible seed sellers	0.127	0.0647	3.378	4.043	21.88	29.71	0.00986	0.0132
	(0.367)	(0.179)	(0.688)	(0.791)	(0.663)	(0.853)	(0.474)	(0.575)
Constant	0.579	0.699	6.775	7.347	118.1**	145.2**	−0.0268	−0.0154
	(1.137)	(1.230)	(0.925)	(0.903)	(2.397)	(2.619)	(−0.862)	(−0.423)
Observations	123	121	124	122	124	122	124	122
R-squared	0.305	0.309	0.230	0.233	0.280	0.259	0.254	0.175

The numbers in parentheses are *t*-statistics

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

[a] Insufficient*downstream is not included due to perfect collinearity with the other variables

therefore remained adopted to help improve yield. Note also that our survey was conducted a year after the completion of the project, which implies the sustainability of the impact of this component.

Another interesting contrast to the 2007 results is that the use of credit and the value of assets are no longer associated with the use of chemical fertilizer. A possible reason for this is the emergence of post-harvest payment arrangements. This idea is supported by a positive and significant coefficient of the number of accessible rice buyers who may be the ones to accept such a payment arrangement. It should, however, be noted that the insignificant effect of credit may simply be due to the fact that the demand for fertilizer decreased when its price increased in 2011. Since the fertilizer is a crucial factor for yield improvement, a further investigation is worthwhile. The number of working-age household members is still highly significant in the total labor input function, indicating that the inactive labor market has remained.

2.7 Determinants of Rice Cultivation Performance in the Rainfed Area

Table 2.10 presents the results of household-level fixed-effect models on the determinants of rice production performance. We make a few remarks about the differences between this and the analysis of the irrigated area data. Firstly, because our

Table 2.10 Determinants of rice cultivated area, output, and yield in 2008 and 2011, Zambézia and Sofala in Mozambique (HH fixed-effect model)

Variables	Cultivated area	Paddy output	Paddy yield	Fallowed lowland size
Land holding (lowland)	0.132***	0.0265**	–0.0680**	0.0312***
	(7.448)	(2.126)	(–2.583)	(3.441)
No. of working household members	0.0456	–0.0153	–0.108	0.0290
	(0.872)	(–0.414)	(–1.380)	(1.078)
Village paddy price	0.0180*	0.00160	–0.0559***	–0.00609
	(1.597)	(0.201)	(–3.334)	(–1.055)
Drought experience dummy	–0.00484	–0.122	–0.444***	0.0357
	(–0.0433)	(–1.542)	(–2.663)	(0.622)
Flood experience dummy	–0.116	0.191**	0.281	0.0266
	(–0.937)	(2.193)	(1.527)	(0.419)
Constant	0.0991	0.484***	2.131***	–0.0278
	(0.496)	(3.434)	(7.164)	(–0.271)
Observations	390	390	390	390
R-squared	0.232	0.070	0.142	0.074
Number of hhid	195	195	195	195

The numbers in parentheses are *t*-statistics

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

focus in the rainfed area is on the extensification process, the dependent variables measure the levels or amounts aggregated over all rice plots, rather than those of survey plot only. Secondly, we exclude the explanatory variables that are employed mainly to explain the adoption of modern technologies because this aspect has not emerged in the rainfed area. An advantage of this treatment is that our models become less likely to suffer endogenous variable problems.[7] Thirdly, in order to capture the price effect, we include the village-level paddy price. In contrast to the data from one irrigation scheme, we have wide geographical price variations in the rainfed area. The available data points for input prices and wage rates are too few because no modern input is used and most of the farmers rely solely on family labor in the rainfed area. We therefore decided not to use these as explanatory variables in our estimation models.

The results show that the cultivated area becomes larger with a greater land endowment and where the paddy price is higher. Our expectation based on Fig. 2.3 is that these two key determinants affect the paddy output in the same manner. Although both have correct signs (i.e., positive signs), only the coefficient of landholding is statistically significant in the paddy output model. This is probably because the area expanded with the price stimulus has yet contributed much to the total output. Figure 2.3 predicts that yield decreases with the expansion of the area if the process is at the extensification stage. The coefficient of the landholding size and that of the price in the yield function have negative signs in the yield regression. The last column shows that the larger the land endowment, the greater the chance of land being put to fallow. The large landholders have room to selectively cultivate their parcels depending on the agronomic, weather, and market condition of each parcel in a particular season. If they cultivated favorable plots of land that season, yield would not largely decline. This could reduce a negative impact on paddy yield among the large landholders.

2.8 Impact of Rice Sector Development on Household Welfare

Our ultimate goal is to identify pathways for welfare improvement and poverty reduction among Mozambican farmers. Can the acceleration of rice sector development contribute to this goal? Figs. 2.4 and 2.5 present non-parametric regression curves on X-Y diagram, where Y measures welfare and X measures rice production performance.[8] The welfare is measured either by the rice income per household member in panel (a), or by the log of non-agricultural asset values per household member in panel (b). The performance indicator in the irrigated area is paddy yield

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[7] The variables excluded are average schooling years, number of cattle, credit use, extension service received, and proportion of salary earners.

[8] We use a locally weighted scatterplot smoothing method setting bundwidth at 0.8.

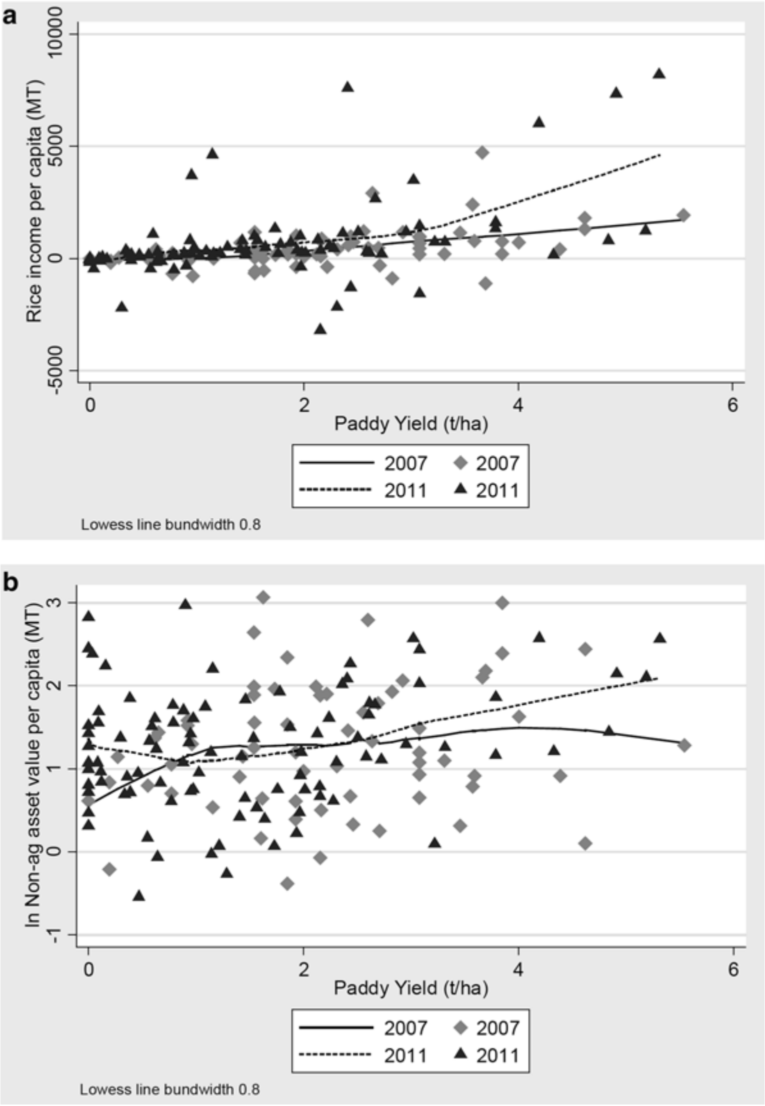

Fig. 2.4 Relationship of paddy yield with (**a**) rice income per capita or (**b**) non-agricultural asset values per capita in Chokwe irrigation scheme in Mozambique

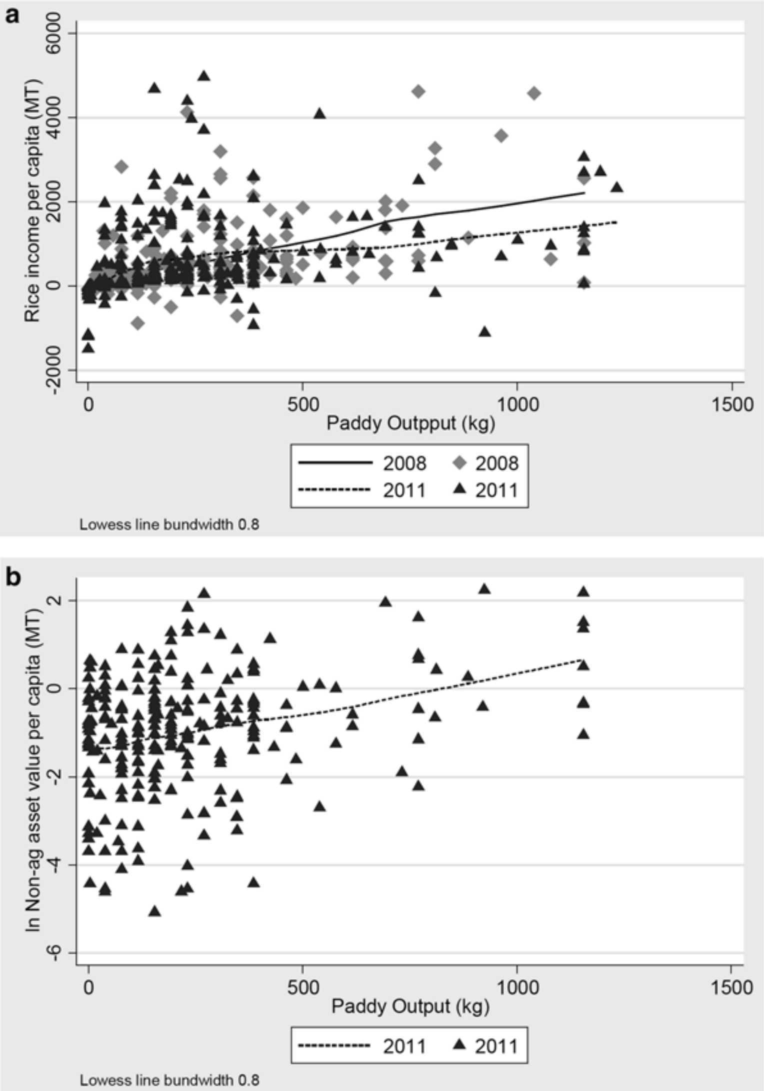

Fig. 2.5 Relationship of paddy output with (**a**) rice income per capita or (**b**) non-agricultural asset values per capita in Zambézia and Sofala in Mozambique

and it is paddy output in the rainfed area. There is only asset data for the rainfed for 2011. All figures show a positive association globally, supporting rice as a strategically important commodity for the improvement of farmers' welfare.

2.9 Concluding Remarks

Our analyses of a rice farmer panel data set collected in 2007/2008 and 2011 identify the constraints on Mozambique's rice sector development. In reaction to the increase in paddy prices, the farmers in the rainfed area are approaching to marginal land of their land frontier, experiencing lowering yield. Most of the farmers in the rainfed area had been relying solely on family labor for their rice production with little use of modern seeds, inputs, animals, and machines. Further increases in rice production in the rainfed area should come from a shift of their production mode from extensification to intensification through the introduction of land saving technologies. One of these technologies is the irrigation development.

Lessons from the Chokwe irrigation scheme are useful for this purpose. Assuring water access through proper irrigation system management is crucially important because timely water application not only directly increases output but also indirectly through its impact on the returns to chemical fertilizer use. An obvious pathway to intensification therefore is the investment in irrigation facilities. Strengthening marketing system is also important judging from the fact that a recent increase in real prices of modern inputs such as fertilizer and tractors made the farmers substitute family labor for modern inputs, that is, the recurrence of traditional farming. The finding that the farmers with access to many rice buyers kept using chemical fertilizer also suggests the importance of marketing. Another critical finding of our analysis is that the farmers who received a rice production management training program achieved a high yield with the use of animal traction. These findings suggest that management training and market development are important for recapturing the momentum of modernization, particularly if irrigation water is available.

Appendix

Table 2.11 Determinants of paddy yield, fertilizer application, labor input, and animal use in 2011, Chokwe irrigation scheme in Mozambique

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	Paddy yield	Paddy yield	NPK amount	NPK amount	Total labor hrs	Total labor hrs	Animal use dummy	Animal use dummy
Credit use in survey year	0.760		−1.800		86.97**		0.0781***	
	(1.621)		(−0.280)		(2.106)		(2.997)	
Extension service, received	0.0861		0.223		7.595		0.00898	
	(0.256)		(0.0485)		(0.257)		(0.482)	
Value of assets		2.64e-06		−1.36e-05		−9.57e-05		2.71e-08
		(1.265)		(−0.477)		(−0.515)		(0.224)
Travel time to the nearest town		−0.00448		−0.0110		−0.648		−6.07e-06
		(−0.746)		(−0.135)		(−1.217)		(−0.0274)
No of working age HH members	−0.0152	−0.0659	−1.367	−1.112	24.94***	21.45***	−0.00321	−0.00630
	(−0.181)	(−0.763)	(−1.185)	(−0.942)	(3.369)	(2.791)	(−0.690)	(−1.256)
Ave. schooling years	0.0630	0.0585	0.687	0.975	−10.77*	−8.687	−0.00137	−0.00124
	(0.972)	(0.829)	(0.772)	(1.011)	(−1.886)	(−1.385)	(−0.381)	(−0.303)
Female-headed dummy	−0.285	−0.287	−8.466**	−8.507**	−9.587	−14.02	−0.0111	−0.0141
	(−1.190)	(−1.176)	(−2.585)	(−2.561)	(−0.456)	(−0.649)	(−0.842)	(−1.001)
HH Head age	0.00334	0.00493	0.0903	0.0895	−0.690	−0.527	0.000158	0.000255
	(0.523)	(0.771)	(1.028)	(1.023)	(−1.224)	(−0.927)	(0.452)	(0.688)
Total land holdings	0.00211	0.0191	2.119**	2.035**	−20.74***	−18.03***	−0.00149	0.000866
	(0.0323)	(0.293)	(2.373)	(2.295)	(−3.620)	(−3.127)	(−0.412)	(0.230)

(continued)

Table 2.11 (continued)

Variables	(1) Paddy yield	(2) Paddy yield	(3) NPK amount	(4) NPK amount	(5) Total labor hrs	(6) Total labor hrs	(7) Animal use dummy	(8) Animal use dummy
No of cattle owned	0.0162	0.000613	0.0347	0.0908	−0.260	−0.0463	0.000663	0.000293
	(0.930)	(0.0302)	(0.145)	(0.327)	(−0.169)	(−0.0257)	(0.684)	(0.249)
Prop of salary earners	1.456	1.844	−21.52	−23.14	181.1*	213.2*	0.221***	0.233***
	(1.249)	(1.521)	(−1.345)	(−1.395)	(1.764)	(1.975)	(3.415)	(3.370)
Downstream dummy	−0.243	−0.282	−8.028	−8.502	70.59*	60.12	−0.00266	−0.00605
	(−0.592)	(−0.683)	(−1.425)	(−1.502)	(1.953)	(1.633)	(−0.117)	(−0.251)
Insufficient irrigation	−0.385	−0.455	−5.793	−6.305	86.83**	69.84*	−0.000928	−0.00944
	(−0.831)	(−0.974)	(−0.912)	(−0.987)	(2.130)	(1.681)	(−0.0361)	(−0.348)
Too much irrigation water	−0.411	−0.391	−4.511	−4.835	−60.52	−67.01	−0.0151	−0.0198
	(−0.872)	(−0.830)	(−0.721)	(−0.778)	(−1.507)	(−1.657)	(−0.598)	(−0.751)
Too much*downstream	−0.450	−0.228	1.919	1.980	−39.66	−29.33	0.0206	0.0251
	(−0.451)	(−0.229)	(0.141)	(0.146)	(−0.455)	(−0.332)	(0.376)	(0.436)
JICA training WUG dummy	0.849**	0.677*	−2.397	−2.684	32.27	17.36	0.0585***	0.0533**
	(2.201)	(1.699)	(−0.453)	(−0.493)	(0.950)	(0.490)	(2.732)	(2.316)
Constant	0.990**	1.222**	9.289	8.652	137.6***	166.8***	−0.0129	−0.000961
	(1.988)	(2.194)	(1.360)	(1.139)	(3.141)	(3.377)	(−0.467)	(−0.0311)
Observations	128	126	129	127	129	127	130	128
R-squared	0.141	0.140	0.131	0.135	0.265	0.243	0.217	0.144

The numbers in parentheses are *t*-statistics
***, **, and * indicate significance at 1, 5, and 10 %, respectively

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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(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

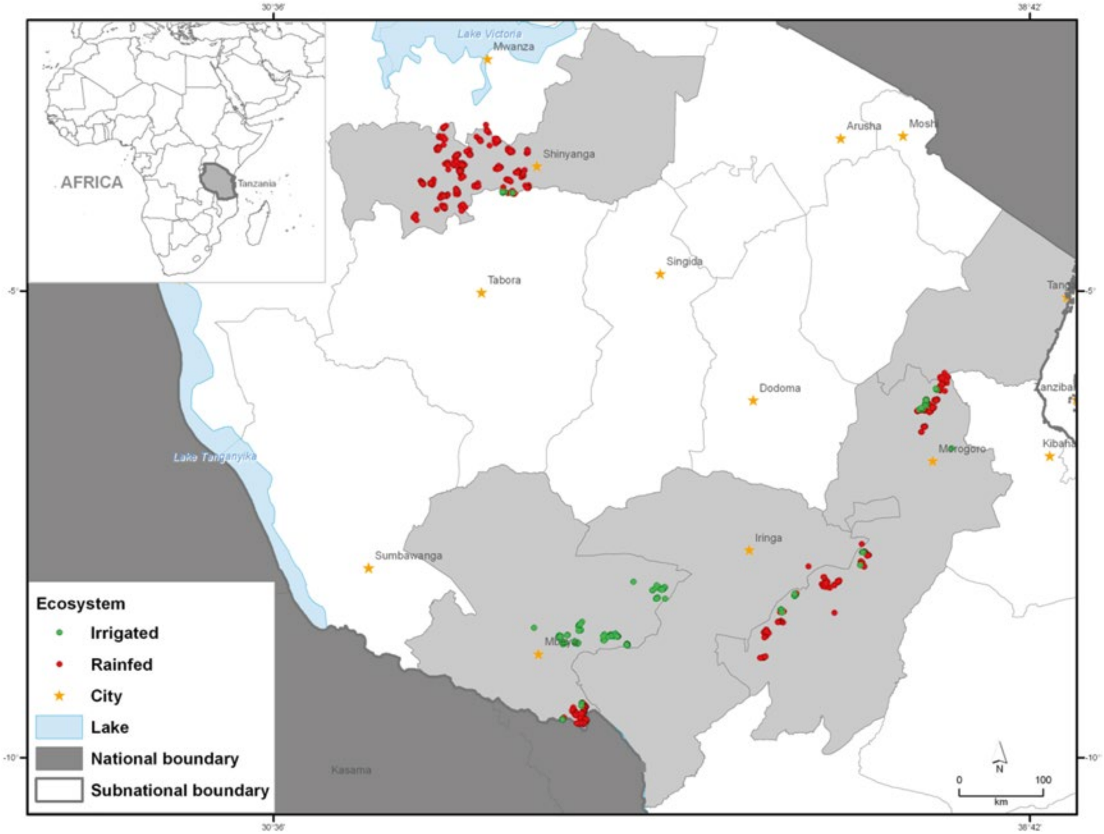

Fig. 3.1 Regions covered by extensive survey and location of the sample plots in Tanzania, by irrigation status

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 $p(x) = p(w = 1 \mid \mathrm{x})$. By using inverse probability weight 1/p(x), ATE can be defined as

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

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:

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

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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Chapter 4
On the Possibility of Rice Green Revolution in Rainfed Areas in Uganda: Impact Evaluation of a Management Training Program and Guidebook Distribution

Yoko Kijima

Abstract After providing an overview of rice sector development in Uganda, this chapter examines the effects of two technology dissemination programs on the enhancement of rice production in Eastern and Northern Uganda. One program was a JICA conventional training program that provided on-the-job training at demonstration plots three to four times a year, while the other was to distribute a rice cultivation guidebook to households that were randomly selected. The training program was shown to have improved rice productivity significantly. In contrast, there were no significant effects of the distribution of the guidebook on technology adoption or rice production. Although the distribution of the guidebook was less costly and easier to implement than the training program, distribution of the guidebook alone cannot be a substitute for conventional training programs.

Keywords Rice production • Uganda • Program evaluation • Cultivation practices • Technology adoption

4.1 Introduction

In Uganda, rice has long been a staple food, even though it is a relatively minor source of calorie intake (Benson et al. 2008). Rapid population growth and urbanization, however, has brought about dramatic increases in rice consumption, resulting in the importation of 60,000 tons of rice annually (Kikuchi et al. 2013b). Since an increase in domestic rice production might provide a way to save foreign currency reserves by decreasing dependence on imported rice and may help to improve food security and decrease rural poverty, the Government of Uganda (GoU) released

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the National Rice Development Policy (NRDP) in 2009. The policy made a commitment to doubling rice production in 10 years by joining the Coalition for African Rice Development (CARD) (MAAIF 2009).

According to the FAO Statistics, in the first 3 years since the target was set (2009–2012), rice production in Uganda has increased only by 3 % from 206,000 tons to 212,000 tons, while the area under rice cultivation increased by 7 %. Given that the areas suitable for rice cultivation will remain limited unless the greater investment in irrigation facilities is made, improving productivity is necessary to boost rice production in Uganda.

Based on the experience from the Asian Green Revolution, there is no doubt that the promotion of modern inputs such as high-yielding seeds and chemical fertilizer contributes to yield enhancement (Barrett et al. 2010). Without irrigation facilities, however, the use of expensive modern inputs may be too risky or may not be profitable, thereby resulting in the non-adoption of modern inputs (Kajisa and Payongayong 2011; Otsuka and Larson 2013b; Nakano and Kajisa 2013). In the case of rice cultivation in sub-Sahara Africa (SSA), agronomists and development practitioners have found that there is room to increase agricultural productivity by improving cultivation practices (Chap. 5). Since this type of technology does not require additional expenses, it may be easily accepted by small farmers. The question is how such information should be conveyed to a large population. The standard method of agricultural technology transfer is through agricultural extension workers (Feder et al. 1985). In many SSA countries, however, the extension system does not function effectively (Anderson and Feder 2007). While international development agencies may also play an important role in transferring agricultural technologies, providing training directly to rural farmers in large areas of the country tends to be excessively costly. It is, therefore, desirable to examine cheaper and more effective alternatives to disseminate relevant information to farm households. Given the high penetration of mobile phones, sending the information to farmers via short text messages has become a viable option (Aker 2011). It is not clear, however, whether farmers can understand and utilize such information on agricultural cultivation practices as effectively as they do when they have attended training programs and received advice from agricultural extension workers.

In 2010 and 2012, a household survey covering major rice growing areas in the rainfed lowlands in Eastern and Northern Uganda was conducted. This panel dataset makes it possible to gain an overview of the current status and the short-term variations in rice production in Uganda. In addition, in the study areas, two programs were implemented to disseminate improved rice cultivation practices: one was on-the-job training in the demonstration plots provided by the experts of the Japan International Cooperation Agency (JICA) and government extension officers in Uganda while the other was the distribution of a “rice cultivation guidebook,” which was prepared by JICA experts and distributed by the survey team led by the author. By estimating the impact of these programs, this chapter attempts to derive policy implications to accelerate rice production in Uganda.

The organization of this chapter is as follows. Section 4.2 provides an overview of rice production in Uganda, which is followed by the explanation of data collection methods and technology dissemination projects in Sect. 4.3 and the examination of descriptive statistics in Sect. 4.4. While Sect. 4.5 explains the estimation methods of assessing the impacts of technology dissemination programs, Sect. 4.6 examines the estimation results. Finally, Sect. 4.7 discusses the conclusions and policy implications of this study.

4.2 Rice in Uganda

Table 4.1 shows the over-time trend of rice production in Uganda from 2008 to 2010 as well as differences by region. According to the Rice Census in 2008 (column 2), about half of the area under rice cultivation was located in the Eastern region (48 %), followed by the Northern region (34 %). The estimated total quantity of milled rice produced domestically (columns 3 and 5) increased from 122,000 tons in 2008 to 232,000 tons in 2011, implying that total rice production almost doubled.[1] In the Eastern region, the largest amount of rice was produced (57 % in 2011). In the Northern and Western regions, rice production has increased more rapidly than in the Eastern region. This is probably because upland rice cultivation has been expanding in the Northern and Western regions after the introduction of NERICA.[2] In 2011, the production in upland rice cultivating areas over the total rice cultivating areas accounted for 53 % and 97 % in the Northern and Western regions, respectively.

This impressive progress in the rice production, however, does not guarantee that this trend will continue in Uganda. In 2011, 70 % of the demand for rice was met domestically (Kikuchi et al. 2013b). According to the domestic resource cost ratio, domestic rice produced in the rainfed lowland and upland ecosystems is slightly less competitive than imported rice (from Pakistan and Tanzania) mainly due to the low yields and the high labor costs, while the rice cultivation in the irrigated ecosystem is competitive (Kikuchi et al. 2013b). Unless productivity is improved, domestic production is unlikely to replace rice imports.

In terms of consumption, rice has been a minor staple crop in Uganda. In 2005, the consumption of rice accounted for only 2.6 % of the total calorie intake in Uganda (Benson et al. 2008). In urban areas, more rice was consumed (6.2 %). Nationally, the main staple foods are tubers (22.6 %), matoke (18.9 %), maize (16.1 %) and pulses (13.1 %). In the rice producing areas, rice is often consumed at home, while rice is still considered a luxury item in non-rice growing areas, mainly

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[1] While this massive increase (2008–2011) seemingly contradicts the FAO statistics cited above in the Introduction (2009–2011), there was a sharp increase in rice production between 2008 and 2009.

[2] NERICA is the abbreviation of New Rice for Africa, an upland rice variety suitable for African environments. See Kijima et al. (2008) for the potential of NERICA in Uganda and Kijima et al. (2011) for studies indicating NERICA's positive effect on household income.

Table 4.1 Trends and differences by region in rice production in Uganda

	Total area under rice cultivation 2008/2009[a]		Rice production 2008[b]		Rice production 2011[c]		Upland rice, 2011[c]	
	(ha)	Share out of total area	(1,000 tons, milled rice)	Share out of total production	(1,000 tons, milled rice)	Share out of total production	(1,000 tons, milled rice)	Share of upland rice
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
North	25,913	0.34	13	0.11	45	0.20	24	0.53
East	36,343	0.48	84	0.69	133	0.57	13	0.10
Central	2,638	0.04	5	0.04	12	0.05	9.1	0.76
Southwest	1,397	0.02	4	0.03	5	0.02	5	1.00
West	9,106	0.12	16	0.13	37	0.16	36	0.97
Total	75,397	1.00	122	1.00	232	1.00	87.1	0.38

[a] Rice Census cited in Kikuchi et al. (2013b)
[b] Kikuchi et al. (2014)
[c] Kikuchi et al. (2013b)

because the relative price of rice is substantially higher than that of maize in Uganda (RATIN 2014).

As stated in Kikuchi et al. (2013a), about 40 different rice varieties were planted by farmers in Uganda. Among the domestic rice varieties, Supa is the most popular variety since it has some aroma and provides a stable yield. The price of Supa is usually higher than the other varieties (e.g., Kaiso and "Upland"), which are not differentiated in the markets. About half of the rice produced domestically is consumed in the capital city and the remainder is consumed in the regions where rice is produced (Kikuchi et al. 2013b).

4.3 Data and Descriptive Statistics

4.3.1 Sampling and Survey

Two types of household surveys were conducted: An extensive survey (ES) in 2010 and 2012 and an intensive survey for case study (CS) in 2010. The objective of ES was to monitor the progress of rice production in Uganda under the rainfed lowland ecosystems, while CS was conducted in areas where the JICA training project was implemented. The household questionnaire contained a wide range of questions so as to capture farm and non-farm activities undertaken in the last 12 months as well as household demography, consumption expenditure, and assets (land, livestock, farm equipment, and other household items). Since the data collected in 2010 and 2012 captured the information in 2009 and 2011, respectively, the years of the data sets will henceforth be referred to as 2009 and 2011.

4.3.1.1 Extensive Survey

The sample districts were purposively selected based on the availability of the wetlands usable for lowland rice production in Eastern and Northern Uganda. The other criteria used in selecting the sample districts were average rice cultivation experience as well as agro-ecological conditions so as to capture a wide variety of the rainfed lowlands and different levels of the rice cultivation skills. Five districts out of 28 Eastern and Northern districts were chosen (Fig. 4.1, Panel A).[3] Butaleja and Lira districts have large irrigation schemes and farmers in these districts have longer experience of rice production than the other districts. Households in Lira and Dokolo districts have larger landholdings on average than the other districts.

Two sub-counties that are locally well known as rice producing areas were selected from each district.[4] In these ten sub-counties, the names of all local council

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[3] For the Northern districts, only those that are around Lake Kyoga are considered as population.

[4] The information was obtained from the district agricultural officer in each district.

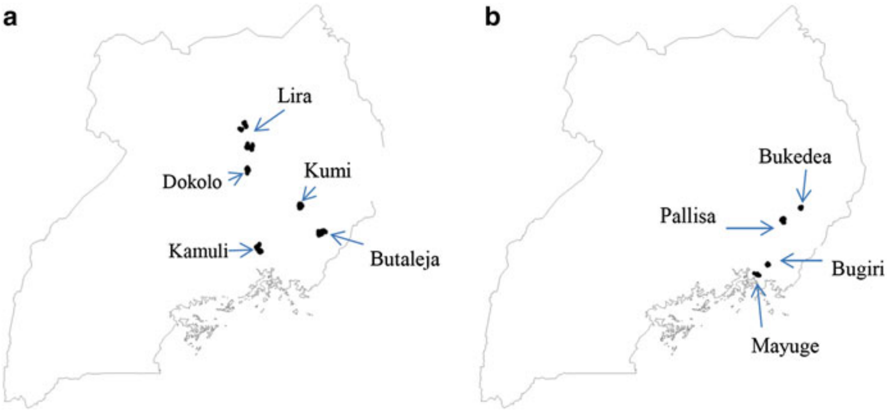

Fig. 4.1 Location of sampled households. (**a**) extensive study, (**b**) case study. Note: Plots were measured from GPS coordinates of the location of sampled households

1s (LC1s, the lowest administrative unit in Uganda) in each sub-county were listed up. From the list, 60 LC1s were randomly selected. In each LC1, ten households were randomly selected by using the lists of the households obtained from the LC1 chiefs. Thus, in total, 600 households were interviewed in 2010. For the second round, 30 sampled households were not available for interview (5 % attrition) and the number of the sampled households in the panel data declined to 570.

In each LC1, a community-level survey was also conducted. The respondents consist of the LC1 chairman, key informants, rice farmers, female farmers, youth, and elders. The questionnaire included general information such as the population, infrastructure, land ownership, land rental transactions, price information on agricultural inputs and outputs, ownership of cattle, access to credit organizations, local associations, and agricultural programs.

4.3.1.2 Case Study

As sample areas for the case study, four rice production areas were selected from (1) the project sites that JICA designated as demonstration plots and had provided training (namely, Bugiri and Mayuge) and (2) the sites that the JICA experts considered as candidates for future training projects (namely, Bukedea and Pallisa). All the sampled areas were located in wetlands that can be used for lowland rice cultivation (Fig. 4.1, Panel B). At each site, the demonstration plot (or plot where the training was planned to be offered) was identified by the JICA experts. Based on the distance from the demonstration plot, 75 households (rice plots) were randomly selected. In other words, sample households were chosen based on the location of their rice plots. Thus, all the sampled households were rice growers.

4.3.2 Projects on Improving Rice Cultivation Practices

4.3.2.1 Randomized Distribution of the Lowland Rice Cultivation Guidebook

In each district covered by ES, a half of the sampled LC1s were randomly selected as treatment LC1s, and the lowland rice cultivation guidebook was given to all sampled households within these selected LC1s when the 1st round of household surveys was conducted in 2010. Since weather patterns might play a critical role in deciding who farms rice and who does not, randomization of the beneficiaries (based on the location of the program) is an ideal method to solve any potential selection bias. As shown in Appendix Table 4.8, the observed characteristics of the sampled households and rice plots of treatment and control LC1s are not statistically different, suggesting that the randomization was successful.

The lowland rice cultivation guidebook was prepared by the JICA experts for the project conducted in Uganda. It is 15-pages long with photos and written in English. The issues covered are carefully selected to be of critical importance for lowland rice cultivation and applicable to the Ugandan small farmers. The guidebook is practical, explaining the advantages of the transplanting method, including how to conduct the germination tests and carry out transplanting (spacing and depth of seedlings), and ways to prepare the land, seeds, and the seedbed for the transplantation. It also explains the appropriate type of fertilizer and the timing and amount of chemical fertilizer to apply, as well as the methods of weed management. There are photos of the insect pests and the diseases of the lowland rice as well as a graph indicating the effect of the seedling age in transplanting on the rice yield, which is meant to emphasize the importance of using the young seedlings for transplanting.

By the time of our survey, certified lowland rice seed had not been released in Uganda – the seeds of improved variety for lowland ecosystems were not yet being produced by seed companies and therefore they were not sold in local shops. When households start growing rice in the lowland ecosystem for the first time, rice seeds have to be obtained from relatives and neighboring households who also acquired the seeds from their neighbors when they started growing rice. Most of the farmers do not know whether their rice seeds are the improved varieties or not. In the guidebook, therefore, the information on the improved variety was not provided explicitly, but the name "K-85" is mentioned in the guidebook. K-85 is planted in large commercial farms in Uganda (Tilda Uganda Limited, Kibimba Rice Scheme) and is known as a high-yielding variety for lowland ecosystems.

4.3.2.2 Lowland Rice Training Project by JICA[5]

The JICA project was designed to build the capacity of the district agricultural officers (extension workers) who are supposed to train farmers after the training. The field training was provided by the JICA experts and the extension workers to

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[5] See Kijima et al. (2012) for the further information on the JICA training project.

farmers at the demonstration plots. The field trainings are offered four times at each site per agricultural season: (1) the establishment of a demonstration plot including the construction of water channels in the surrounding area, and leveling the main field (1–3 days); (2) the preparation of nursery beds and seedlings at the nursery beds (0.5 day); (3) the methods of transplanting and weeding (0.5 day); and (4) the methods of harvesting and threshing (0.5 day). The contents taught in each session were summarized so that the trainees were able to remember the key points. In the training, the project did not involve the construction of the modern irrigation facilities. Chemical fertilizers and other kinds of chemicals were neither given to the training participants nor applied in the demonstration plots. Rice seeds used in the demonstration plots were selected by the JICA experts.

4.4 Descriptive Statistics

4.4.1 Community Information and Prices in 2009 and 2011 (ES Data)

Table 4.2 shows the input and output prices calculated from the community survey (ES data). All figures are the nominal prices. As shown in columns (2) and (4), in half of the sampled communities, rice was mainly sold as paddy rice (before milling) while in the other LC1s, rice was sold after milling it. The milled rice price was 350 shillings higher than the paddy rice price in 2009, while the difference increased by up to about 525 shillings in 2011. The rice price obtained by farmers during the harvesting season was lower than that sold during the off-harvest season by 400–550 shillings. Thus, the producer price of rice differs a lot by the form of rice sold and the timing of sales. Compared with maize, the other storable staple food, output price of rice per kilogram is two to four times higher.

The next sets of variables are the input prices. As shown in column 2, the number of observations is small (especially for chemical fertilizer) since the farmers rarely apply the agro-chemicals and they do not know the price. The relative prices of urea and diammonium phosphate (DAP) to the rice do not seem so expensive when compared with those in other SSA countries, because these prices are those charged by the agro-dealers in Kampala (RATIN 2014). Therefore, the actual costs of using the chemical fertilizer should be much higher.

Since agro-chemicals are rarely applied to rice production in Uganda, the labor and the land are the most important inputs. Table 4.2 indicates the piece rate wage per acre of rice plot, which is the cost of hiring labor to finish each task per acre This measure is used because in most labor activities, the labor cost is paid per land size, not per hour, and because the information on hours worked by hired labor tends to be inaccurate since those who hire labor do not care how long it takes for the hired labor to complete the assigned tasks. The labor cost per acre did not change much over time, except for harvesting. This was applicable to the land rent as well. Thus, the output-input price ratio for rice production did not change from 2009 to 2011.

Table 4.2 Median prices of paddy and purchased inputs, wage rates, and land rents in extensive survey sites in Uganda (LC1 level)

	2009		2011	
	Median	# obs	Median	# obs
	(1)	(2)	(3)	(4)
Producer price				
Paddy rice (harvesting season) (USh/kg)	750	29	1,100	29
Paddy rice (off-harvesting season) (USh/kg)	1,150	29	1,650	29
Milled rice (harvesting season) (USh/kg)	1,100	29	1,625	30
Milled rice (off-harvesting season) (USh/kg)	1,500	29	2,600	30
Maize (harvesting season) (USh/kg)	300	57	300	55
Maize (off-harvesting season) (USh/kg)	500	57	900	55
Input price				
UREA (USh/kg)	2,000	4	4,000	9
DAP (USh/kg)	3,000	3	3,000	7
Pesticide (1,000 Ush/l)	16.0	27	24.0	31
Fungicide (1,000 Ush/l)	20.0	12	20.0	14
Herbicide (1,000 Ush/l)	21.0	5	25.0	12
Wage rate				
Wage for rice production (1,000 Ush/acre) – all	55.5	56	60.0	45
Wage for rice production (1,000 Ush/acre) – harvesting	35.0	28	60.0	21
Wage for rice production (1,000 Ush/acre) – weeding	60.0	44	60.0	40
Wage for rice production (1,000 Ush/acre) – ploughing	50.0	45	60.0	40
Land				
% of HHs rented in land via fixed rent in upland areas	27.3	57	37.7	60
% of HHs rented in land via fixed rent in lowland areas	30.8	58	31.6	59
Land rent (1,000 USh, 1 season, 1 acre) – upland areas	50.0	50	55.0	51
Land rent (1,000 USh, 1 season, 1 acre) – lowland areas	100.0	43	100.0	41

4.4.2 Rice Cultivation Practices in 2009 and 2011 Based on ES Data

Table 4.3 indicates the changes in the rice cultivation practices in 2009 and 2011 based on ES data. The percentage of the households growing rice decreased from 67 to 54 %. This is likely to be due to the fact that some of the lowlands in the sample area suffered from the drought or the floods in 2011. However, among those who grew rice, the area under rice cultivation and the share of the rice area out of the total cultivated area did not change over time. The average size of rice plots per household is 0.6 ha, which accounts for 28 % of the total cultivated land (including both upland and lowland plots). The total rice production at household level slightly increased from 2009 to 2011 to just above 1 ton per year.

Table 4.3 Rice cultivation and income at household and plot levels in extensive survey sites in Uganda in 2009 and 2011

	2009	2011
Household level		
Number of households	564	564
% of households who grew rice	66.5	54.1
Rice cultivated area (ha) (among growers)	0.598	0.581
Share of rice area over cultivated land	0.283	0.275
Total rice production (household level) (tons)	0.82	1.19
Share of rice income over total household income	0.176	0.135**
Share of crop income over total household income	0.750	0.751
Rice cultivation experience (years)	8.32	9.83**
Per capita income (USD)	255	251
Rice plot level		
Number of observations (lowland rice plots × cultivation times in a year)	573	394
Number of rice plots	454	332
Number of plots where rice was grown more than once within a year	113	57
(% of plots under double cropping)	(20.8)	(18.3)
Number of households growing rice in 1 plot and once a year	227	232
Number of households with rice plot sample	368	302
% of plots with:		
Bunding	57.8	70.6**
Leveling	60.7	75.4**
Transplanting	59.3	56.3
Transplanting in rows	9.8	5.6
Improved seeds	9.4	9.1
% of plots where chemical fertilizer was applied	6.8	4.3
Yield (tons/ha)	2.53	2.28
% of rice plots with hired labor	73.4	72.5
On land preparation	49.5	49.6
On sowing	36.0	37.8
On weeding	35.5	37.0
On bird scaring	22.6	21.4
On harvesting	47.2	39.5
On post-harvest	34.3	38.3

**Indicates that means over time (2009 and 2011) are statistically different at 5 % level

The sample households tend to have about 9 years of experience of rice cultivation. The annual per capita income is about USD 250. The share of income earned from crop production reached 75 % and did not change over time, which means that economically, the sample households depend heavily on crop production. The income from rice production accounted for 17 % of the total household income in 2009.

The bottom half of Table 4.3 shows the management characteristics of the sample rice plots. The number of observations (rice plot level data) was quite different between 2009 and 2011 (573 and 394, respectively), even though the percentage of sampled plots where rice was grown more than once within a year did not change much over time (approximately 20 %). This change is greater than that of the number of households growing rice (from 368 to 302). This suggests that drought and floods in 2011 made some plots too dry or too flooded to cultivate rice. Even those who grew rice in 2011 cultivated rice in fewer plots than in 2009.

Regarding the rice cultivation practices, the proportion of rice plots in which bunding and leveling were being conducted increased over time. In contrast, the adoption of the other cultivation practices (transplanting and transplanting in rows) and the use of chemical fertilizer did not change over time. In terms of the productivity measured by the quantity harvested per hectare, there was no significant change over time (2.5 tons in 2009 and 2.3 tons in 2011). This seems puzzling since the improved cultivation practices (i.e., constructing bunds and leveling) were more frequently applied in 2011 without enhancing productivity.

4.4.3 Cultivation Practice and Rice Yield in 2009 (CS Data)

Table 4.4 shows the adoption rate of improved cultivation practices separately for each sample village in the CS data. In Bugiri, an area that was covered by the JICA project, all the recommended cultivation practices were adopted by most of the sample households. In Mayuge, which is another JICA project village, as well as Pallisa which is the non-project village, the proper timing of transplanting and transplanting in rows were not implemented on a large scale. In Bukedea, another non-project village, the adoption rate of all the practices was as low as 10–28 %. The table also shows the rice yield separately according to the number of improved cultivation practices adopted. It is clear that the average yield rises as more of the improved practices were adopted by the farmers. In Bugiri, the average yield was 4.5 tons per hectare when four of the practices were adopted, while the yield was 2.3 tons per hectare when only one practice was adopted. This significant difference in the rice yield suggests that there is some complementarity between the improved cultivation practices. In Mayuge, another JICA project village, a similar but less clear-cut relationship can be observed between the yield and cultivation practices. In contrast, there was no clear relationship between the number of practices applied and the yield in the other two non-project villages. Therefore, further detailed examination is needed in order to understand the relationship between the rice yield and cultivation practices.

Table 4.4 Adoption of cultivation practices and rice yield by case study villages in Uganda

	All	Bugiri	Mayuge	Bukedea	Pallisa
Cultivation practice	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
Transplanting in rows	33.0	81.8	4.8	10.3	3.7
Number of cultivation practices applied	Yield (ton/ha)				
4 practices[a]	4.13	4.47	2.89	1.22	0.37
	(3.14)	(3.20)	(1.83)	(0.74)	–[c]
3 practices[b]	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)
0 practice	1.33	–	0.79	1.42	0.66
	(1.99)	–	–[c]	(2.10)	(0.56)[d]

[a] 4 practices include bunding, leveling, proper timing of transplanting, and transplanting in rows
[b] 3 practices indicate that among the 4 practices, 3 of them were implemented
[c] Only 1 observation
[d] Only 3 observations

4.5 Methodology

4.5.1 Average Treatment Effect on the Treated (ATT)

Can the provision of cultivation guidebook be a substitute for the field training to increase rice production in Uganda? To investigate this question, the average treatment effect on the treated (ATT) is estimated for the two projects: the JICA training project and the distribution of the guidebook. Propensity score matching method was applied to construct a comparable control group. It is likely that the training participants were inherently different from the non-participants (Winters et al. 2011). Since CS data is non-experimental and cross-sectional data, the training participants and non-participants may not be directly comparable.[6] Thus, it is necessary to construct an appropriate counterfactual that has similar observable characteristics to those of the treated households (i.e., the JICA training participants). The propensity score is the predicted probability that a household has access to the treatment. The propensity scores are estimated by a Probit model of training participation, where the household-level control variables are the years of experience of rice cultivation, number of household members, age and years of education of household

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[6] As shown in Appendix Table 4.9, characteristics of the training participants and non-participants are significantly different in CS sample.

heads, value of household assets, and membership in a local organizations; the plot-level variables are the size of the rice plot, the water source dummy, and the ownership of the rice plot; and the village level variables are the annual rainfall amount and the traveling time to the nearest district town (Kijima et al. 2012). Kernel matching is applied.

The effect of the distribution of the rice cultivation guidebook on the rice production was analyzed by using the ES data in 2011 (after the distribution). Unlike the JICA training, the beneficiaries of the guidebook distribution were randomly assigned, which means that treatment and control groups are comparable. Actually, in Appendix Table 4.8, where the household characteristics in 2009 are shown by the recipient status of the cultivation guidebook, the characteristics of households and rice plots before the distribution (2009) are not statistically different between the treatment and control households. In order to make the results comparable with those for the JICA training, the same methodology (ATT by using propensity score matching with the data collected after the treatment) was applied to the impact evaluation of the guidebook distribution. The descriptive statistics of the data after the treatment (2011) are provided separately for the treatment and control groups in Appendix Table 4.10.[7]

These programs (the JICA training and the guidebook distribution) may have a variety of effects on the rural households in Uganda. First, households who had not previously grown rice may commence growing rice following the program.[8] Second, households who grew rice before the program might learn more about the proper cultivation practices and apply them, resulting in higher productivity. While applying better cultivation practices and commencing rice cultivation are likely to increase the income from rice production, it is not clear whether the total household income and expenditure also increase significantly as more resources may be allocated to rice farming at the expense of other activities. Therefore, the effect of the program on household welfare measured by per capita expenditure and income was also examined.

4.5.2 Adoption of Cultivation Practices in Case Study

The determinants of adopting designated cultivation practices are analyzed by IV Probit model. The main question is whether the JICA training had increased the probability of adoption of the improved cultivation practices or not. Participation in the JICA training was expected to enhance the knowledge that was gained regarding improved production practices and to increase adoption rates. Even without the training, some farmers may have learned effective ways of growing rice based on their own experience, which may lead to an increased adoption rate among more

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[7] Given that the randomization is preferred to the matching method, the results of ATT without matching are estimated and compared with the results with matching.

[8] Regarding the decision to grow rice, the effect of JICA training cannot be estimated since all the households selected grew rice at the time of the sampling.

experienced farmers. Since these practices require greater labor inputs, households may need to hire additional labor. Thus, asset holdings may affect their adoption. These practices also can have particularly significant impacts on rice production when water is available, and thus their adoption is also likely to be affected by the availability of irrigation water. If the plot is rented, the tenant farmers may attempt to increase the net returns so as 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, transplanting, or transplanting in rows) was adopted. Explanatory variables at the household and plot level take the values before the households made decisions on cultivation practices at each respective cropping season. As explained before, the training variable is considered to be an endogenous variable. Thus, the IV Probit model is applied. The instrumental variable for the JICA training participation (precisely, the training participation is measured by the number of training days participated) is the membership of farmers organizations unrelated with rice farming. The reason why this variable suits the condition of IV for training participation status in input demand functions for rice cultivation is that since the participation in JICA training requires the formation of producer group, those farmers who are members of farmers organization may have advantage in the participation, even though the membership per se does not affect rice farming efficiency.

4.5.3 Yield Function in Case Study

The yield is assumed to be determined by the household characteristics such as participation in the JICA training, application of the recommended practices, rice cultivation experience, asset holdings, and household composition 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 and application of the improved cultivation practices are highly correlated, these variables are used in different estimation models separately. As explained in the previous sub-section, the cultivation practices are endogenous. Therefore, the predicted adoption status of the cultivation practice, instead of the actual adoption status, is used as the explanatory variable.

4.6 Results

4.6.1 Adoption of Management Practices

The estimation results examining the adoption of improved management practices are provided in Table 4.5, which shows the results for the adoption function of constructing bunds, leveling, transplanting, and planting in rows in columns 2–5,

Table 4.5 Estimation results on adoption function of improved cultivation practices in case study villages in Uganda

	Num. of days of training	Bunds	Leveling	Trans planting	Trans planting in rows
	OLS	IV Probit	IV Probit	IV Probit	IV Probit
	(1)	(2)	(3)	(4)	(5)
Number of days of JICA training[a]		0.691**	−0.014	0.287*	0.257**
		(2.53)	(0.17)	(1.80)	(2.37)
Household head's age	−0.035**	−0.028	−0.023**	−0.016	0.013
	(2.02)	(1.03)	(2.26)	(1.24)	(0.80)
Household head's years of schooling	0.060	0.076	−0.011	0.026	0.024
	(1.10)	(1.17)	(0.37)	(0.50)	(0.47)
Female-headed household	0.536	0.139	0.000	−0.410	0.000
	(0.48)	(0.10)	(0.00)	(0.63)	(0.000)
Rice cultivation experience (years)	−0.237	0.552	0.148	0.476	0.997**
	(0.61)	(1.05)	(0.72)	(1.40)	(2.28)
Moved to this area after 2,000 dummy	0.013	0.060	0.013	0.026	0.009
	(0.46)	(1.44)	(0.84)	(0.93)	(0.36)
Land owned (ha)/number of adult family members (aged 15–64)	−0.817	−1.291	0.024	0.368	−0.558
	(1.65)	(1.90)	(0.09)	(0.88)	(1.25)
Initial assets (household, agricultural, livestock) (thousand USD)	0.218	0.409	0.140	0.178	−0.585
	(0.80)	(1.10)	(1.00)	(0.73)	(1.49)
Water source: depending solely on rainfall	−0.149	−1.710**	−0.582**	−0.635	−0.594
	(0.28)	(2.50)	(2.10)	(1.58)	(1.11)
Plot is rented	0.510	1.549**	0.286	−0.233	0.098
	(1.25)	(2.27)	(1.23)	(0.64)	(0.26)
Size of the plot (ha)	−0.043	1.252	0.023	0.368	−1.676
	(0.04)	(0.84)	(0.04)	(0.45)	(1.62)
Plot is under a customary tenure system	−0.089	0.410	0.735	−0.420	1.060
	(0.09)	(0.60)	(1.33)	(0.62)	(0.83)
Distance to demonstration plot (km)	−0.407	−1.919***	−0.159	0.429	−1.873***
	(1.15)	(3.02)	(0.75)	(1.52)	(3.69)
Farmers association member (non-rice)	3.415***				
	(7.01)				
District dummies	Yes	Yes	Yes	Yes	Yes
Planting month dummies	Yes	Yes	Yes	Yes	Yes
Observations	252	252	252	252	252
R-squared	0.51				
Log likelihood		−632.4	−711.6	−291.9	−629.2
Prob > Chi-squared		0.044	0.001	0.001	0.001

The numbers in parentheses are *t*-statistics in column (1) and *z*-statistics in columns (2) to (5)

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

Column (2) to (5) show the marginal effects (dF/dX)

[a] Endogenous variable whose IV is a dummy variable of being a member of a local organization (other than rice association)

respectively. Since training participation is an endogenous variable, the instrumental variable estimation model is applied where an instrumental variable for training participation is a dummy variable of being a member of a local organization (other than the rice association). The estimation result for the first stage analysis is shown in column 1, in which the coefficient of the farmer group membership dummy is found to be positive and significant.

The training participation (the number of JICA training days participated in) had significant and positive effects on the adoption of the improved cultivation practices except the leveling (column 3). The more experienced farmers with rice cultivation tended to adopt transplanting in rows more frequently. The younger household heads tended to adopt leveling. Poor access to water had a negative effect on the adoption of constructing bunds and leveling.[9] A shorter distance to the demonstration plot increased the probability of constructing bunds and transplanting in rows, which are reasonable.

4.6.2 Effects of Training and Management Practices on Rice Yield

Table 4.6 shows the estimation results of the rice yield function. As shown in columns 1–4, all cultivation practices had positive impacts on rice yields. The marginal effect of applying the cultivation practice on rice yield was approximately 0.26 tons per hectare, except for transplanting replacing direct seeding, whose marginal effect is 0.70 tons per hectare. Since the average rice yield was 2.5 tons per hectare, the marginal effect means that applying the cultivation practice can increase the yield by 10 % on average. Our analysis, however, cannot assess the effect of package adoption of new management practices due to high correlation among them. Unexpected result is that the direct effect of the training participation on the rice yield is not significant (column 5). This seems to indicate that the JICA training participation has only indirect effects by increasing the application rate of the cultivation practices, which turns out to be the factor significantly enhancing rice yield.

Somewhat unexpectedly, previous rice cultivation experience did not increase the yield. Recent migrant households tend to have a higher yield. The other household characteristics also did not have a significant impact on rice yields. Among the plot characteristics, the size of the plot is the only variable that is significant: Smaller plots are associated with higher yields, probably due to better field leveling, water control and good crop management.

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[9] Access to water is measured by a dummy indicating that the rice plot depends only on rainfall (compared with the plots with additional water sources such as canals or wells).

Table 4.6 Yield function (ton/ha) using case study survey data in Uganda by 2SLS estimation

	(1)	(2)	(3)	(4)	(5)
Bunds = 1[a]	0.265***				
	(4.04)				
Leveling = 1[a]		0.261***			
		(2.69)			
Transplanting = 1[a]			0.700***		
			(4.32)		
Transplanting in rows = 1[a]				0.261***	
				(2.69)	
Number of days of JICA training[b]					−0.097
					(0.95)
Household head's age	−0.012	−0.014	0.006	−0.014	−0.014
	(0.93)	(1.06)	(0.45)	(1.06)	(0.97)
Household head's years of schooling	−0.004	−0.030	−0.045	−0.030	−0.007
	(0.09)	(0.70)	(1.06)	(0.70)	(0.17)
Female-headed household	−0.609	−0.403	−0.305	−0.403	−0.645
	(0.71)	(0.46)	(0.36)	(0.46)	(0.74)
Rice cultivation experience (years)	0.361	0.040	−0.099	0.040	0.177
	(1.21)	(0.13)	(0.32)	(0.13)	(0.59)
Moved to this area after 2,000 dummy	0.054**	0.031	0.017	0.031	0.047**
	(2.47)	(1.42)	(0.76)	(1.42)	(2.07)
Land owned (ha)/number of adult family members (aged 15–64)	0.105	0.437	0.170	0.437	0.375
	(0.27)	(1.12)	(0.45)	(1.12)	(0.96)
Initial assets (household, agricultural, livestock) (thousand USD)	0.185	0.367	−0.008	0.367	0.190
	(0.88)	(1.62)	(0.04)	(1.62)	(0.91)
Water source: dependent solely on rainfall	−0.455	0.043	0.441	0.043	0.070
	(1.10)	(0.10)	(1.04)	(0.10)	(0.17)
Plot is rented	−0.117	−0.487	−0.380	−0.487	−0.326
	(0.36)	(1.51)	(1.21)	(1.51)	(0.98)
Size of the plot (ha)	−3.788***	−3.766***	−4.365***	−3.766***	−4.309***
	(4.52)	(4.35)	(5.28)	(4.35)	(5.08)
Plot is under a customary tenure System	−0.534	−0.551	−0.266	−0.551	−0.210
	(0.69)	(0.70)	(0.34)	(0.70)	(0.30)
District dummies	Yes	Yes	Yes	Yes	Yes
Planting month dummies	Yes	Yes	Yes	Yes	Yes
Observations	268	268	268	268	268
R-squared	0.38	0.36	0.39	0.36	0.28

The numbers in parentheses are *t*-statistics

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

[a] Predicted value of adoption of each cultivation practice by IV probit model shown in Table 4.5

[b] Endogenous variable whose IV is a dummy variable of being a member of a local organization (other than rice association)

4.6.3 ATT

Table 4.7 shows the means of outcome variables separately for the treatment and control groups as well as ATT.[10] Columns 1–4 present the results of the JICA training, while columns 5–8 are for the distribution of the rice cultivation guidebooks. Regarding the effects on the decision to grow rice, neither the training nor the guidebook distribution increased the area size under rice cultivation or the share of the area under rice over the total cultivated land. Distribution of the guidebook failed to provide sufficient incentives to enhance the probability of growing rice. This is likely because those who have never grown rice need to obtain rice seeds as well as rice plots located in the lowlands suitable for rice cultivation. Unlike upland rice cultivation, there appears to be entry barriers for the expansion of lowland rice cultivation because unutilized wetlands tend to be customary land or communally owned. When such lands are used as communal grazing lands, permission from the local chief as well as the community members is needed for converting the wetlands into rice fields, which are managed individually. Therefore, it is plausible that both receiving the guidebook and participating in the JICA training will not result in significant effects on the area expansion for rice cultivation. This is also consistent with the fact that the training program and the guidebook focus on the intensification rather than on the expansion of rice cultivation areas.

The next set of outcome variables are related to the adoption of the improved management practices. The distribution of the guidebook increased the probability of applying the transplanting in rows by 6 percentage points, while there was no effect on the adoption of the other cultivation practices. The JICA training also increased the probability of applying the transplanting in rows and the effect was much greater than that of the distribution of the guidebook (22 percentage points vs. 6 percentage points). Participation in the training had a positive and significant impact on the probability of applying the chemical fertilizer (4 percentage points). A question therefore is why the guidebook distribution program had a significant effect only on the adoption of the transplanting in rows. This may be because the transplanting in rows can be easily observed and, hence, imitated and because in the guidebook, more than half of the pages are used for explaining the methods and benefits of transplanting in rows.

Looking at the productivity and the income of rice production, this study found that the JICA training increased the yield, while the distribution of the guidebook did not have any effect on rice productivity. The impact of the training on the rice yield was far from negligible (0.45 ton per hectare). In contrast, participation in the training did not have significant impacts on rice income. A possible explanation for the contrasting results of the training participation on rice yield and income is that transplanting in rows takes more time than direct seeding and “random” transplanting, resulting in higher costs of hiring labor.

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[10] The results without matching for ES are provided in Appendix Table 4.11.

Table 4.7 Average treatment effects of the distribution of rice cultivation guidebook and the JICA training participation in extensive survey in Uganda (Kernel matching method 2011)

	ES 2011				CS 2009			
	Treatment (recipient)	Control (non-recipient)	ATT	s.e.[a]	Treatment (participants)	Control (non-participant)	ATT	s.e.[a]
Plot level	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Adoption of cultivation practice								
Bunding	0.741	0.674	0.067	0.058	0.974	0.992	–0.018	0.016
Leveling	0.793	0.725	0.068	0.054	0.838	0.778	0.059	0.088
Transplanting	0.565	0.542	0.023	0.050	0.923	0.971	–0.048	0.055
Transplanting in rows	0.088	0.021	0.067	0.023***	0.718	0.496	0.222	0.119*
Improved variety (k-series)	0.104	0.064	0.040	0.036	0.829	0.907	–0.078	0.083
Chemical fertilizer use	0.052	0.052	–0.000	0.029	0.043	0.000	0.043	0.024*
Yield (ton/ha)	2.23	2.30	–0.067	0.187	3.673	3.221	0.452	0.221*
Rice income (USD/ha)	6.306	6.348	–0.042	0.135	6.865	6.641	0.224	0.581
Household level								
Growing rice (dummy)	0.548	0.541	0.007	0.036	–	–	–	–
Area under rice (ha)	0.512	0.295	0.217	0.177	0.385	0.446	–0.060	0.096
Share of area under rice over cultivated land	0.153	0.147	0.006	0.014	0.272	0.282	–0.009	0.060
ln (per capita income)	4.730	4.846	–0.115	0.102	4.804	4.596	0.207	0.310
ln (per capita expenditure)	5.366	5.390	–0.024	0.043	5.476	5.433	0.043	0.137

[a] bootstrapped standard errors

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

Even though the distribution of the guidebook increased the probability of transplanting in rows, the program did not have a significant impact on the rice yield and income. The question here is then why the JICA trainings had significant effects on the yield, while the distribution of the guidebook did not. One possibility was the difference in transplanting experience among the CS and ES sample households. Most of the sample households in the CS applied transplanting, while transplanting was conducted in only in about half of the rice plots of the ES In order for the transplanting method to enhance the rice yield, the timing (the age of seedlings) is critical. As pointed out in the guidebook, however, farmers tend to transplant when the seedlings have already grown too much, which affects the yield negatively. It is likely that those who received guidebook might be less able to comprehend the essence of the transplanting method. Similar arguments may be applied with regard to the adoption of other cultivation practices.

The bottom part of Table 4.7 shows the results in terms of household welfare. Neither the JICA training program nor the distribution of the guidebook increased per capita household income or consumption expenditure significantly.[11] This is consistent with the results that they did not increase the rice income or the area under rice cultivation.

4.7 Conclusion

This chapter examined the extent to which the JICA onsite training and the distribution of the cultivation guidebook had any impacts on the enhancement of rice production in this country. Unlike the estimates from the other sources, rice production did not increase much from 2009 to 2011 among the sample households in Eastern and Northern Uganda. This is likely because there were wetlands that were severely affected by drought and floods in 2011. The rainfed lowlands in the sample areas are vulnerable to floods and drought since it is difficult for farmers to control the amount of water. It is important to note, however, that 72 % of the sample households in the ES grew rice in 2010, which is 5 percentage points higher than in 2009. Without the unfavorable weather shocks in 2011, the proportion of households who grew rice would likely have been increased. Therefore, it may not be necessary to draw adverse conclusions about the negative trend in rice production witnessed from 2009 to 2011. Having noted this, the goal of doubling rice production in 10 years may prove difficult.

In Uganda, the area under rice cultivation rapidly increased prior to 2009, a fact that was mainly explained by push factors such as the shortage of agricultural land for upland crops (Kijima 2012). According to the ES in 2011, the main reasons why rice was not grown in 2011 were the labor shortage (reported by 48 % of households who did not grow rice in 2011), the drought (13 %), floods (14 %), and the shortage of land suitable for rice cultivation (6 %). Thus, it may not be realistic to expect that

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[11] Income and expenditure are in natural logarithm form.

rice production in Uganda will continue to grow as rapidly as in the period prior to 2009.

As examined in Kikuchi et al. (2014), unless productivity is improved, rainfed lowland rice production in Uganda cannot compete with imported rice. To enhance productivity through improved cultivation practices, two programs (the JICA training and the distribution of the rice cultivation guidebook) were implemented in the Eastern and Northern Uganda. A comparable control group was constructed by the propensity score matching method so as to overcome endogenous program placement and the selection bias of program participation. The training program provided by the JICA showed promising results, since it had a positive impact on the rice yield by 0.45 tons per hectare. Even though the distribution of the guidebook enhanced the probability of applying the transplanting in rows, there was no appreciable impact on the rice yield. These results, therefore, suggest that distributing the guidebook alone cannot be a substitute for conventional training programs. The guidebook distribution project should be either abandoned or improved, e.g., by supplementing it by the use of mobile phones to facilitate discussions between farmers and extension workers.

Appendix

Table 4.8 Household characteristics before the distribution of the cultivation guide book in extensive survey sites in Uganda in 2009

	Received guidebook (treatment)		Not received (control)		Diff in means[b]
	Means	(s.d.)	Means	(s.d.)	
Household characteristics					
Number of household members	8.00	(3.50)	7.95	(3.82)	
Share of male members aged 15–64	0.245	(0.137)	0.238	(0.141)	
Share of female members aged 15–64	0.348	(0.120)	0.235	(0.124)	
Female headed household dummy	0.093	(0.295)	0.078	(0.269)	
Head's age	44.8	(13.47)	45.1	(13.96)	
Head's years of schooling completed	6.21	(3.52)	5.72	(3.30)	
Land owned (ha)	1.96	(2.33)	1.71	(1.83)	
Ownership of bull (dummy variable)	0.291	(0.455)	0.344	(0.476)	
Rice cultivation experience (years)	8.840	(10.24)	7.801	(8.854)	
% of households who grew rice	65.2	(47.7)	67.7	(46.8)	
Rice cultivated area (ha)	0.604	(0.700)	0.592	(0.700)	
Share of rice area (out of cultivated land)	0.184	(0.198)	0.194	(0.202)	
Per capita income (USD)	187.5	(216.6)	201.0	(232.3)	
Per capita expenditure (USD)	285.3	(223.1)	257.9	(154.8)	

(continued)

Table 4.8 (continued)

	Received guidebook (treatment)		Not received (control)		Diff in means[b]
	Means	(s.d.)	Means	(s.d.)	
Share of crop income	0.738	(0.258)	0.775	(0.261)	
Share of livestock income	0.106	(0.167)	0.082	(0.150)	
Share of non-farm income	0.098	(0.194)	0.095	(0.216)	
Share of non-labor income	0.058	(0.110)	0.048	(0.113)	
Share of rice income	0.182	(0.254)	0.170	(0.226)	
Plot characteristics					
Share of rice plots with					
Bunding	0.564	(0.497)	0.592	(0.492)	
Leveling	0.632	(0.483)	0.581	(0.494)	
Transplanting	0.588	(0.493)	0.599	(0.491)	
Line planting	0.139	(0.346)	0.054	(0.227)	
Improved variety (k-series)	0.091	(0.288)	0.097	(0.297)	
Fertilizer use	0.084	(0.279)	0.051	(0.219)	
Rice yield (ton/ha)	2.569	(1.623)	2.420	(1.742)	
Income from rice (USD/ha)	634.9	(507.4)	713.1	(848.5)	
Walking time from homestead to rice plot (mins)	35.64	(35.47)	32.29	(32.91)	
Plot size (ha)	0.705	(0.666)	0.730	(0.818)	
Plot tenure: owner[a]	0.520	(0.500)	0.455	(0.499)	
Plot tenure: tenant[a]	0.291	(0.455)	0.310	(0.464)	

For all variables, the means of two groups are not statistically different at 5 % level

[a] Reference group is occupant

[b] *Indicates that mean between treatment and control groups is significantly different at 5 % level

Table 4.9 Household characteristics by training participation in case study sites in 2009 (before matching)

	Training participants (treatment)		Non-participant (control)		Diff in means[b]
	Means	(s.d.)	Means	(s.d.)	
Number of observations	82		218		
Household characteristics					
Number of household members	6.743	(2.956)	7.830	(3.735)	*
Share of male members aged 15–64	0.283	(0.231)	0.242	(0.149)	*
Share of female members aged 15–64	0.264	(0.151)	0.246	(0.135)	
Female headed household dummy	0.024	(0.155)	0.064	(0.246)	
Head's age	39.90	(11.54)	40.77	(13.33)	

(continued)

Table 4.9 (continued)

	Training participants (treatment)		Non-participant (control)		Diff in means[b]
	Means	(s.d.)	Means	(s.d.)	
Head's years of schooling completed	5.829	(3.150)	5.791	(3.927)	
Land owned (ha)	0.836	(1.501)	1.670	(1.615)	*
Ownership of bull (dummy variable)	0.073	(0.262)	0.358	(0.480)	*
Rice cultivation experience (years)	8.122	(6.743)	9.151	(8.795)	
Rice cultivated area (ha)	0.385	(0.413)	0.395	(0.304)	
Share of rice area (out of cultivated land)	0.272	(0.219)	0.201	(0.184)	*
Per capita income (USD)	169.4	(150.2)	137.4	(137.6)	
Per capita expenditure (USD)	264.7	(127.5)	280.2	(155.8)	
Share of agricultural income	0.689	(0.322)	0.549	(0.296)	*
Share of livestock income	0.061	(0.131)	0.176	(0.223)	*
Share of non-farm income	0.209	(0.314)	0.242	(0.283)	
Share of non-labor income	0.049	(0.129)	0.052	(0.111)	
Plot characteristics					
Share of rice plots with					
Bunding	0.974	(0.159)	0.719	(0.451)	*
Leveling	0.838	(0.370)	0.595	(0.493)	*
Transplanting	0.923	(0.268)	0.634	(0.483)	*
Line planting	0.718	(0.452)	0.124	(0.331)	*
Improved variety (k-series)	0.829	(0.378)	0.490	(0.502)	*
Fertilizer use	0.043	(0.203)	0.007	(0.081)	*
Rice yield (ton/ha)	3.05	(2.03)	2.11	(1.89)	*
Income from rice (USD/ha)	1327.3	(1327.5)	905.09	(1496.6)	*
Distance from homestead to rice plot (km)	0.718	(0.452)	0.124	(0.331)	*
Plot size (ha)	0.215	(0.168)	0.297	(0.206)	*
Plot tenure: owner[a]	0.308	(0.464)	0.556	(0.499)	*
Plot tenure: tenant[a]	0.641	(0.482)	0.386	(0.488)	*

*Indicates the means of two groups are statistically different at 5 % level

[a] Reference group is occupant

[b] *Indicates that mean between treatment and control groups is significantly different at 5 % level

Table 4.10 Rice cultivation by recipient status of guide book in extensive survey in Uganda in 2011

	Received guidebook (treatment)		Not received (control)		Diff in means[b]
	Mean	s.d.	Mean	s.d.	
Household level					
Number of households	288		282		
% of households who grew rice	0.550	0.498	0.532	0.500	
Rice cultivated area (ha)	0.332	0.601	0.295	0.477	
Rice cultivated area (ha) (among growers)	0.607	0.702	0.554	0.533	
Share of rice area (out of cultivated land)	0.154	0.196	0.146	0.187	
Share of rice area (among rice growers)	0.280	0.185	0.275	0.173	
Income from rice (USD/ha)[a]	731.8	(825.0)	713.1	(872.8)	
Per capita income (USD)[a]	209.7	(234.9)	201.0	(180.5)	
Per capita expenditure (USD)[a]	263.8	(206.2)	257.9	(259.4)	
Share of crop income	0.760	(0.242)	0.775	(0.267)	
Share of livestock income	0.133	(0.184)	0.082	(0.216)	
Share of non-farm income	0.059	(0.153)	0.095	(0.141)	
Share of non-labor income	0.048	(0.109)	0.048	(0.107)	
Share of rice income	0.135	(0.214)	0.136	(0.208)	
Number of lowland rice plots	206		188		
% of plots with:					
Bunding	73.8	(44.1)	67.0	(47.1)	
Leveling	76.7	(42.4)	74.6	(43.7)	
Transplanting	57.8	(49.5)	54.6	(49.9)	
Transplanting in rows	9.22	(29.0)	1.62	(12.7)	*
Improved seeds	12.1	(32.7)	5.41	(22.7)	*
Fertilizer use	6.80	(25.2)	1.62	(12.7)	*
Yield (ton/ha)	2.23	(1.57)	2.35	(1.75)	
ln(rice income USD/ha)[a]	6.26	(1.26)	6.36	(1.14)	

[a] Deflated into 2009 price level

[b] *Indicates that mean between treatment and control groups is significantly different at 5 % level

Table 4.11 ATT without matching in extensive survey data in ES 2011

	Treatment (recipient)	Control (non-recipient)	ATT	s.e.[a]
Plot level	(1)	(2)	(3)	(4)
Adoption of cultivation practice				
Bunding	0.738	0.670	0.068	0.046
Leveling	0.767	0.746	0.021	0.044
Transplanting	0.578	0.546	0.032	0.050
Transplanting in rows	0.092	0.016	0.076	0.023***

(continued)

Table 4.11 (continued)

	Treatment (recipient)	Control (non-recipient)	ATT	s.e.[a]
Plot level	(1)	(2)	(3)	(4)
Improved variety (k-series)	0.121	0.054	0.067	0.029**
Chemical fertilizer use	0.068	0.016	0.052	0.021**
Yield (ton/ha)	2.23	2.35	0.12	0.17
Ln(rice income (USD/ha))	6.256	6.357	0.101	0.130
Household level				
Growing rice (dummy)	0.512	0.295	0.217	0.185
Area under rice (ha)	0.550	0.532	0.018	0.042
Share of area under rice over cultivated land	0.154	0.146	0.008	0.016
ln(per capita income)	4.728	4.857	0.129	0.092
ln(per capita expenditure)	5.365	5.370	0.004	0.049

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

Chapter 5
On the Possibility of Rice Green Revolution in Rainfed Areas in Northern Ghana: An Assessment of a Management Training Program

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Abstract This chapter investigates the impact of technical intervention on the adoption of a set of improved rice production technologies, as well as on productivity and profit for smallholders in rainfed lowland areas in Northern Ghana. The key finding is that productivity and profit are significantly enhanced when modern varieties (MVs) and chemical fertilizer are adopted, coupled with water control techniques. This is essentially the transfer of the Asian Green Revolution to sub-Saharan Africa. Such transfer, however, is not truly successful unless information about the use of MVs and fertilizer are directly disseminated by extension activities.

Keywords Rice technology • Impact assessment • Rainfed ecology • SSA • Asian Green Revolution

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This chapter draws on deGraft-Johnson et al. (2014)

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5.1 Introduction

One management training program designed to realize an Asian rice Green Revolution (GR) is the Lowland Rice Development Project (LRDP), which was implemented in Northern Ghana (Mercer-Quarshie 2000). The project, which spanned from 1998 to 2003, was funded by the Agence Francaise de Development (AFD) of France in collaboration with the Ministry of Food and Agriculture (MOFA) of Ghana. The objective of the project was to enhance rice production through the adoption of improved technologies and management practices as well as to improve the processing and marketing of rice. In an effort to help smallholders overcome production challenges such as periodic droughts and poor soil quality, the project introduced to the farmers water and soil conservation techniques such as bunding and leveling.[1] The project also promoted the adoption of MVs, chemical fertilizer application and dibbling, which are designed to be yield enhancing.[2] These five technologies are referred to as improved technologies in this chapter. Since these technologies, except for dibbling, are core technologies of the Asian GR, this study amounts to assessing the transferability of the Asian rice GR to rainfed area in SSA, using micro-level data of 545 smallholder lowland rice farmers in Northern Ghana.[3]

It is well known from the experience in Asia that the dissemination of MVs was mainly limited to irrigated and favorable rainfed areas, even though the dissemination area expanded further to less favorable areas in later periods (David and Otsuka 1994; Estudillo and Otsuka 2006). In light of this, extensive studies have been conducted regarding the impact of improved technology adoption under irrigated conditions in SSA (Kajisa and Payongayong 2011; Nakano and Otsuka 2011). We extend the existing studies by examining the impact of the adoption of MVs, fertilizer and improved water management practices in rainfed areas.

The specific objectives of this chapter are (1) to explore how small-scale farmers in the project communities have responded to the promotion of improved technologies, (2) to examine how technology is disseminated to surrounding communities, and (3) to assess the effect of technology adoption on productivity and profitability in both the project and non-project communities under rainfed conditions.[4] Since

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[1] Bunding and leveling ensure that water stored on the field is evenly distributed, and this promotes the uniform growth of plants as well as controls the growth of weeds. Adoption of these technologies implies that less time will be spent on crop care management. Planting by dibbling, which is usually practiced in upland field, helps ensure the efficient use of seeds and facilitates weeding, the application of fertilizer and harvesting.

[2] Note that some farmers in the region may have had prior knowledge of some of these technologies due to the introduction to large-scale irrigation schemes such as the Tano, Vea and Botanga constructed during the 1970s (Kranjac-Berisavljevic et al. 2003; Namara et al. 2011). However, because the adoption rates were much lower prior to the project phase (Table 5.2), the LRDP introduced these technologies formally to the communities.

[3] Dibbling is seldom adopted in lowland rice farming in Asia.

[4] We are interested in the knowledge transfers between farmers, rather than through formal teaching intervention delivered by professional instructors/extension workers.

rainfed ecology is dominant in SSA, the empirical findings from this study would contribute to the design of future technology promotion projects of a similar nature.

The rest of the paper is organized as follows. Section 5.2 explains the survey design and sampling structure, and provides descriptive analyses of the improved technology adoption and its impact. Section 5.3 discusses the analytical framework for the improved technology adoption, and the estimation of yield and profit functions. The empirical results are presented in Sect. 5.4, while the conclusion and policy implications are presented in Sect. 5.5.

5.2 Data and Descriptive Statistics

5.2.1 Survey Design and Sampling Structure

The LRDP was implemented by MOFA in 58 communities (natural villages) in three selected districts around Tamale, the capital city of Northern region. For our study, we randomly selected 20 communities from the list of 58 project communities. Then, with the help of 1/50,000 scale topographic sheets, we randomly selected 20 non-project communities within a 20 km radius from any of the project communities, and another 20 non-project communities located beyond the 20 km radius, in order to assess how information is diffused across geographical peers. In this chapter, we designate the former as "nearby" communities and the latter as "remote" communities relative to the project sites. In this way, we selected 60 communities for our study (see Fig. 5.1). The survey was conducted in May 2010 and August 2011 in collaboration with Savanna Agricultural Development Institute (SARI) located in Nyankpala, 15 km away from Tamale. During the first survey in 2010, we

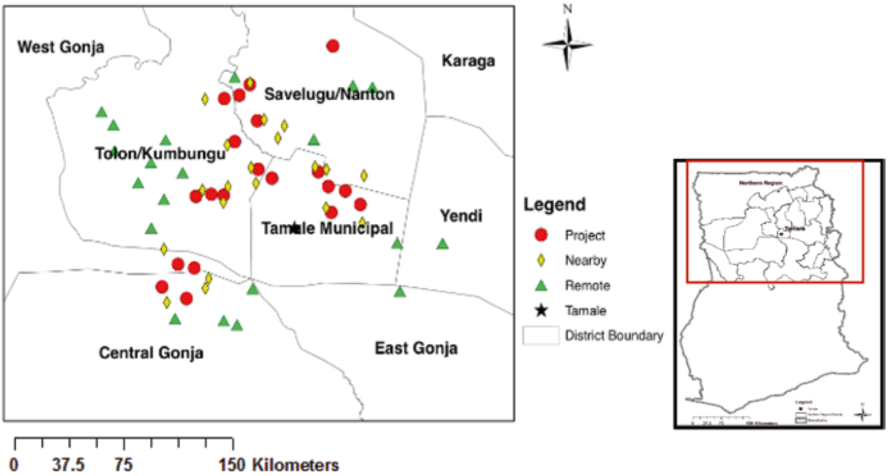

Fig. 5.1 Map of survey region – northern Ghana (Source: Survey data on rice production in 2010)

collected community-level information and applied a random sampling of 10 rice farmers in each of the 60 communities. Subsequently, the household survey in 2011 gathered data on a broad range of socioeconomic variables, farming practices, institutional factors, input use and rice production, and the history of technology adoption regarding the periods when the farmers first adopted the improved technology, whether they discontinued its use and if so whether they re-adopted after disadoption. Although the total number of sample households was 600, due to incomplete data and outliers only 545 households are used in this analysis.

5.2.2 Overview of Rice Production in Ghana and Study Area

Rice has become a major staple in Ghana and is currently the third most important grain after maize and sorghum. Rice accounts for about 15 % of the agricultural gross domestic product, and the per capita annual consumption of milled rice as of 2010–2011 was 24 kg per annum (Kranjac-Berisavljevic et al. 2003; MOFA 2010). The continuous growth in the consumption of rice, particularly among urban dwellers, is due to the ease of preservation and cooking and the effective marketing strategies of importers. However, the increasing growth in demand has not been backed by local production. As a result, the value of rice imports has increased from $65 million in 2000 to $201 million in 2010, amounting to 39.4 % of domestic consumption (MOFA 2010). Scarce foreign reserves are therefore channeled to rice importation instead of importing more productive capital goods and intermediate inputs. Interestingly, studies conducted by MOFA have shown that Ghana has a huge potential to increase its paddy rice production, under rainfed condition, from an average yield of 2.4 t/ha to 6.5 t/ha, with more effective extension and the use of recommended technologies (MOFA 2010).[5] The report by Asuming-Brempong (1998) also places Ghana at a comparative advantage compared to other countries in the sub-region in the production of paddy rice. Generally, rice can be grown in almost all parts of the country, but the major producing regions are Upper East region, Northern region and Volta region. Of the three, the Northern region produces the bulk of the nation's paddy rice. This study, therefore, focuses on lowland rice farming in Northern Ghana.

The study area is located in the northern part of Ghana, and Tamale is the regional capital.[6] The rainfall distribution in this region is uni-modal, and this results in a single growing season. The mean annual rainfall ranged from 880 mm in 2001 to 1,292 mm in 2010 with a 10-year average of 1,204 mm in the 2000s (MOFA 2010). Rice farming in the region is mostly carried out by small-scale farmers who depend entirely on rainfall for production. However, farming in the lowland areas is often

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[5] The target yield of 6.5 t/ha is too ambitious in view of the fact that the average yield in Asia is 4 t/ha.

[6] Northern region is the largest of the ten regions in Ghana and is a sparsely populated region.

hampered by frequent flooding from precipitation and ground water. The average monthly rainfall over the past decade (2001–2010) in Tamale and its environs varied from as low as 3.2 mm in January to as high as 228.2 mm in August according to the data gathered from the Ghana Meteorological Agency (GMET). The onset of the raining season in the region is usually from April to September/October with the maximum amount of rainfall is recorded in August. The rainfall data from the GMEt also showed that over the past decade the maximum rainfall amount recorded in August varied from as low as 88.1 mm in 2005 to as high as 334.6 mm in 2008 with an average of 228.2 mm. The variability of rainfall and periodic droughts often have a damaging effect on the rice harvest. In the quest to improve the productivity of the rice sector, the AFD, in collaboration with MOFA, implemented the Lowland Rice Development Project (LRDP) in parts of Tamale. The main objective of the project, which spanned from 1998 to 2003, was to increase rice productivity, by introducing the Asian-type modern rice varieties, chemical fertilizer and improved production management practices such as bunding and leveling, which are common in Asia.

5.2.3 Descriptive Analyses

5.2.3.1 Characteristics of Sampled Households and Survey Communities

First let us assess how well small-scale farmers have responded to the promotion of the five improved technologies and examine the rate of disadoption in the region. Table 5.1 shows the socioeconomic and plot characteristics of the surveyed communities. The project and nearby communities are quite homogenous in terms of household, plot and community characteristics. The soils in the surveyed region have a light to slightly heavier texture with various variations – sandy, loamy, laterite and clay. The only significant differences are that the project communities have relatively smaller farm sizes with good water retention capacity represented by clay soil. There are no significant differences among the three categories of communities in terms of formal education, age, family labor endowment and community paddy price. However, we observe a number of significant differences when we compare the project and nearby communities with the remote communities. In terms of the household characteristics, the farmers from the project and nearby communities have longer years of rice farming experience than those from the remote communities. In addition, the remote communities have relatively larger farm size, and the distance from homestead to these farms is much farther. In some instances, the farmer has to walk for over 4 h to visit the farm. The scarcity of labor relative to land in these communities could account for the significantly high community wage rates recorded for the remote communities, which is shown under the community characteristics in the table.

Table 5.1 Socioeconomic and plot characteristics of surveyed communities in Ghana

	Project communities		Non project communities			
	Project		Nearby		Remote	
Number of households	178	*Diff*	181	*Diff*	186	*Diff*
Household characteristics						
Formal education (%)	8.0		10.0		7.0	
Non-farm income (%)	25.0		30.0		37.0	*c**
Member of local farmers group (%)	71.0		65.0		60.0	*c**
Age of household head (years)	46.58		46.70		44.89	
	(16.08)		(15.99)		(15.84)	
Experience in rice farming (years)	9.47		8.59	*b**	6.29	*c**
	(7.21)		(7.60)		(5.97)	
Rice farming experience prior to LRDP (years)	1.88		1.77		0.66	*c**
	(4.76)		(5.31)		(4.23)	
Family labor (15–65 years)	5.47		5.75		5.48	
	(2.79)		(2.98)		(3.48)	
Total farm size (ha)	2.81	*a**	3.30	*b**	4.36	*c**
	(2.06)		(2.37)		(3.79)	
Rice cultivating area (ha)	0.99		1.19		1.41	*c**
	(0.63)		(1.18)		(1.53)	
Maize cultivating area (ha)	1.34		1.31	*b**	1.60	
	(1.18)		(0.97)		(1.27)	
Plot characteristics						
Soil with good water retention – clay (%)	69.0	*a**	56.0	*b**	68.0	
Land slope -flat slope dummy (%)	62.0		71.0	*b**	82.0	*c**
Walking from homestead to farm (min)	24.07		27.86	*b**	48.71	*c**
	(21.71)		(29.10)		(65.70)	
Community characteristics						
Distance from community to district capital (km)	21.55		20.63	*b**	30.94	*c**
	(8.80)		(7.34)		(8.60)	
Distance from non-project community to nearest project community	0.00		2.98	*b**	12.42	*c**
			(1.66)		(6.24)	
Community price for paddy (USD/kg)	0.22		0.23		0.20	
	(0.04)		(0.04)		(0.04)	
Community standard wage (USD/day)	1.29		1.46	*b**	1.93	*c**
	(0.46)		(0.42)		(0.62)	
Number of community	19		19		20	

Source: Survey data on rice production in 2010

a*Is the significant difference in means between project communities and nearby zones at the 5 % level

b*Is the significant difference in means between nearby communities and remote zones at the 5 % level

c*Is the significant difference in means between project communities and remote zones at the 5 % level

5.2.3.2 Adoption of Improved Technology

Now let us explore the technology adoption pattern based on the recall survey on the adoption history and the household's current adoption status.[7] To aid the analyses, the farmers were stratified into five groups. First, the early adopters (pre–LRDP) are farmers who adopted the technology before the LRDP phase (1997 and before) and are still using the technology. The second, the mid-adopters (LRDP) are those who adopted the technology during the LRDP phase (1998–2003) and are still using the technology. The third group, the late adopters (post–LRDP), are farmers who adopted the technology after the project phase (2004–2010) and are still using the technology. The fourth group, the disadopters are those who adopted the technology before and discontinued the use of the technology by 2010. Non-adopters, the last group, are those who have never used the technology as of 2010. In binary terms, the current users of the technology include the early adopters, mid-adopters and late adopters. The current non-users are the disadopters and the non-adopters.

Table 5.2 shows the means of the adoption classifications for each of the five technologies. As observed in column (1) of the table, fewer than 6 % of the farmers were using any of the technologies before the project intervention. The notable technologies are chemical fertilizer (5.1 %) and leveling (4.2 %). This group of early adopters might have realized the importance of these technologies through self-experimentation or from other farmers, since farmers often experiment on their own or learn from the experiences of others. The percentage of adopters increased moderately in the project communities during the project phase for all five technologies, especially for MVs. In column (3) of the table, we observe that many of the late-adopters (post–LRDP) of leveling, dibbling, MVs and fertilizer are from the nearby communities. The percentage for the late adoption of leveling, MVs and fertilizer increased in the remote communities. The increase in the number of adopters for the non-project communities could be due to information and knowledge obtained from the project communities.

Figure 5.2 displays the relative comparison of the adoption of the five technologies. Overall, the most widely adopted technologies are MVs and fertilizer. Bunding is the least popular, and less than 25 % of the farmers have adopted this technology. Table 5.3 shows the extent to which farmers have adopted improved technologies but subsequently discontinued their use. A relative comparison between the current adopters and farmers who have ever used the technology shows a generally low trend of disadoption with the exception of dibbling. We observe that the share of disadoption of dibbling among the ever-adopted is close to 42 %, which suggests that this technology might not be appropriate for the farming communities in this area. If that is the case, then further analysis needs to be conducted to explain why. According to our interviews, the major constraints on the continuous use of dibbling

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[7] Using farmer recall we obtained information regarding when the farmer first adopted the technology, whether the farmer discontinued the use of technology after adoption, and whether the farmer re-adopted after disadoption. We used the Lowland Rice Development Project (LRDP) as the reference period for the classification.

Table 5.2 Means of adoption classification for the five improved technologies in Ghana (%)

Improved practices	Current adopters			Current non-adopters		Total sample
	Pre-LRDP phase (1)	LRDP phase (2)	Post-LRDP phase (3)	Dis-adopters (4)	Non-adopters (5)	
Bunding	(6)	(59)	(69)	(23)	(388)	(545)
Project	0.4	8.3	6.6	3.5	13.9	
Nearby	0.7	1.7	5.3	0.7	24.8	
Remote	0.0	0.9	0.7	0.0	32.5	
Total	1.1	10.8	12.7	4.2	71.2	100.0
Leveling	(23)	(76)	(189)	(51)	(206)	(545)
Project	1.7	7.7	8.3	3.9	11.2	
Nearby	1.8	3.3	14.5	4.8	8.8	
Remote	0.7	2.9	11.9	0.7	17.8	
Total	4.2	13.9	34.7	9.4	37.8	100.0
Dibbling	(14)	(42)	(82)	(100)	(307)	(545)
Project	0.7	4.6	5.3	8.3	13.8	
Nearby	1.5	1.8	6.8	7.3	15.8	
Remote	0.4	1.3	2.9	2.8	26.8	
Total	2.6	7.7	15.0	18.3	56.3	100.0
MV	(11)	(100)	(302)	(20)	(112)	(545)
Project	0.6	12.5	16.3	1.1	2.2	
Nearby	0.7	2.8	20.7	0.7	8.3	
Remote	0.7	3.1	18.3	1.8	10.1	
Total	2.0	18.3	55.4	3.7	20.6	100.0
Fertilizer	(28)	(105)	(269)	(50)	(93)	(545)
Project	2.8	11.4	16.1	1.3	1.1	
Nearby	1.7	4.6	18.3	3.5	5.1	
Remote	0.7	3.3	14.9	4.4	10.8	
Total	5.1	19.3	49.4	9.2	17.1	100.0

Source: Survey data on rice production in 2010
The number of observations is in parenthesis

technology include: the labor intensive nature of the technology (47 %), lack of cash to pay hired laborers (24 %), excessively large farm size (7 %), and flooded fields, which made dibbling impossible (22 %). We use regression analysis to investigate what led farmers to disadopt this technology in Sect. 5.3.2.

5.2.3.3 Impact of Technology Adoption

For the assessment of the introduction of any new technology it is informative to undertake a factor-share analysis and examine the possible factor use bias in the technology choice (David and Otsuka 1994; Kijima et al. 2008). For this analysis,

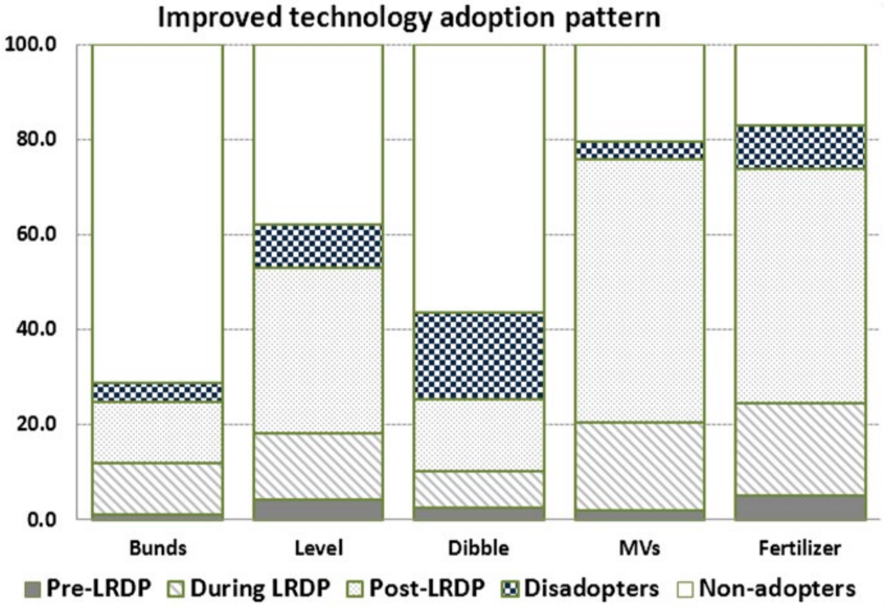

Fig. 5.2 Relative comparison of the adoption trend among the five technologies in Ghana (Source: Survey data on rice production in 2010)

Table 5.3 Rate of disadoption of the five improved technologies in Ghana (%)

	Improved technologies				
	Bunding	Leveling	Dibbling	MVs	Fertilizer
Farmers who have ever used the technology (by 2010)	28.8	62.2	43.7	79.4	82.9
Current adopters of the technology (in 2010)	24.6	52.8	25.3	75.8	73.8
Share of disadopters among those who ever adopted of which[a]	14.6	15.1	42.1	4.5	11.0
Project community	18.6	17.9	43.7	3.6	4.1
Nearby community	8.7	19.5	42.1	2.9	12.4
Remote community	0.0	4.5	37.5	7.6	18.9

Source: Survey data on rice production in 2010

[a] shows the share of disadopters in terms of the survey communities

we stratified the farmers into non-adopters, partial adopters and package adopters. Our earlier estimation, which is not reported here, showed that the most popular combination of technology choice in the region is MVs and fertilizer.[8] Hence, based on this finding we examine the impact of four possible combinations to investigate the potential gains from adopting a set of practices. These combinations include: (1) the adoption of only modern inputs (MVs and fertilizer), (2) the adoption of modern inputs and water control practices only (MVs, fertilizer, bunding, and leveling), (3) the adoption of at least modern inputs and water control practices, and (4) package adoption (MVs, fertilizer, bunding, leveling and dibbling). Table 5.4 summarizes the input and output relationship and factor shares. Rice income is calculated as the value of production per hectare minus the actual paid out cost per hectare, which includes the costs of current inputs (seeds and fertilizer cost), machinery services, and hired labor. The total cost is the sum of the actual paid out cost and the imputed cost of family labor days used in production. The cost of current inputs and machinery are computed using the prevailing prices at the time of the survey (August, 2011). For the imputed family labor we used the average wage rate observed in the community.[9] The profit (net return) is derived as the value of production less the total cost per hectare. Thus, the profit is expected to capture the returns to land and management ability.

The value of production per hectare for package adopters (column (5)) is significantly higher than that of the partial adopters (columns (2–4)) and almost twice that of the non-adopters (column (1)). The factor shares of labor, which is defined as the sum of the hired labor cost and the imputed cost of family labor divided by the value of production, are similar across the three cases, indicating that new technologies are largely factor neutral. We observe that although package adopters incur a higher cost of labor and current inputs due to the use of more labor intensive practices and cash intensive technologies, the net return for the package adopters is twice that of the partial and almost thrice that of the non-adopters. Another interesting finding is that the net return for the adoption of only modern inputs is much smaller than that of the non-adopters. This is due to the high input cost, especially of labor. The yield difference between the two groups is relatively small. This suggests that the adoption of modern inputs without water management practices requires more labor for crop care without increasing yields significantly under rainfed conditions. Hence, we can deduce from these observations that the net returns to technology adoption are much higher when all the technologies are adopted as a package. However, since the choice of technologies is endogenous, the simple comparison of the net returns can be biased. Therefore, we would like to confirm these findings more rigorously using regression analysis in Sect. 5.3.3. In terms of capital use, although a greater percentage of the farmers use tractors for land preparation, the factor share is relatively lower for package adopters (5.6 %).

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[8] We used the multivariate probit to examine the possible technology combination for the five technologies. The result of this estimation is not provided here.

[9] It should be noted that the wage rate used for the imputation of family labor cost is not activity-specific, as wage rates are similar across different tasks.

Table 5.4 Factor payments (USD/ha) and factor share (%) in terms of various technology combinations in Ghana

		Partial adopters			
	None	Modern inputs only	Modern inputs + bunding + leveling	At least modern inputs + bunding + leveling	Package
	(1)	(2)	(3)	(4)	(5)
Production					
Yield (tons/ha)	1.46	1.70	1.98	2.33	2.59
Value of production (USD/ha) (A)	304.07	377.04	444.90	524.26	586.73
Current input cost	56.86	112.10	120.73	135.93	147.90
	(18.7)	(29.7)	(27.1)	(25.9)	(25.2)
Seed cost	24.00	25.41	22.38	25.90	28.68
Fertilizer cost	0.00	53.77	70.81	79.49	86.32
Machinery services	32.86	32.92	27.54	30.54	32.90
	(10.8)	(8.7)	(6.2)	(5.8)	(5.6)
Labor cost	188.03	236.14	234.93	259.70	279.19
	(61.8)	(62.6)	(52.8)	(49.5)	(47.6)
Hired labor cost	19.39	52.74	85.67	73.74	64.35
Imputed family labor cost	168.64	183.40	149.26	185.95	214.84
Total paid-out cost (B)	76.25	164.84	206.40	209.67	212.25
Total cost (C)	244.89	348.24	355.66	395.63	427.09
	(80.5)	(92.4)	(79.9)	(75.5)	(72.8)
Income (A) − (B)	227.81	212.21	238.49	314.58	374.48
Profit (net return) (A) − (C)	59.18	28.81	89.24	128.63	159.64
	(19.5)	(7.6)	(20.1)	(24.5)	(27.2)
Labor share[a] (%)	61.8 %	62.6 %	52.8 %	49.5 %	47.6 %
Family labor (man-days/ha)	90.71	119.96	129.87	170.95	203.29
Hired labor (man-days/ha)	11.49	32.27	73.75	66.70	61.15
Number of observations	63	78	37	84	47

Source: Survey data on rice production in 2010
Numbers in parentheses are the factor shares in percentage terms
[a] Total labor cost divided by value of production

On the whole, the results suggest that there are net gains by the adoption of improved technology. Indeed, package adopters attain much higher yields and net profits (2.6 t/ha and 159.6 USD/ha) than partial adopters. It should be noted that this yield level is comparable to the yield in rainfed areas of Asia in the late 1980s when MVs were largely adopted, suggesting that comparable yields can be attained in SSA if new technologies are completely adopted (David and Otsuka 1994). It is also worth mentioning that the yield of 1.46 t/ha for the non-adopters is probably close to the average yield of rice under rainfed condition in SSA at present and the average yield in Asia before the GR (Balasubramanian et al. 2007).

5.3 Methodology and Variable Construction

5.3.1 Determinants of Improved Technology Adoption

In this sub-section, we investigate the determinants of improved technology adoption using two logit regression functions. A major challenge in assessing new technology adoption is the presence of unobserved factors that may cause endogeneity in the estimation. The use of panel data in a randomized-control-and-trial setting is more preferable, but since we have cross-sectional data with historical data on adoption, we rely on logit regression, by separating the innovators and all current adopters. Here, the farmers who adopted the technology before and during the LRDP and continue to use the technology are considered as innovative farmers. In the first function, the dependent variable (adoption decision) is 1 if the farmer is an innovative farmer and zero otherwise. In the second function, the dependent variable is 1 if the farmer is currently using the technology and zero otherwise.[10] The current adopters in this case include the innovators and the post–LRDP adopters.

The community-level explanatory variables used in the models are the wage rate (USD/day), community paddy price (USD/kg) and the distance to the district capital, Tamale (km). The community wage rate is used as a proxy for the cost of hired labor as well as the opportunity cost of family labor. A higher wage rate may have a negative effect especially on the adoption of labor intensive technologies. The distance from the community to the district capital is used as a proxy for access and proximity to a central market. We control for the effects of the LRDP and of the dissemination of information across geographical communities by including the project community dummy and the distance from the non-project community to the nearest project community (km). We predict that the closer the non-project communities to the project communities, the higher the probability of obtaining information from the project community and, hence, the higher the likelihood of adoption. Although we recognize that the distance to the nearest project community may capture various effects other than technology information, we follow the convention in the technology adoption literature that uses distance to measure access to information (e.g., Amare et al. 2012). Moreover, as will be shown later, this variable is significant in several regression estimates. The project community dummy is predicted to capture the direct learning effect of the project.

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[10] The multinomial logit regression model is also used to check the robustness of our estimation method and to compare the significance of key variables. The dependent variable in this case has four categories (pre–LRDP adopter, during–LRDP adopter, post–LRDP adopter and non-adopter). The estimation result, which is found to be consistent with the logit regression models, is provided in the Appendix Tables 5.9, 5.10, 5.11, 5.12, and 5.13.

The plot characteristics are captured by the land slope, the soil type and the walking distance between the farm and the homestead (minutes). The farmers in the survey communities perceive clay soil to be of high quality and conducive to rice cultivation, and hence, a clay soil dummy is used as a proxy for soil of high quality. We also controlled for flooding, which is a serious problem in the region and possibly an important factor in deciding whether to adopt water control technologies. We do so by including the land slope dummy which takes a value of 1 if the plot is perceived to be flat and zero otherwise because flat land is more prone to flooding relative to steep land.

The household variables include education (formal level), age and experience of the household head, family labor endowment (the number of economically active members of the household between 15 and 65 years of age), and total farm size. Experience pertains to the household head's rice farming experience prior to the implementation of the LRDP.

5.3.2 Determinants of Dibbling Disadoption

Since the disadoption rate of dibbling is very high, the question raised is whether this technology is appropriate for Northern Ghana. Thus, we attempt to explore the determinants of dibbling disadoption using the multinomial logit regression model. Here, the dependent variable has three outcomes – disadopters, continuous adopters and non-adopters. The explanatory variables used are the same as earlier.

5.3.3 Determinants of Yield and Profit

To assess the impact of improved technology adoption on productivity and profitability, we estimate two regression function, the yield function and the profit function, using the same model specification. The dependent variable of the yield function is the paddy yield in tons per hectare, while the dependent variable of the profit is the residual profit in USD per hectare. The dependent variable in each case is expressed as a function of technology, input prices, and other exogenous factors such as socioeconomic and farm characteristics. However, since the technology variable of interest is considered as an endogenous binary choice variable, the estimation may suffer from the selection bias, i.e., those farmers achieving higher yields may have done so even without adopting the technology due to some unobserved factors. Experimental panel data would allow us to obtain unbiased estimates; however, it is not always available. Several methods are used in the evaluation literature to correct for this bias for cross-sectional data, such as the propensity-score matching method (e.g., Faltermeier and Abdulai 2009), the endogenous switching regression model (e.g., Amare et al. 2012), and the instrumental variable method. In our case, we applied the treatment effects model (TEM), which is a variant of the

Heckman two-step model and is essentially the same as the Roy model or endogenous switching regression model (Cameron and Trivedi 2005; Guo and Fraser 2009). The TEM models the selection bias specifically in the selection equation rather than assuming it random as explained below. We did not use the propensity-score matching method because it does not control the unobserved heterogeneity among the sample. We preferred the TEM over the IV as one of the conditions for an instrument for the IV method cannot be tested (i.e., the instrument is not correlated with the outcome equation) and thus it is difficult to guarantee the validity of the instrument (Guo and Fraser 2009).

The TEM is given as:

$$\begin{gathered} y_i = \beta_i X_i' + \delta T_i + \varepsilon_{i,} \\ i = 1,2\ldots..545, \end{gathered} \tag{5.1}$$

where y_i is a dependent variable that represents an outcome (either yield or profit); X_i' represents a vector of explanatory factors; β_i is a vector of coefficients parameters for X_i'; T_i is the technology adoption status and represents the binary outcome of the probit model; δ is the coefficient estimator for the technology (the outcome of the probit model) and ε_i is the error term. To account for the endogeneity of technology (T_i), we introduce an unobserved latent variable (T_i^*) that determines whether technology is adopted or not $\left(i.e.\ T_i{}^* = 1 or 0\right)$. The treatment ($T_i$) is modeled by a probit model and specified as:

$$T_i^* = \gamma W_i' + \upsilon_i, \tag{5.2}$$

where $T_i = \begin{cases} 1 & if\, T_i^* > 0 \text{ i.e. famer used technology} \\ 0 & otherwise \end{cases}$.

The adoption of improved technology in Eq. 5.2 is specified as a function of a set of explanatory factors (W_i'). Here, we include the walking time from the homestead to the farm, which proves to be a significant determinant of technology adoption in the technology function. γ is a vector of unknown parameters and υ_i is the error term. The assumption made here is that the error terms (ε_i, υ_i) are bivariate normal with mean zero and covariance given as $Cov\left(\varepsilon_i, \upsilon_i\right) = \rho\sigma^2$. If the correlation between the error terms (denoted as ρ) is zero, then there is no endogeneity problem and the two error terms are independent. The estimation of the treatment effects model is done using either a maximum likelihood (MLE) approach or the two-step estimation method. We use the MLE method since it estimates the technology adoption equation and the profit or yield equation jointly, and hence, enables us to test for endogeneity (Cameron and Trivedi 2009; Greene 2008).

Here, we consider a reduced form with specific technology combinations. That is, we focus only on the impact of technology adoption on yield and profit and do not consider explicitly the use of other inputs, such as labor or tractor use due to endogeneity problems. For the factor payment analysis in Sect. 5.2.3.3, we classify the status of technology adoption into four groups: adoption of modern inputs only (MVs and fertilizer), adoption of modern inputs and water control practices only

(MVs, fertilizer, bunding, leveling), adoption of at least modern inputs and water control practices, and package adoption (MVs, fertilizer, bunding, leveling and dibbling). However, for the regression analysis, the use of a dummy variable for the adoption of modern inputs only, as well as the use of dummy variables for the adoption of modern inputs and water control technology only, is not appropriate as the default group includes not only non-adopters, but also adopters of additional technologies. Therefore, we use the following two inclusive dummies: (1) at least modern inputs and water control technologies and (2) package adoption. In effect, the first specification is a subset of the second specification. As we observe that the disadoption rate of dibbling was quite high, the result in these models helps us analyze the effects of adopting dibbling technology on productivity and profit. The coefficient on the dummy for package adoption will be large if dibbling is complementary to the other technologies. The explanatory variables included in X_i' are the same as those used for technology adoption except for the walking time from the homestead to the farm.

5.4 Results

5.4.1 Determinants of Improved Technology Adoption

Table 5.5 shows the determinants of technology adoption. Columns (1–5) provide the results for the innovative farmers, while columns (6–10) show the results for all the current adopters (innovators and post–LRDP adopters). The displayed coefficients are the marginal effect on the probability of adoption, which are evaluated at the sample means. The project community dummy is found to be positive and highly significant for the adoption of modern inputs shown in columns (4–5), and (9–10), but generally not so for the other three technologies. These findings suggest that for technologies that require s ome level of technical know-how, such as the use of MVs and chemical fertilizer application, learning directly from project developers and extension agents increases the probability of adoption.[11] Similar results are reported in Amare et al. (2012) which found that contact with government and non-government extension agents increases the rate of technology adoption. The distance to the nearest project community was found to be negative and significant in the case of bunding and leveling (columns (1), (2), and (6)). One possible explanation for the

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[11] The application of chemical fertilizer requires some level of instruction in terms of the application timing and rate. The LRDP provided participating farmers with credit to purchase inputs such as seed and fertilizer. It may have contributed to the positive effect of the project community dummy on the adoption of the modern inputs. The dummy has a positive effect even after the project, implying that the learning through using such modern inputs has a long-lasting impact. Since the adoption of improved technologies might not be solely induced by LRDP, that some farmers rely on self-experimentation or learning from the experiences of other farmers, we try to interpret the regression results with caution.

Table 5.5 Estimation results of the determinants of improved technology adoption in Ghana (logit-model – marginal effects)

	Innovative adopters					All current adopters (innovators and post-LRDP adopters)				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Explanatory variable	Bunding	Leveling	Dibbling	MVs	Fertilizer	Bunding	Leveling	Dibbling	MVs	Fertilizer
Experience prior to LRDP (years)	0.001	0.012***	0.003***	0.008***	0.017***	–0.000	0.009	0.004	0.006	0.005
	(1.04)	(4.05)	(2.79)	(3.14)	(4.25)	(–0.11)	(1.61)	(1.30)	(1.21)	(1.06)
Age (years)	–0.000	0.000	0.000	–0.000	–0.001	0.001	0.001	0.002**	–0.002	–0.003**
	(–0.09)	(0.21)	(0.19)	(–0.02)	(–0.52)	(0.65)	(0.31)	(2.01)	(–1.53)	(–2.45)
Formal education (dummy)	–0.006	–0.023	–0.022	–0.055	–0.036	0.012	0.071	0.122*	–0.020	0.025
	(–0.32)	(–0.48)	(–1.39)	(–1.28)	(–0.63)	(0.24)	(0.85)	(1.65)	(–0.29)	(0.39)
Family labor (number)	0.001	0.007	0.002	0.012**	0.011	0.003	0.012	0.006	0.010	0.015**
	(0.38)	(1.32)	(1.00)	(2.15)	(1.64)	(0.56)	(1.35)	(0.86)	(1.52)	(2.12)
Total farm size (ha)	–0.001	–0.006	–0.005	–0.002	0.004	–0.004	–0.017*	–0.031***	–0.015**	–0.004
	(–0.15)	(–0.94)	(–1.41)	(–0.41)	(0.56)	(–0.58)	(–1.72)	(–2.93)	(–2.26)	(–0.52)
Soil with high water retention (dummy)	0.032**	0.003	0.020	–0.006	–0.025	–0.040	–0.182***	–0.052	–0.125***	0.013
	(2.07)	(0.09)	(1.50)	(–0.19)	(–0.62)	(–1.23)	(–3.62)	(–1.28)	*(–3.58)	(0.31)
Land slope (dummy)	–0.002	0.021	–0.021	–0.010	–0.044	–0.008	0.057	–0.045	0.082*	0.004
	(–0.19)	(0.67)	(–1.31)	(–0.31)	(–1.08)	(–0.25)	(1.05)	(–1.08)	(1.83)	(0.10)
Walking from homestead to farm (min)	–0.000	0.000	–0.001***	–0.001*	–0.001*	–0.001	0.000	0.000	0.001	0.000
	(–0.92)	(0.26)	(–2.60)	(–1.79)	(–1.72)	(–1.40)	(0.71)	(0.23)	(1.33)	(0.64)
Project community (dummy)	0.015	0.040	–0.007	0.206***	0.156***	0.053	–0.139**	–0.014	0.164***	0.201***
	(0.62)	(0.97)	(–0.44)	(3.75)	(2.81)	(1.18)	(–2.24)	(–0.31)	(4.26)	(4.88)

Nearest project community distance (km)	−0.011***	−0.008*	−0.001	0.002	−0.007	−0.027***	−0.006	−0.005	0.003	−0.007
	(−4.34)	(−1.92)	(−0.48)	(0.41)	(−1.24)	(−5.39)	(−0.96)	(−1.06)	(0.71)	(−1.62)
Community wage rate (USD/day)	−0.045*	−0.137***	−0.092***	−0.136***	−0.085**	−0.132***	−0.323***	−0.159***	−0.219***	−0.105***
	(−1.94)	(−3.95)	(−4.92)	(−3.87)	(−2.01)	(−3.19)	(−5.86)	(−3.73)	(−5.41)	(−2.79)
Distance to district capital (km)	0.001	0.006**	0.001	0.001	−0.001	0.008***	0.008**	0.004	0.010***	−0.000
	(1.29)	(2.41)	(1.09)	(0.40)	(−0.43)	(3.25)	(2.22)	(1.45)	(3.81)	(−0.08)
Community paddy price (USD/kg)	0.241	0.911**	0.163	0.183	0.950*	1.252***	2.348***	2.688***	2.673***	1.926***
	(1.28)	(2.10)	(0.92)	(0.42)	(1.82)	(2.78)	(3.37)	(5.10)	(5.04)	(3.39)
McFadden's R^2	0.211	0.143	0.199	0.190	0.184	0.217	0.123	0.145	0.223	0.178
Correctly predicted	88.073	83.119	89.908	83.486	79.633	75.963	68.440	74.495	80.734	76.514
Model X^2 − Chi^2	83.870	74.113	71.701	104.457	111.611	131.990	92.711	89.521	134.433	111.753
Number of observations	545	545	545	545	545	545	545	545	545	545

The numbers in parentheses are *t*-statistics

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

distance effects on bunding and leveling is that since these technologies are observable, the farmers in close proximity can observe and imitate without coming into direct contact with the project developers.

Rice farming experience prior to LRDP has a positive and strong impact on the innovators' adoption decisions (columns (2–5)) but has no significant impact on the all current adoption decision (columns (6–10)). The lower importance of experience on the all current adoption decisions suggests that experience has only a short-run effect on adoption. Probably, the experienced farmer is able to better assess the impact of a new technology quickly, which influences the early adoption decision. The post–LRDP adopters with less experience, however, are able to realize the benefits of improved technology through the experience of adopting new technologies and learning from neighbors. What we deduce from this finding is that in the long-run, learning substitutes experience.

Total farm size does not significantly affect the adoption of improved technologies in the earlier periods. In columns (7), (8) and (9) of Table 5.5, however, we observe an inverse and significant relationship between farm size and the adoption of leveling, dibbling and MVs at present. One possible explanation is that since the technology is found to be labor intensive, having large farm units discourages adoption in later periods. This finding is critically important because it indicates that new technologies do not favor wealthy, large farmers, as in the case of the Asian GR (David and Otsuka 1994). Further, the cost of hired labor as well as the opportunity cost of family labor, which is proxied by the wage rate, affects negatively the adoption of all five technologies.

Unexpectedly, we did not find a generally significant impact of education on the technology adoption. This variable is only positive and significant in the case of the current adoption of dibbling. This insignificant impact of education is not typically observed in adoption studies in SSA (Abdulai and Huffmann 2005; Doss and Morris 2001; Amare et al. 2012). One possible explanation for the insignificant effect might be the generally low and similar level of education among the sample farmers.

5.4.2 Determinants of Dibbling Disadoption

Table 5.6 presents the estimated effects in the dibbling function in terms of the marginal effect evaluated at the sample means. Column (1) shows the results for the disadopters of dibbling, while the results for the continuous adopters and non-adopters are provided in columns (2) and (3). The possible constraints on the continuous adoption of dibbling technology are large farm size, high wage rate, low paddy prices, poor soil type, and close proximity to the nearest project community. These findings confirm the responses we received from farmers in our interviews that the high labor intensity of dibbling was the major constraints on continuous adoption (by 47 % of the farmers). The labor-intensive nature of dibbling seems to discourage large farm owners in communities with high wage rate from the continuous use of the technology. Since the rate of disadoption of dibbling is very high, this

Table 5.6 Determinants of the disadoption of dibbling technology in Ghana (multinomial logit – marginal effect)

Explanatory variables	Dis-adopters (1)	Continuous adopters (2)	Non-adopters (3)
Experience prior to LRDP (years)	0.005*	0.006*	–0.011**
	(1.66)	(1.65)	(–2.10)
Age (years)	0.002*	0.003**	–0.005***
	(1.69)	(2.21)	(–2.95)
Formal education (dummy)	0.111	0.138*	–0.249***
	(1.47)	(1.77)	(–2.89)
Family labor (number)	0.004	0.007	–0.010
	(0.62)	(0.92)	(–1.16)
Total farm size (ha)	0.011*	–0.032***	0.021*
	(1.72)	(–2.84)	(1.84)
Soil with high water retention (dummy)	–0.071**	–0.065	0.136***
	(–1.99)	(–1.48)	(2.64)
Land slope (dummy)	0.049	–0.043	–0.006
	(1.54)	(–0.97)	(–0.11)
Walking from homestead to farm (min)	0.001	0.000	–0.001
	(1.58)	(0.40)	(–1.24)
Project community (dummy)	–0.023	–0.001	0.025
	(–0.59)	(–0.02)	(0.41)
Nearest project community distance (km)	–0.024***	–0.006	0.030***
	(–5.17)	(–1.00)	(4.59)
Community wage rate (USD/day)	0.034	–0.169***	0.135**
	(0.85)	(–3.67)	(2.51)
Distance to district capital (km)	0.003	0.005	–0.008**
	(1.02)	(1.60)	(–2.01)
Community paddy price (USD/kg)	–1.670***	2.821***	–1.152
	(–3.03)	(4.97)	(–1.64)
Chi2	180.012	180.012	180.012
Pseudo R^2	0.168	0.168	0.168
Number of observations	545	545	545

The numbers in parentheses are *t*-statistics
***, **, and * indicate significance at 1, 5, and 10 %, respectively

technology might not be desirable for the rainfed regions in Northern Ghana. An alternative to dibbling, which is more desirable, would be broadcasting (direct seedling) if proper water control technologies are adopted.[12] The finding that the nearest project community distance has a negative effect on the disadoption indicates that

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[12] This is based on personal interviews with agricultural scientists of the International Rice Research Institute who are familiar with lowland rainfed rice farming in West Africa.

farmers near the project communities temporarily adopted dibbling and abandoned it later. This may be taken to imply that dibbling is a seemingly useful technology, and thus, nearby farmers adopted it, but after implementation, they realized that it was too labor-intensive and thus was not profitable relative to its cost requirement. This finding is further examined in the impact assessment section.

5.4.3 Productivity and Efficiency

Tables 5.7 and 5.8 show the determinants of paddy yield in t/ha and profit in USD/ha, respectively. Column (1) shows the results for the combination of at least modern inputs and leveling and bunding and column (2) provides the results for package adopters. The chi-square test of independent equations $(\rho = 0)$, which is provided at the bottom of the table, shows that we can reject the null hypothesis of no endogeneity at the 5 % significance level. Overall, we observed a positive and highly significant relationship between technology adoption and productivity performance. This suggests that when controlling for other factors, the adoption of improved technology clearly results in increases in yield and profit per hectare.

In Table 5.7 we observe that the farmers who adopted the entire technological package obtained a higher yield than the partial adopters in column (1), which is supposed to reflect the contribution of dibbling (1.67 t/ha vs. 2.01 t/ha). Overall, the results indicate a positive relationship between yield and the number of technologies adopted, with package adopters realizing the highest gains. The project community dummy has a positive impact on yield, but it is weakly significant only in the case of package adoption (column (2)), which indicates that the project affected rice yield primarily through affecting the technology adoption rather than through providing additional technological information. The age of the household head and experience did not have much impact on yield while the experience prior to the project had significantly positive effects in both models.

Table 5.8 summarizes the findings of the profit function. Here, the result also indicates a positive and highly significant relationship between technology adoption and profit. Similar to the yield function, we observe that due to the strong complementary relationship among the five technologies, package adopters in column (2) realized a higher profit than partial adopters (column (1)). High soil quality, proxied by clay, has a positive impact on profit. The project community dummy and the nearest project community distance are found to have no additional impacts on profit. The farmer's human capital (age and education) had no impact on profit, but the experience did have positive and significant effect in column (1). Unexpectedly, family labor is found to impact negatively on profit, even though it has no impact on yield.[13] As predicted, community paddy prices have positive and very significant effect on the profit. Examining the difference in the magnitude of

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[13] This may be due to the over-estimation of the family labor cost, as the wage rate used for the imputation pertains to labor cost at peak seasons.

Table 5.7 Determinants of paddy yield in tons per hectare in Ghana (treatment effects model)

	At least modern inputs + bunding + leveling	Package adopters
	(1)	(2)
Experience prior to LRDP (years)	0.019**	0.015*
	(1.97)	(1.65)
Age (years)	0.001	0.003
	(0.49)	(1.08)
Formal education (dummy)	0.016	0.035
	(0.10)	(0.23)
Family labor (number)	–0.001	0.001
	(–0.09)	(0.04)
Total farm size (ha)	–0.011	–0.018
	(–0.64)	(–1.02)
Soil with high water retention (dummy)	0.138	0.135
	(1.38)	(1.40)
Land slope (dummy)	–0.043	–0.044
	(–0.43)	(–0.44)
Project community (dummy)	0.149	0.222*
	(1.24)	(1.93)
Nearest project community distance (km)	–0.004	–0.011
	(–0.40)	(–1.03)
Community wage rate (USD/day)	0.189*	0.123
	(1.90)	(1.31)
Distance to district capital (km)	0.007	0.015**
	(1.07)	(2.40)
Community paddy price (USD/kg)	0.278	1.139
	(0.22)	(0.93)
At least modern inputs + bunding + leveling (dummy)	1.663***	
	(8.35)	
Package adopters (dummy)		2.010***
		(9.28)
Constant	0.888**	0.637*
	(2.34)	(1.72)
Number of observations (N)	545	545
Wald (chi2)	103.983	122.400
Endogeneity test: prob > chi2	0.002	0.003

The numbers in parentheses are *t*-statistics
***, **, and * indicate significance at 1, 5, and 10 %, respectively

coefficients of technology adoption dummies across these models, the effect of dibbling is positive and significant, possibly because bunding and leveling are not complete, so that broadcasting leads to the uneven growth of rice plants and the failure of germination.

Table 5.8 Determinants of profit USD/hectare in Ghana (treatment effects model)

	At least modern inputs + bunding + leveling	Package adopters
	(1)	(2)
Experience prior to LRDP (years)	4.392*	3.701
	(1.67)	(1.41)
Age (years)	–0.192	0.129
	(–0.23)	(0.15)
Formal education (dummy)	–23.163	–20.110
	(–0.51)	(–0.45)
Family labor (number)	–10.246**	–9.924**
	(–2.16)	(–2.11)
Total farm size (ha)	7.469	6.353
	(1.48)	(1.27)
Soil with high water retention (dummy)	64.450**	64.711**
	(2.31)	(2.34)
Land slope (dummy)	–17.056	–17.607
	(–0.60)	(–0.63)
Project community (dummy)	35.434	48.956
	(1.06)	(1.49)
Nearest project community distance (km)	2.743	1.550
	(0.92)	(0.52)
Community wage rate (USD/day)	1.171	–10.216
	(0.04)	(–0.38)
Distance to district capital (km)	–0.630	0.933
	(–0.34)	(0.51)
Community paddy price (USD/kg)	942.025***	1099.277***
	(2.64)	(3.14)
At least modern inputs + bunding + leveling (dummy)	315.429***	
	(5.14)	
Package adopters (dummy)		394.452***
		(6.06)
Constant	–191.332*	–240.832**
	(–1.80)	(–2.27)
Number of observations (N)	545	545
Wald (chi2)	62.024	72.672
Endogeneity test: prob > chi2	0.001	0.002

The numbers in parentheses are *t*-statistics
***, **, and * indicate significance at 1, 5, and 10 %, respectively

5.5 Concluding Remarks

This chapter explored the determinants and impact of the adoption of modern inputs and proper water control technologies on the productivity and profitability of rice farming under a rainfed ecology in Ghana. As in the case of the Asian GR, our findings suggest that new technologies do not favor wealthy large farmers in the rainfed regions, as small farmers are more likely to adopt labor-intensive technologies such as dibbling and MVs (David and Otsuka 1994; Otsuka and Larson 2013b).[14] We also observed that although the experience gained from rice farming prior to LRDP increases the early adoption decisions of the new technologies in the short-run, the effect of pre-project experience diminishes in the long run and is substituted by own learning. Our findings also suggest that learning directly from the project or extension services increases the probability of the continuous adoption of MVs and fertilizer. This finding implies that for technologies that require some level of technical know-how, having direct contact with extension services and projects increases the acquisition of relevant knowledge. This finding is consistent with the finding in Tanzania that farmers who have taken training directly achieve higher productivity than followers (see Chap. 3). For the adoption of observable technologies such as bunding and leveling, the distance to the nearest project community was negative and significant. These findings imply that there is a need to increase and strengthen the capacity of extension services for the adoption of modern inputs, while the construction of demonstration plots will be effective for the diffusion of observable technologies.

Another major finding of this study is that the Asian rice GR is directly transferable to rainfed areas in SSA and can result in yield gains similar to those in Asia and significantly higher profit. The gains realized are significantly enhanced if these technologies are adopted together due to the strong complementarities among them. Whether dibbling is an appropriate technology for Northern Ghana needs to be analyzed carefully as it was disadopted by many farmers, but we found the evidence of its positive impacts on both yield and profit. Although it will be possible to improve lowland rice technology further, we would like to argue that the fuller dissemination of the currently available technological package can bring about revolutionary changes in the productivity and profitability of rice farming in SSA.

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[14] MVs are also labor intensive because they require more crop care relative to traditional varieties.

Appendix

Table 5.9 Determinants of bunding adoption in Ghana (marginal effects – multinomial logit regression model)

Explanatory variables	(1) Pre-LRDP phase	(2) During LRDP phase	(3) Post-LRDP phase	(4) Non-adopters
Experience prior to LRDP (years)	0.000	–0.000	–0.003	0.003
	(0.01)	(–0.09)	(–1.02)	(0.94)
Age (years)	0.000	0.000	0.001	–0.001
	(0.01)	(0.05)	(0.95)	(–0.82)
Formal education (dummy)	0.000	–0.008	0.027	–0.019
	(0.01)	(–0.43)	(0.60)	(–0.39)
Family labor (number)	0.000	0.001	0.002	–0.003
	(–0.01)	(0.63)	(0.46)	(–0.68)
Total farm size (ha)	–0.000	0.001	–0.003	0.003
	(–0.01)	(0.21)	(–0.64)	(0.41)
Soil with high water retention (dummy)	–0.000	0.027*	–0.085***	0.058*
	(–0.01)	(1.87)	(–2.82)	(1.70)
Land slope (dummy)	0.002	–0.010	–0.008	0.017
	(0.64)	(–0.76)	(–0.34)	(1.50)
Walking from homestead to farm (min)	0.000	–0.000	–0.000	0.001
	(0.01)	(–1.19)	(–0.98)	(1.50)
Project community (dummy)	–0.000	0.027	0.016	–0.044
	(–0.01)	(0.93)	(0.54)	(–1.05)
Nearest project community distance (km)	–0.000	–0.009***	–0.014***	0.023***
	(–0.01)	(–3.79)	(–3.80)	(4.83)
Community wage rate (USD/day)	0.000	–0.047**	–0.063**	0.110***
	(0.01)	(–2.11)	(–2.11)	(2.97)
Distance to district capital (km)	–0.000	0.002	0.005***	–0.007***
	(–0.01)	(1.62)	(2.97)	(–3.36)
Community paddy price (USD/kg)	–0.001	0.345*	0.844**	–1.188***
	(–0.01)	(1.71)	(2.36)	(–2.82)
Chi2	187.793	187.793	187.793	187.793
Pseudo R^2	0.225	0.225	0.225	0.225
Number of observations	545	545	545	545

The numbers in parentheses are *t*-statistics

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

Table 5.10 Determinants of leveling adoption in Ghana (marginal effects – multinomial logit regression model)

Explanatory variables	(1) Pre-LRDP phase	(2) During LRDP phase	(3) Post-LRDP phase	(4) Non-adopters
Experience prior to LRDP (years)	0.003***	0.007***	–0.011	0.000
	(3.02)	(2.83)	(–1.50)	(0.03)
Age (years)	0.001	–0.000	0.000	–0.000
	(1.30)	(–0.44)	(0.12)	(–0.23)
Formal education (dummy)	0.021	–0.039	0.105	–0.087
	(0.68)	(–1.10)	(1.25)	(–1.02)
Family labor (number)	0.001	0.006	0.005	–0.012
	(0.55)	(1.26)	(0.59)	(–1.33)
Total farm size (ha)	–0.000	–0.005	–0.010	0.016
	(–0.15)	(–0.96)	(–1.05)	(1.60)
Soil with high water retention (dummy)	–0.017	0.017	–0.193***	0.193***
	(–1.08)	(0.64)	(–3.82)	(3.77)
Land slope (dummy)	0.022*	–0.003	0.035	–0.054
	(1.91)	(–0.09)	(0.67)	(–1.00)
Walking from homestead to farm (min)	0.000	–0.000	0.000	–0.000
	(1.53)	(–0.62)	(0.79)	(–0.54)
Project community (dummy)	0.003	0.018	–0.188***	0.166***
	(0.18)	(0.53)	(–3.53)	(2.69)
Nearest project community distance (km)	–0.001	–0.009**	0.002	0.007
	(–0.30)	(–2.34)	(0.36)	(1.20)
Community wage rate (USD/day)	–0.014	–0.127***	–0.193***	0.334***
	(–0.93)	(–4.12)	(–3.75)	(6.03)
Distance to district capital (km)	–0.000	0.007***	0.002	–0.008**
	(–0.07)	(3.21)	(0.48)	(–2.22)
Community paddy price (USD/kg)	–0.281	1.155***	1.525**	–2.399***
	(–1.27)	(3.07)	(2.28)	(–3.40)
Chi2	168.579	168.579	168.579	168.579
Pseudo R^2	0.137	0.137	0.137	0.137
Number of observations	545	545	545	545

The numbers in parentheses are *t*-statistics

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

Table 5.11 Determinants of dibbling adoption in Ghana (marginal effects – multinomial logit regression model)

	(1)	(2)	(3)	(4)
Explanatory variables	Pre-LRDP phase	During LRDP phase	Post-LRDP phase	Non-adopters
Experience prior to LRDP (years)	0.000	0.001	–0.004	0.002
	(0.91)	(1.00)	(4.04)	(0.63)
Age (years)	–0.000	0.000	0.002***	–0.003***
	(–0.47)	(0.61)	(2.62)	(–2.62)
Formal education (dummy)	0.002	–0.026**	0.166**	–0.142*
	(0.52)	(–2.08)	(2.31)	(–1.95)
Family labor (number)	0.000	0.001	0.002	–0.003
	(0.84)	(0.26)	(0.34)	(–0.47)
Total farm size (ha)	–0.000	–0.003	–0.022***	0.025***
	(–0.67)	(–0.88)	(–2.68)	(2.90)
Soil with high water retention (dummy)	0.001	0.014	–0.090**	0.075**
	(0.76)	(1.25)	(–2.57)	(2.04)
Land slope (dummy)	0.001	–0.024	–0.013	0.036
	(0.59)	(–1.59)	(–0.42)	(1.05)
Walking from homestead to farm (min)	0.000	–0.001***	0.000	0.001*
	(0.43)	(–3.29)	(1.01)	(1.82)
Project community (dummy)	–0.004	0.006	–0.019	0.017
	(–1.08S)	(0.42)	(–0.61)	(0.47)
Nearest project community distance (km)	–0.000	–0.000	–0.005	0.006
	(–1.09)	(–0.32)	(–1.17)	(1.30)
Community wage rate (USD/day)	–0.010	–0.057***	–0.035	0.103***
	(–1.12)	(–3.27)	(–1.06)	(2.72)
Distance to district capital (km)	0.000	0.001	0.002	–0.003
	(0.63)	(1.19)	(0.85)	(–1.26)
Community paddy price (USD/kg)	0.005	0.207	2.078***	–2.291***
	(0.31)	(1.31)	(5.13)	(–5.22)
Chi2	176.708	176.708	176.708	176.708
Pseudo R^2	0.204	0.204	0.204	0.204
Number of observations	545	545	545	545

The numbers in parentheses are *t*-statistics

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

Table 5.12 Determinants of MVs adoption in Ghana (marginal effects – multinomial logit regression model)

Explanatory variables	(1) Pre-LRDP phase	(2) During LRDP phase	(3) Post-LRDP phase	(4) Non-adopters
Experience prior to LRDP (years)	0.001*	0.006**	–0.003	–0.003
	(1.76)	(2.14)	(–0.61)	(–0.64)
Age (years)	0.000	–0.000	–0.002	0.002
	(0.32)	(–0.06)	(–1.32)	(1.52)
Formal education (dummy)	0.020	–0.071*	0.028	0.024
	(0.84)	(–1.90)	(0.35)	(0.31)
Family labor (number)	0.003*	0.007	–0.000	–0.009
	(1.91)	(1.25)	(–0.01)	(–1.27)
Total farm size (ha)	–0.001	–0.000	–0.015	0.016**
	(–0.83)	(–0.04)	(–1.62)	(2.10)
Soil with high water retention (dummy)	0.003	–0.011	–0.129***	0.137***
	(0.50)	(–0.34)	(–2.84)	(3.63)
Land slope (dummy)	0.001	–0.016	0.104**	–0.089*
	(0.11)	(–0.50)	(2.03)	(–1.84)
Walking from homestead to farm (min)	–0.000	–0.001	0.001**	–0.000
	(–0.80)	(–1.44)	(2.22)	(–0.98)
Project community (dummy)	–0.001	0.196***	–0.034	–0.161***
	(–0.09)	(3.45)	(–0.54)	(–3.85)
Nearest project community distance (km)	0.000	0.000	0.002	–0.002
	(0.31)	(0.11)	(0.28)	(–0.49)
Community wage rate (USD/day)	0.003	–0.157***	–0.089*	0.243***
	(0.37)	(–4.44)	(–1.78)	(5.54)
Distance to district capital (km)	–0.000	0.002	0.010***	–0.011***
	(–0.37)	(0.69)	(2.88)	(–3.85)
Community paddy price (USD/kg)	–0.212*	0.483	2.665***	–2.936***
	(–1.77)	(1.12)	(4.06)	(–5.06)
Chi2	240.421	240.421	240.421	240.421
Pseudo R^2	0.208	0.208	0.208	0.208
Number of observations	545	545	545	545

The numbers in parentheses are *t*-statistics

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

Table 5.13 Determinants of fertilizer adoption in Ghana (marginal effects – multinomial logit regression model)

Explanatory variables	(1) Pre-LRDP phase	(2) During LRDP phase	(3) Post-LRDP phase	(4) Non-adopters
Experience prior to LRDP (years)	0.004***	0.011***	–0.018**	0.003
	(3.11)	(2.59)	(–2.36)	(0.46)
Age (years)	0.000	–0.001	–0.002	0.003**
	(0.40)	(–0.80)	(–1.56)	(2.44)
Formal education (dummy)	0.013	–0.050	0.066	–0.029
	(0.50)	(–0.97)	(0.84)	(–0.42)
Family labor (number)	0.002	0.010	0.005	–0.016**
	(0.63)	(1.58)	(0.57)	(–2.15)
Total farm size (ha)	–0.006	0.007	–0.005	0.004
	(–1.46)	(1.08)	(–0.51)	(0.53)
Soil with high water retention (dummy)	–0.012	–0.009	0.035	–0.014
	(–0.79)	(–0.23)	(0.70)	(–0.33)
Land slope (dummy)	0.003	–0.047	0.048	–0.003
	(0.19)	(–1.20)	(0.94)	(–0.07)
Walking from homestead to farm (min)	–0.000	–0.001*	0.001**	–0.000
	(–0.22)	(–1.87)	(2.10)	(–0.13)
Project community (dummy)	0.031	0.148***	0.029	–0.208***
	(1.25)	(2.69)	(0.45)	(–4.67)
Nearest project community distance (km)	0.001	–0.006	–0.003	0.008*
	(0.42)	(–1.06)	(–0.52)	(1.75)
Community wage rate (USD/day)	–0.019	–0.062	–0.035	0.115***
	(–1.17)	(–1.52)	(–0.68)	(2.85)
Distance to district capital (km)	–0.000	–0.001	0.001	0.000
	(–0.24)	(–0.51)	(0.41)	(0.09)
Community paddy price (USD/kg)	0.190	0.911*	0.934	–2.035***
	(1.06)	(1.82)	(1.40)	(–3.35)
Chi2	209.971	209.971	209.971	209.971
Pseudo R2	0.165	0.165	0.165	0.165
Number of observations	545	545	545	545

The numbers in parentheses are *t*-statistics

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

Chapter 6
On the Determinants of High Productivity in Rice Farming in Irrigated Areas in Senegal: Efficiency of Large-Scale vs. Small-Scale Irrigation Schemes

Takeshi Sakurai

Abstract Irrigated rice farming in the Senegal River Valley is known to be highly productive, as indicated by the average yield of nearly 5 tons per ha, and the extensive adoption of modern seed-fertilizer technology. This study seeks to understand why rice farming is so productive in this region; analyzing this situation from the viewpoint of the management efficiency of large versus small scale irrigation schemes. Contrary to popular belief, the study found that farmers in large-scale irrigation schemes achieve significantly higher yields and profits than those in small-scale irrigation schemes.

Keywords Large-scale irrigation schemes • Small-scale irrigation schemes • Productivity • Rice farming • Senegal River Valley

6.1 Introduction

Since irrigated lowland farming is generally more productive than any other rice production ecology, the expansion of irrigated land for rice crops offers great potential for the enhancement of rural incomes and food security in Sub-Saharan Africa (SSA) (Balasubramanian et al. 2007; Larson et al. 2010). However, international agencies and national governments have become reluctant to develop irrigation schemes due to the high investment cost, declining world food prices, and the failure of many irrigation projects previously carried out in the 1970s and 1980s (Kay 2001; Inocencio et al. 2007). In this regard, Adams (1992) noted when reviewing the outcomes from large-scale irrigation projects in Sub-Saharan Africa, that: "The poor performance of large-scale irrigation in Africa is now widely acknowledged." Later, Inocencio et al. (2005) provided confirming evidence by showing that smaller irrigation schemes in SSA have performed better, as measured by the economic

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internal rate of return of projects that are controlled for project size. However, since the world food crisis in 2008, economic conditions have changed, and there is now an opportunity for public investment to raise agricultural productivity in SSA (Masters 2011). However, questions about the optimal size of irrigation schemes still remain unanswered.

With respect to rice production, there are several large-scale irrigation schemes in SSA that achieve relatively high yields. For example, Nakano and Otsuka (2011) report that the average rice yield was 5.3 tons per ha in the large-scale irrigation schemes of the Senegal River Valley, and Njeru et al. (2014) report that the average rice yield was 5.0 tons per ha in the Mwea irrigation scheme in Kenya. In their concluding remarks, Nakano and Otsuka (2011) wrote: “Although small-scale irrigation development seems to be a current trend in SSA among aid organizations, our analyses show that large-scale irrigation schemes also have high potential under proper management and are equally important.” Nevertheless, the authors did not compare the two types of irrigation scheme directly. Such a comparison is difficult because the two types do not usually coexist, and differ not only in size but also in terms of irrigation technologies. But in the case of the Senegal River Valley, both types are located close to each other, and use similar irrigation technologies involving pumping water from the Senegal River.

This paper takes advantage of this rare setting to compare the performances of large and small-scale irrigation schemes, using household data collected in the Senegal River Valley. To the best of our knowledge, this is the first study that investigates the impact of irrigation scheme size on rice production efficiency in the smallholder agricultural sectors of SSA or Asia.[1]

Organization of this paper is as follows. Section 6.2 explains the basic characteristics of the study sites and the nature of the data collected by this study. Section 6.3 postulates the testable hypotheses, and is followed by the descriptive analyses found in Sect. 6.4, and the regression analyses outlined in Sect. 6.5. Finally, conclusions and policy implications are provided in Sect. 6.6.

6.2 Study Site and Data

6.2.1 Background of the Study Site

The study site is located in the Senegal River Valley. The Senegal River, originating in the highlands of Guinea, forms a 800 km long boundary between Mauritania to the north and Senegal to the south. Irrigated rice schemes in the Senegal River

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[1] In the case of the Senegal River Valley, the study by Diagne et al. (2013a, b), who analyze the determinants of rice production efficiency based on 5 year panel data obtained from about 100 households, may be exceptional. A dummy for large-scale irrigation schemes was used in this study as one of the variables to explain the residual from the translog production function, but had insignificant impact on this residual. But since their focus is not on scheme size, they do not discuss this result at all in their paper.

Valley exist on both sides of the river.[2] This study focuses however on the Senegalese side only, where the total area of irrigated rice is about 103,000 ha (SAED 2011). SAED[3] divides the Senegalese side of the Valley into four delegations: Dagana, Podor, Matam, and Bakel in the order from the mouth of the river. Dagana and Podor were selected for this study since most of the large-scale irrigation schemes are located in these two delegations.

The construction of large-scale irrigation schemes started in 1960 after independence, except for one constructed in 1938 by France, which was later updated to its current full-water control technology during the 1970s (Diallo 1980). SAED constructed all the irrigation schemes presently equipped with irrigation pumps, drainage pumps, and canal networks. SAED was not only in charge of their construction, but also their operation and maintenance. The latter responsibility included farm machinery services for land preparation, harvesting, and threshing, and input supplies in the form of in-kind credit, rice marketing, and extension services. Large-scale irrigation schemes were divided into blocks with feeder canals, and a group of 15–20 farmers made responsible for water distribution and feeder canal maintenance within each block.

In response to a series of severe droughts and famines from 1968 to 1974, villagers requested the government to construct irrigation facilities. As a result, the construction of small-scale irrigation schemes was added to the mission of SAED in 1975 (Wester et al. 1995). The small-scale irrigation schemes were village-based: a village-level committee for management and operation was established before construction, and the construction was carried out collectively by villagers (Diallo 1980). From 1975, SAED has not only constructed small-scale schemes (including the installation of one irrigation pump at times), but has also provided them with such services as given for large-scale schemes. These have included pump maintenance, and input supplies in the form of in-kind credit, rice marketing, and extension services (Wester et al. 1995). Around this core, local farmers formed a group, and were engaged in water distribution and canal maintenance. Since farm machines were not available outside the large-irrigation schemes, land preparation, seeding, harvesting, and threshing were done manually at least in the early period. Therefore, the differences between large-scale and small-scale irrigation schemes in the Senegal Ricer Valley were not only in their average size,[4] but also their technologies and governance structure at the time when they were constructed.

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[2] An example of a Mauritania side study is Comas et al. (2012).

[3] SAED (Société Nationale d'Exploitation des Terres du Delta du Fleuve Sénégal et des Vallées Sénégal et de la Falémé) is a parastatal agency specializing in the development of irrigation schemes in the Senegal River Valley.

[4] The average size of large-scale irrigation schemes is 761 ha, and that of small-scale irrigation schemes is 27 ha, according to the author's calculation based on SAED (2011). In the Senegal River Valley, the large-scale irrigation schemes are called GA (Grand Aménagement) or AI (Aménagement Intermédiaire), depending on scheme size. The total area of GAs is above 1,000 ha and that of AIs is less than 1,000 ha. Thus, large-scale irrigation schemes in this paper include both large and medium scales according to SAED's classification. On the other hand, the small-scale irrigation schemes are called PIV (Périmètre Irrigué Villageois), since they are managed by villagers.

This costly government intervention into both large and small scale irrigation schemes through SAED could not be sustained. During the structural adjustment program requested by donors, a disengagement policy began, starting with the liberalization of input and output prices in 1984, and the withdrawal of SAED in 1987 (Wester et al. 1995). As a result, the maintenance of irrigation facilities such as pumps and main canals has become farmers' own responsibility. In the case of large-scale schemes, farmer groups that managed irrigation blocks formed a union to take the maintenance responsibility from SAED, while in the case of small-scale schemes, the responsibility was turned over to existing farmer groups. As for the provision of credit, this was transferred from SAED to the Caisse Nationale de Crédit Agricole du Sénégal (CNCAS), established in 1987 as part of the reforms of public irrigation schemes (Dia 2001).

In response to the liberalization of the agricultural market, private investment in irrigation has increased since the late 1980s in the Senegal River Valley.[5] The total area of such schemes reached 42,600 ha in 1993, but then declined due to the increases in input costs caused by the devaluation of the CFA Franc in 1994 (Dia 2001). Stimulated by the food crisis in 2008, and resulting high international prices, private investment in irrigation schemes has been growing again. In 2008/2009, the total area of private irrigation schemes in the Senegal River Valley increased to 51,600 ha, and the average size per scheme was 22 ha, according to the author's calculation based on SAED (2011). Thus, in terms of scheme size, the private irrigation schemes are also categorized as small-scale irrigation schemes. Not only their size but also their use of particular irrigation technologies is similar to that of village-based schemes: both use an irrigation pump to get water from streams (directly from the main stream or from its branches). However, an important difference is that one is owned and managed privately, and the other is owned and managed collectively by villagers. Thus, in the Senegal River Valley, large-scale and small-scale irrigation schemes coexist, and the small-scale irrigation schemes can be further classified into village-based and private ownership.

6.2.2 Data

Sampling was conducted based on the list of farmer groups provided by SAED. In the case of small-scale irrigation schemes and private irrigation schemes, each farmer group listed corresponds to an irrigation scheme, since each scheme has only one farmer group that manages the scheme. As for the large-scale irrigation schemes, the groups listed are not unions of farmer groups responsible for the management of the whole scheme, but those who manage blocks within a large-scale irrigation scheme. The total number of the farmer groups on the SAED list was 3,304, and 120

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[5] Private irrigation schemes are called PIP (Périmètre Irrigué Privé) in the Senegal River Valley.

were randomly selected for study. Then, five households were randomly selected from the member lists of each group. Thus, the total number of households surveyed was 600. The farmer group surveys were carried out via a group interview, and the household survey via an interview with the household head. These surveys were conducted during 2012, covering the rainy season of 2011, in collaboration with the Institut Sénégalais de Recherches Agricoles (ISRA).

As shown in Table 6.1, among the 120 farmer groups, there are 42 groups belonging to large-scale irrigation schemes and 78 belonging to small-scale irrigation schemes. Of the small-scale ones, 40 groups represent village-based irrigation schemes, and 38 groups represent private irrigation schemes. Most of these groups were established in the early 1990s, and the total area under their individual management averages about 40 ha. There are no significant differences in area controlled among the three types; however, the number of members and therefore the area per member are significantly different. Private schemes have the smallest number of members and hence the largest land area per member. On the other hand, village-based small-scale schemes have the largest number of members on average and the smallest area per member. As for scheme size, the farmer groups in the large-scale category belong to a large-scale irrigation scheme whose size is about 1,200 ha on average, while small-scale ones by definition do not belong to any large-scale schemes; and the size of the scheme is the same as the total area managed by the group.

Table 6.1 Basic characteristics of sample farmer groups in Senegal

		Small-scale		
	Large-scale	Village-based	Private	Total
Number of sample FGs	42	40	38	120
In Dagana Department	35	20	22	77
In Podor Department	7	20	16	43
Year when the FG was established*	1994	1990	1992	1992
	(8.8)	(9.3)	(9.7)	(9.4)
Total area managed by the FG (ha)	40.2	41.9	33.1	38.6
	(31.5)	(46.3)	(33.6)	(37.5)
Total number of FG members	47.5	100.0	21.2	56.7
	(55.2)	(147.0)	(24.0)	(96.8)
Managed area per member (ha/capita)**	1.16	0.88	5.07	2.31
	(0.87)	(1.27)	(10.9)	(6.41)
Size of the scheme (ha)[a,***]	1,167	41.9	33.1	433
	(829)	(46.3)	(33.6)	(728)

FG stands for farmer group. Standard deviations are in parentheses. ***, **, and * indicate that the mean results for farmer groups in the large-scale irrigation schemes and those in small-scale irrigation schemes are statistically different at the significance level of 1 %, 5 %, and 10 %, respectively

[a] In the case of small-scale schemes, size of the scheme is the same as the total area managed by the group

6.3 Assumptions and Hypotheses

6.3.1 Assumptions

The study adopted two assumptions; one about the type of irrigation scheme, and the other about the use of formal credit:

Assumption 1 While each farmer can make a decision to be engaged in rice production, individual farmers cannot control the construction of an irrigation scheme, and hence a farmer has little choice but to use a rice plot in the irrigation scheme that is the most accessible one. Therefore, a farmer's selection of scheme type among the three – large scale, village-based small scale, and private small scale – is assumed to be exogenous. Please note that the types themselves have been fixed since the time of construction. Even in the case of large-scale irrigation schemes, although the management responsibility has been transferred from public to farmers' groups, their category is always large-scale.[6]

Assumption 2 We expected that credit will play an important role in irrigated rice production in the Senegal River Valley. As mentioned above, CNCAS was established in 1987 as part of a reform of public irrigation schemes, and even now CNCAS is the dominant formal credit institution in the study site although credits from input dealers and rice millers have also become available. One important feature of CNCAS credit is that it adopts a group lending and group liability policy; although each farmer decides the amount to be borrowed and bears the responsibility to pay this back, the contract is made between CNCAS and the farmer group. Thus, if a farmer in the group goes into default, all the farmers in the group become ineligible for further credit until the debt is cleared. This means that eligibility for CNCAS credit is beyond the control of an individual farmer. Thus, this paper assumes that CNCAS eligibility at the group level is exogenous when individual farmers make decisions.

6.3.2 Hypotheses

Our main hypothesis in this paper is that large-scale irrigation schemes are as equally well managed as small-scale irrigation schemes. This main hypothesis is divided into three testable hypotheses; postulated in accordance with the following considerations.

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[6] In management terms, this is a case of irrigation management transfer (IMT), as documented by Garces-Restrepo et al. (2007). Our study, however, is not concerned with such transfers since they had been completed by the time of survey, and all the irrigation schemes are managed by farmers regardless of scheme size.

Regardless of the type of irrigation scheme, water sources and irrigation methods are the same: water is pumped from the Senegal River or its branches. Since there is always enough water, there is no problem of water supply, as long as the pumps work well and canals are well maintained. Water users must pay the maintenance costs as well as the running costs at the beginning of the cropping season, but since operating credit is not available to cover such costs, it is difficult for a farmers' group to collect sufficient funds for ongoing maintenance. In contrast, CNCAS credit does cover the payment of irrigation fees, so that farmer groups eligible for CNCAS credit can maintain irrigation facilities more easily than non-eligible groups. As will be shown, the probability of being eligible for CNCAS is higher amongst farmer groups in large-scale irrigation schemes than in small-scale irrigation schemes. Thus, Hypothesis 1 may be stated as:

Hypothesis 1 Irrigation performance is better in large-scale irrigation schemes than in small-scale irrigation schemes.

The use of chemical fertilizers is quite high in both large-scale and small-scale irrigation schemes (Nakano and Otsuka 2011; Diagne et al. 2013b). This was confirmed even for private irrigation schemes during the preliminary interviews at our study site. Farmers told us that rice cannot be harvested without using a sufficient amount of chemical fertilizer, and that even though credit is not available (i.e. ineligibility for CNCAS), much fertilizer will be used. In addition, since credit for chemical fertilizer is available from other sources outside CNCAS, differences in the application rates of chemical fertilizer will be small. Hence, our second hypothesis is:

Hypothesis 2 The application rate of chemical fertilizer in small-scale irrigation schemes is no different to that in large-scale irrigation schemes.

If Hypotheses 1 and 2 are supported, rice yield and rice profit is higher in large-scale irrigation schemes than in small-scale irrigation schemes, because irrigation facilities are better maintained in the former even if the use of inputs is not much different between them. In other words, if we control for irrigation performance, rice yield and rice profit do not differ significantly between large-scale irrigation schemes and small-scale irrigation schemes. Therefore, Hypothesis 3 can be derived as follows:

Hypothesis 3 Rice yield and rice profit do not differ significantly between large-scale irrigation schemes and small-scale irrigation schemes.

6.4 Data Description

6.4.1 Irrigation Performance

At the study site, rice can be grown three times a year, but is usually grown twice a year (once in the rainy season and once in the dry season), or only once in a year (mainly in the rainy season, but sometimes in the dry season). Since this study uses

Table 6.2 Irrigation performance of sample farmer groups in Senegal

		Large-scale	Small-scale		Total
			Village-based	Private	
2009	Number of FGs that did not grow rice	9	7	8	24
	% of irrigated area in total area of FG[a,***]	0.79	0.57	0.54	0.64
		(0.27)	(0.32)	(0.29)	(0.31)
2010	Number of FGs that did not grow rice	13	10	9	32
	% of irrigated area in total area of FG[a,***]	0.74	0.61	0.50	0.62
		(0.29)	(0.31)	(0.30)	(0.31)
2011	Number of FGs that did not grow rice	15	8	10	33
	% of irrigated area in total area of FG[a,**]	0.75	0.60	0.55	0.63
		(0.29)	(0.32)	(0.28)	(0.30)
Number of pumps owned by FG[b,***]		0	1.40	1.32	0.88
			(1.13)	(1.40)	(1.20)
Use of rental pumps (dummy)[***]		0	0.13	0.21	0.11
Total expenditure for pump repair in 2009, 2010, and 2011 (10^3 FCFA)[*]		91.7	186	231	167
		(33.5)	(256)	(375)	(327)
Length of canal managed by FG (m)		1,533	1,447	1,311	1,434
		(1,787)	(1,313)	(1,170)	(1,449)
Canal management by participation (dummy)		0.76	0.85	0.84	0.82
Penalty for absence from participation (dummy)		0.57	0.55	0.29	0.48
Number of sample FGs		42	40	38	120

FG stands for farmer group. Standard deviations are in parentheses. ***, **, and * indicate that the mean results for farmer groups in the large-scale irrigation schemes, and those in small-scale irrigation schemes are statistically different at the significance level of 1 %, 5 %, and 10 % respectively

[a] The percentages are calculated among those farmer groups that grew rice during the rainy season in question (that is, farmer groups that did not grow rice were excluded from the average)

[b] In the case of large-scale irrigation schemes, each member FG does not own pumps. In the case of small-scale irrigation schemes, FGs usually use only one irrigation pump. Some FGs have two or more pumps, but the second ones are old and need to be repaired. There are several FGs, particularly in the case of private schemes, that do not own pumps and have to rent one

data on household rice production obtained during the rainy season of 2011, we will focus only on rainy season rice production. Table 6.2 relates production to the proportion of land actually irrigated, and to irrigation pump and canal management, in 2009, 2010, and 2011. Every rainy season, regardless of scheme type, a significant number of farmer groups (from 20 to 30 % of the total) did not grow rice, or grew nothing at all. This may be due to the break-down of pumps or a lack of funds for land preparation. The frequency of "no rice" did not, however, significantly differ between the three types of scheme. On the other hand, the proportion of irrigated area was significantly higher in large-scale schemes than in small-scale schemes. Since the area irrigated is an indicator of irrigation performance, this result means that large-scale schemes perform better than small-scale ones.

Irrigation performance should be largely determined by the maintenance of pumps and canals. As shown in Table 6.2, total expenditure for pump repair during the past 3 years was significantly lower in large-scale schemes than in small-scale schemes. High repair costs can be taken to imply that pump condition is not so good. As for canal maintenance, because canal length per group is very similar, and both large and small schemes depend on members' participation in canal cleaning (there is a penalty for non-performance), the maintenance levels of each scheme will not be very different. However, overall irrigation performance is better in large-scale schemes than in small-scale schemes, thus Hypothesis 1 is supported.

6.4.2 Eligibility for CNCAS Credit

Table 6.3 shows that the number of farmer groups that are eligible for CNCAS credit is much higher in large-scale schemes than in small-scale schemes. In addition, the ineligible period is significantly longer in the case of small-scale schemes than for large-scale schemes, implying that the latter tend to clear debts more quickly. In other words, farmers in small-scale irrigation schemes do not depend on CNCAS but must use other sources of credit, as will be shown in the next section.

6.4.3 Rice Production Technologies in the Rainy Season of 2011

Rice production technologies at the farmer group level are summarized in Tables 6.4, 6.5, 6.6, and 6.7. Of the 120 sample farmer groups, 87 grew rice in the rainy season of 2011. As shown in Table 6.4, average rice planted area per group does not

Table 6.3 Credit eligibility of sample farmer groups in Senegal

	Large-scale	Small-scale		Total
		Village-based	Private	
Number of FGs eligible for CNCAS[a], ***	21	10	3	34
Number of FGs ineligible for CNCAS due to default in the past[a], *	18	9	12	39
Year since when the FG has been ineligible for CNCAS**	2005 (4.0)	2003 (5.6)	1999 (6.2)	2003 (5.6)
Number of FGs that cannot tell since when it has been ineligible	5	4	4	13
Number of sample FGs	42	40	38	120

FG stands for farmer group. Standard deviations are in parentheses. ***, **, and * indicate that the mean results for farmer groups in the large-scale irrigation schemes, and those in small-scale irrigation schemes are statistically different at the significance level of 1 %, 5 %, and 10 %, respectively

[a] The sum of the two numbers is not equal to the total number because ineligibility for CNCAS can be due to other reasons than default. In addition, several FGs do not depend on CNCAS from the beginning. In this case, eligibility for CNCAS is not known

Table 6.4 Production technologies by farmer groups in Senegal in the rainy season of 2011

			Small-scale		
		Large-scale	Village-based	Private	Total
Area planted to rice (ha)		33.3	39.6	21.4	31.8
		(33.8)	(52.5)	(19.1)	(38.9)
Eligibility for CNCAS (dummy)***		0.63	0.22	0.11	0.31
Land preparation[a]	By hand (% of farmers)*	0	12.5	7.14	6.90
			(33.6)	(26.2)	(25.5)
	By tractor (% of farmers)***	94.4	66.8	82.1	80.3
		(19.7)	(47.0)	(39.0)	(39.0)
Leveling	By hand (% of farmers)	70.0	82.0	69.0	74.1
		(42.6)	(35.9)	(45.9)	(41.4)
	By tractor (% of farmers)	5.19	1.88	0	2.30
		(20.5)	(10.6)		(13.1)
Seeding	Transplanting (% of farmers)*	10.2	25.6	21.4	19.5
		(29.6)	(39.9)	(39.5)	(37.0)
	Direct seeding (% of farmers)	82.4	74.4	78.6	78.2
		(37.9)	(39.9)	(39.5)	(38.8)
Chemical weeding after seeding (% of farmers)*		68.1	42.2	51.8	53.3
		(45.4)	(47.7)	(50.0)	(48.4)
Modern varieties[b] (% of farmers)		88.7	99.7	93.8	94.4
		(28.6)	(1.77)	(20.7)	(20.1)
Use of Sahel 108 (% of farmers)		47.0	58.7	63.8	56.7
		(43.3)	(43.8)	(41.7)	(43.1)
Use of Sahel 134 (% of farmers)		8.93	4.94	1.25	4.99
		(20.3)	(18.5)	(5.02)	(16.3)
Number of sample groups that grew rice in the rainy season 2011		27	32	28	87

Standard deviations are in parentheses. *** and * indicate that the mean results for farmer groups in the large-scale irrigation schemes, and those in small-scale irrigation schemes are statistically different at the significance level of 1 % and 10 %, respectively

[a] Land preparation is not deep ploughing, but harrowing with disc plough. In the study area this is called offsetting

[b] In the study site, rice is not a traditional crop but is a new crop introduced by SAED. Therefore, all the farmers grew modern varieties from the beginning. In this table, relatively recent varieties developed by Africa Rice Center are counted as "modern varieties" namely Sahel 108, Sahel 201, and Sahel 202 (released in the early 1990s), and Sahel 134 (released in 2005). According to the Africa Rice Center, other new varieties (Sahel 159, Sahel 208, Sahel 209, and Sahel 210) were also released in 2005. Some farmers have adopted them, but they are not included in the figure

significantly differ between large-scale and small-scale schemes, although it is relatively smaller in private schemes. However, large-scale schemes are more likely to adopt labor-saving technologies: using tractors for land preparation, conducting direct seeding, and spraying chemicals for weed control after seeding. On the other

Table 6.5 Production technologies by farmer groups in Senegal in the rainy season of 2011

			Small-scale		
		Large-scale	Village-based	Private	Total
Area planted to rice (ha)*		33.3	39.6	21.4	31.8
		(33.8)	(52.5)	(19.1)	(38.9)
Eligibility for CNCAS (dummy)***		0.63	0.22	0.11	0.31
Use of basal fertilizer (% of farmers)		61.9	58.6	62.9	61.0
		(48.7)	(45.4)	(46.5)	(46.3)
Use of top dressing (% of farmers)		66.7	55.6	81.3	67.3
		(47.9)	(48.3)	(38.9)	(46.1)
Weeding during growth	Manual (% of farmers)	51.7	53.1	49.5	51.5
		(46.1)	(46.0)	(45.4)	(45.3)
	Herbicide (% of farmers)	40.4	42.2	40.3	41.0
		(45.3)	(46.3)	(45.8)	(45.3)
Number of sample groups that grew rice in the rainy season 2011		27	32	28	87

Standard deviations are in parentheses. *** and * indicate that the mean results for farmer groups in the large-scale irrigation schemes, and those in small-scale irrigation schemes are statistically different at the significance level of 1 % and 10 %, respectively

hand, the study found no difference in the adoption rate of manual leveling and modern varieties. It thus seems clear that credit from CNCAS makes it easy to pay cash for hiring tractors. As for the adoption of modern varieties of rice, since almost all farmers use them, there is no difference between the schemes. Both the varieties shown in Table 6.4 (i.e. Sahel 108 and Sahel 134) were originally selected by IRRI and developed for the irrigation conditions in the Sahel by the Africa Rice Center, according to their variety description notes.

Table 6.5 shows the use of chemical fertilizer and the methods of weeding after emergence. In spite of the significant difference in eligibility for CNCAS credit, the use of fertilizer and herbicide does not differ significantly. This implies that farmers have other sources of credit to purchase fertilizer, which supports Hypothesis 2. Table 6.6 concerns harvesting and threshing methods, and shows that combine harvesters are becoming popular in the study site. But in 2011 when the production survey was conducted, their adoption rate was low, and not significantly different between large and small schemes. As for threshing, although mechanical threshers are widely used, small-scale schemes tend to do it manually more often than large-scale schemes.

According to farmers, costs for harvesting and threshing do not differ between machine and hand, as common piece rates are applied: 10 % of the harvest for harvesting, and 10 % of the harvest for threshing (in the case of combine harvesters, 20 % of the harvest). Since payment for crops is made after harvesting/threshing

Table 6.6 Production technologies by farmer groups in Senegal in the rainy season of 2011

		Large-scale	Small-scale		Total
			Village-based	Private	
Area planted to rice (ha)*		33.3	39.6	21.4	31.8
		(33.8)	(52.5)	(19.1)	(38.9)
Eligibility for CNCAS (dummy)***		0.63	0.22	0.11	0.31
Harvesting	By hand (% of farmers)	88.2	84.0	98.2	90.0
		(25.3)	(32.3)	(7.72)	(25.0)
	By harvester (% of farmers)	0.74	0.63	0.36	0.57
		(3.85)	(3.54)	(1.89)	(3.18)
	By combine harvester (% of farmers)	11.2	5.97	1.43	6.14
		(25.3)	(17.1)	(7.56)	(18.2)
Threshing	By hand** (% of farmers)	10.0	31.9	23.6	22.4
		(28.4)	(46.1)	(41.1)	(40.3)
	By thresher* (% of farmers)	78.8	52.7	75.0	68.0
		(37.5)	(47.6)	(41.0)	(43.7)
	By combine harvester (% of farmers)	11.2	5.97	1.43	6.14
		(25.3)	(17.1)	(7.56)	(18.2)
Number of sample groups that grew rice in the rainy season 2011		27	32	28	87

Standard deviations are in parentheses. ***, **, and * indicate that the mean results for farmer groups in the large-scale irrigation schemes, and those in small-scale irrigation schemes are statistically different at the significance level of 1 %, 5 %, and 10 %, respectively

regardless of the method used, this choice does not seem to be related to the use of credit. But machines save time, and their use is important for farmers who have to pay back credit and borrow again to grow rice in the coming dry season. In sum, farmers in large-scale irrigation schemes tend to use more labor-saving technologies for land preparation and harvesting/threshing, but the use of chemical fertilizer and herbicide does not differ between the two scales. CNCAS credit seems to be related to machine use, either directly in the case of land preparation or indirectly in the case of harvesting/threshing.

Table 6.7 gives the data on irrigation facility maintenance for the rainy season of 2011. Canal maintenance is done by village participation and hired labor, and the cost of labor and machine rental is not significantly different, so neither is total cost. Pump repair expenditure, on the other hand, is much lower in the case of large-scale schemes than for small-scale schemes, indicating that pump condition is better in the former and repairs are needed less frequently. Another possible explanation is that there are economies of scale in pump repair, since large-scale schemes share one or several pumps among many farmer groups.

Table 6.7 Facility maintenance by farmer groups in Senegal in the rainy season of 2011

	Large-scale	Small-scale		Total
		Village-based	Private	
Canal management by participation (dummy)	0.63	0.72	0.75	0.70
Participation rate of canal management	0.49	0.50	0.76	0.58
	(0.43)	(0.48)	(0.97)	(0.67)
Cost of participation labor per canal length (FCFA/m)[a]	146	265	85.3	170
	(259)	(347)	(104)	(270)
Cost of hired labor per canal length (FCFA/m)	9.20	11.0	8.69	9.71
	(20.4)	(34.0)	(29.1)	(28.5)
Cost of machinery rental per canal length (FCFA/m)	34.4	30.6	41.2	35.2
	(93.7)	(61.9)	(91.0)	(81.6)
Total cost for canal maintenance per canal length (FCFA/m)	190	306	135	215
	(266)	(337)	(160)	(275)
Total cost for pump repairing (10^3 FCFA)***	23.7	99.3	91.5	73.3
	(68.0)	(139)	(153)	(130)
Number of sample groups that grew rice in the rainy season 2011	27	32	28	87

Standard deviations are in parentheses. *** indicates that the mean results for farmer groups in the large-scale irrigation schemes, and those in small-scale irrigation schemes are statistically different at the significance level of 1 %

[a] Members' participatory labor is evaluated at the standard daily wage rate of 2,000 FCFA

6.5 Regression Analysis

6.5.1 Sample Household Characteristics

While evidence at the farmer group level supports Hypothesis 1, Hypotheses 2 and 3 were tested using household data. For the hypothesis testing we use sample households belonging to the farmer groups that grew rice in the rainy season of 2011; as shown in Table 4.7 there were only 87 out of 120 groups that grew rice in 2011. Some farmers have several rice plots in different schemes. In such cases, it is difficult to control for farmers' decisions about resource allocation among plots in different schemes. Therefore, in order to examine the impact of scheme size, farmers that had only one rice plot were selected. This meant that, finally, 228 farmers were included in the analysis.

The characteristics of the sample households are shown in Table 6.8. Farmers belonging to large-scale irrigation schemes and those belonging to small-scale irrigation schemes are very similar, except for the education level and marital status of the household head, and household size. In spite of these differences, there is no indication that there are systematic differences in household characteristics between the two groups. However, the inputs and outputs relating to rice production are significantly different, as shown in Table 6.9. Farmers in large-scale irrigation schemes

Table 6.8 Household characteristics in Senegal in the rainy season of 2011

	Large-scale	Small-scale		Total
		Village-based	Private	
Age of household head	47.7	49.9	44.3	47.3
	(12.4)	(14.5)	(14.6)	(14.2)
Number of female household heads	0	1	2	3
Number of years in education, household head**	2.76	3.70	3.22	3.29
	(2.07)	(2.34)	(2.21)	(2.26)
Number of household members**	12.5	10.7	9.62	10.8
	(6.71)	(5.24)	(6.45)	(6.16)
Single household head (dummy)***	0.26	0.08	0.05	0.11
Monogamous household head (dummy)**	0.52	0.63	0.73	0.64
Polygamous household head (dummy)	0.19	0.27	0.19	0.22
Having self-employment jobs (dummy)	0.16	0.12	0.19	0.15
Having employment jobs (dummy)	0.12	0.08	0.04	0.07
Number of months of head's absence in the past year	0.93	0.47	0.11	0.46
	(2.97)	(1.93)	(0.81)	(2.00)
Rice plot size (ha)	1.29	1.38	1.63	1.45
	(2.36)	(4.29)	(5.02)	(84.17)
Households whose farmer group is located in Podor Department (dummy)***	0.17	0.54	0.40	0.39
Number of sample households having only one rice plot and grew rice in 2011	58	81	89	228

Standard deviations are in parentheses. *** and ** indicate that the mean results for farmer groups in the large-scale irrigation schemes, and those in small-scale irrigation schemes are statistically different at the significance level of 1 % and 5 %, respectively

use less fertilizer, less labor, and more machinery than those in small-scale schemes. Moreover, farmers in large-scale irrigation schemes enjoy significantly higher yields, profit, and income per hectare.

Since harvesting and threshing are not directly correlated with production efficiency, we consider two types of profit here: one is profit before harvesting, and the other is profit after harvesting and threshing (standard profit). In terms of credit use, as shown in Table 6.9, 6 % of farmers belonging to large-scale irrigation schemes are members of farmer groups eligible for CNCAS credit. This share is significantly larger statistically than that of farmers belonging to small-scale irrigation schemes. But only a few farmers actually used CNCAS credit to purchase fertilizer in the rainy season 2011, even in the case of large-scale irrigation schemes. Also, many farmers use credit to buy fertilizer regardless of the type of irrigation scheme, but this is not necessarily CNCAS credit. And the share of credit users is not significantly different between large and the small schemes. Thus, from this simple comparison, it is not clear if credit has any impact on fertilizer use and rice yields.

Table 6.9 Rice production in Senegal in the rainy season of 2011

	Large-scale	Small-scale		Total
		Village-based	Private	
Seed cost per ha (10^3 FCFA/ha)	40.0	35.7	44.7	47.0
	(16.9)	(17.2)	(25.2)	(20.6)
Fertilizer cost per ha (10^3 FCFA/ha)**	68.5	70.8	99.2	80.3
	(32.3)	(43.1)	(67.9)	(53.0)
Fertilizer application rate (kg/ha)***	315	350	496	393
	(131)	(214)	(318)	(253)
CNCAS credit eligible (dummy)	0.60	0.29	0.13	0.31
Use CNCAS credit for fertilizer (dummy)	0.07	0.04	0	0.04
Use of other credit for fertilizer (dummy)	0.26	0.17	0.38	0.27
Other chemical input per ha (10^3 FCFA/ha)	25.4	20.8	17.9	21.0
	(28.2)	(27.6)	(19.4)	(25.2)
Machinery cost per ha (10^3 FCFA/ha)***	163	128	144	143
	(57.1)	(67.9)	(79.8)	(71.0)
Hired labor cost per ha (10^3 FCFA/ha)**	58.6	79.0	154	100
	(54.4)	(147)	(388)	(252)
Household labor cost per ha (10^3 FCFA/ha)[a], ***	534	1,187	640	827
	(611)	(1,573)	(921)	(120)
Rice output per ha (kg/ha)***	5,220	3,916	4,512	4,460
	(2,164)	(2,574)	(3,024)	(2,689)
Rice profit before harvesting per ha (10^3 FCFA/ha)***	147	–517	–104	–201
	(360)	(1,075)	(801)	(883)
Rice profit after threshing per ha (10^3 FCFA/ha)***	–201	–1,005	–505	–622
	(596)	(1,562)	(1,119)	(1,260)
Rice income per ha (10^3 FCFA/ha)***	334	182	136	204
	(213)	(280)	(518)	(378)
Rice income per household (10^3 FCFA/household)	239	210	320	256
	(382)	(414)	(1,134)	(748)
Number of sample households having only one rice plot and growing rice in 2011	58	81	89	228

Standard deviations are in parentheses. *** and ** indicate that the mean results for farmer groups in the large-scale irrigation schemes, and those in small-scale irrigation schemes are statistically different at the significance level of 1 % and 5 %, respectively

[a] Household labor is evaluated at the standard daily wage rate of 2,000 FCFA

6.5.2 Regression Results

In order to test Hypotheses 2 and 3, input use function and profit function are estimated by a two stage regression model, where the dummy variable of credit use is treated as an endogenous variable. There are two types of credit, CNCAS credit and the non-CNCAS credit provided by input dealers and rice millers, but as shown in Table 6.9, the number of users of CNCAS credit is very small, and so the two types are combined as one credit use variable. The finding that input dealers and rice millers provide credit is interesting, as it is common in Asia but seldom reported in SSA except for the Mwea irrigation scheme in Kenya (Njeru et al. 2014). Since the credit use variable is an endogenous binary dummy variable, selection bias is controlled for by the predicted probability of credit use obtained by a first-stage probit regression.

There are two explanatory variables concerning scheme size: one is a dummy variable for large-scale schemes, and the other is for scheme size. The former is expected to capture the unspecified institutional differences between large and small schemes, such as governance structure, and the latter is expected to capture the effect of the physical size of the schemes. However, since the two variables are highly correlated, we cannot use both at the same time due to multicollinearity. We present regression results using the dummy variable for large-scale schemes only because scheme size provides similar results. In order to control for the quality of irrigation facilities, the average percentage of irrigated area in the past 3 years, and total expenditure for pump repairs in the past 3 years were added as explanatory variables.

Table 6.10 shows the regression results of the input use functions. The dummy variable for large-scale schemes has a significant impact only on machine rental cost. Our main concern is the use of fertilizer. As is postulated in Hypothesis 2, scheme size does not influence fertilizer use. Rather, being consistent with Table 6.9, the private scheme dummy has a positive, significant effect on the use of fertilizer, which suggests superior management in the private system as opposed to the collective system.

Table 6.11 gives the regression results of yield and profit functions. As hypothesized, when controlled for irrigation performance and credit use, scheme size does not affect rice income or rice profit. However, rice yield is still significantly, but only statistically at the 10 % level, higher in large-scale irrigation schemes than in small-scale irrigation schemes, even after controlling for irrigation performance and credit use. Although Table 6.9 shows that profit is highest in large-scale irrigation schemes, this may be due to the irrigation performance captured by percentage area planted and pump repair cost in the past 3 years. As for yield, there may be other factors that affect the difference in yields between large-scale and small scale irrigation schemes. Thus, Hypothesis 3 is supported for rice income and profits, but not so strongly for rice yield.

So far, the comparison is being made between large-scale schemes and small-scale schemes, but as indicated in the tables, small-scale schemes include both village-based irrigation schemes and private irrigation schemes. Since these are quite different in all respects other than scheme size, dummy variables for private schemes are included in the regression analyses. However, in order to check the robustness of the results, regression analyses without private schemes were also conducted. Table 6.12 gives the regression results about the input functions, and Table 6.13 is for the regression results about the yield/profit functions. Scheme

Table 6.10 Determinants of input use for rice production in Senegal in the rainy season of 2011

	Eq. 1	Eq. 2	Eq. 3	Eq. 4	Eq. 5	Eq. 6
Dependent variable	Seed cost (10^3 FCFA/ha)	Fertilizer cost (10^3 FCFA/ha)	Other chemicals (10^3 FCFA/ha)	Machine rental cost (10^3 FCFA/ha)	Hired labor cost (10^3 FCFA/ha)	Household labor cost (10^3 FCFA/ha)
Explanatory variables						
Scheme/Farmer Group (FG) level variables						
Large-scale scheme (dummy)	2.712	0.516	0.800	23.789	−2.411	−127.329
	[5.737]	[14.326]	[5.630]	[14.089] *	[44.154]	[246.443]
Area managed by the FG (ha)	−0.115	−0.521	−0.236	−0.351	−0.051	−9.189
	[0.059]*	[0.236]**	[0.066]***	[0.162]**	[0.455]	[4.123]**
Private scheme (dummy)	10.712	27.309	0.580	20.927	70.445	−255.042
	[5.845]*	[16.645]*	[5.578]	[13.053]	[52.204]	[351.253]
% irrigated area (mean of 3 years)	−6.917	−12.911	5.648	29.966	−76.217	218.26
	[7.757]	[22.346]	[7.937]	[19.904]	[114.691]	[314.959]
Total canal length (km)	3.705	11.108	1.638	8.829	3.202	95.171
	[1.792]**	[4.639]**	[2.210]	[3.626]**	[9.653]	[81.479]
Pump repair in 3 years (10^5 FCFA)	−0.759	−1.733	−1.032	−1.536	5.92	25.056
	[0.595]	[2.522]	[0.498]**	[1.757]	[3.986]	[51.154]
Total number of FG members	0.027	0.114	0.034	0.141	0.058	2.462
	[0.025]	[0.059]*	[0.023]	[0.040]***	[0.098]	[1.369]*
Year of group formation	−0.052	−0.16	−0.428	−0.529	3.841	−14.232
	[0.231]	[0.580]	[0.235]*	[0.600]	[2.977]	[11.725]
Located in Podor (dummy)	−12.274	12.633	−23.855	−28.67	5.737	1,303.222
	[6.162]**	[18.352]	[5.507]***	[14.730]*	[90.772]	[335.628]***
Household (HH) level variables						
Credit for fertilizer purchase (dummy) endogenous	−11.655	76.715	−20.679	26.329	−39.739	1,232.114
	[8.854]	[16.029]***	[8.651]**	[27.717]	[33.417]	[537.851]**

(continued)

Table 6.10 (continued)

	Eq. 1	Eq. 2	Eq. 3	Eq. 4	Eq. 5	Eq. 6
Dependent variable	Seed cost (10^3 FCFA/ha)	Fertilizer cost (10^3 FCFA/ha)	Other chemicals (10^3 FCFA/ha)	Machine rental cost (10^3 FCFA/ha)	Hired labor cost (10^3 FCFA/ha)	Household labor cost (10^3 FCFA/ha)
Age of HH head	−0.113	−0.054	−0.199	−0.452	−1.426	6.814
	[0.113]	[0.332]	[0.139]	[0.349]	[1.336]	[6.109]
Years in education of HH Head	−0.457	−0.646	0.936	−1.633	1.864	−51.346
	[0.651]	[1.999]	[0.586]	[1.978]	[3.910]	[35.430]
Number of HH members	−0.035	0.025	0.691	−1.276	−2.324	9.110
	[0.265]	[0.789]	[0.391]*	[0.829]	[2.251]	[15.024]
Monogamy HH head (dummy)	4.493	9.976	3.197	−6.289	53.18	−4.147
	[4.381]	[14.150]	[3.839]	[15.899]	[31.684] *	[203.373]
Polygamy HH head (dummy)	3.895	24.299	0.699	3.293	61.006	443.252
	[4.822]	[13.635]*	[5.902]	[18.303]	[39.548]	[273.806]
Self-employment (dummy)	−8.893	2.76	0.487	−8.292	−65.889	389.349
	[3.072]***	[9.738]	[5.486]	[12.860]	[44.517]	[207.237]*
Number of months being away home	−0.204	1.889	0.549	4.023	−2.85	30.778
	[0.452]	[2.032]	[0.611]	[4.126]	[3.931]	[32.852]
Size of rice plot in question (ha)	−0.065	−1.122	−0.435	−1.663	−2.202	−27.429
	[0.227]	[1.004]	[0.317]	[1.037]	[1.433]	[21.534]
Constant	155.376	360.926	888.617	1,207.494	−7,482.079	27,926.025
	[462.326]	[1,161.216]	[468.737]*	[1,193.184]	[5,865.710]	[23,327.871]
Number of Obs.	228	228	228	228	228	228

Standard errors are in parentheses. ***, ** and * indicate statistical significance level of level of 1 %, 5 %, and 10 %, respectively

Each equation (Eq. 1–Eq. 6) is estimated separately, including the dummy variable for the use of credit for purchasing fertilizer. Since this dummy variable is assumed to be endogenous in each equation, the selection bias is controlled for by the predicted probabilities obtained by a first stage probit regression as shown in the last column of Table 6.11

Table 6.11 Determinants of the yield and profit of rice production in Senegal in the rainy season of 2011

	Eq. 7	Eq. 8	Eq. 9	Eq. 10	Eq. 11	First stage
Dependent variable	Rice yield (kg/ha)	Rice income per area (10^3 FCFA/ha)	Rice income per HH (10^3 FCFA/HH)	Profit before harvesting (10^3 FCFA/ha)	Profit after threshing (10^3 FCFA/ha)	Credit for fertilizer purchase (dummy)
Explanatory variables						
Scheme/Farmer Group (FG) level variables						
Large-scale scheme (dummy)	901.101	92.536	−166.755	220.311	222.171	−0.166
	[533.658]*	[71.407]	[127.666]	[171.856]	[257.606]	[0.323]
Area managed by the FG (ha)	−13.286	−0.570	−0.250	6.046	8.827	0.005
	[6.138]**	[0.772]	[2.389]	[3.079]**	[3.965]**	[0.005]
Private scheme (dummy)	792.702	−33.403	66.765	224.973	240.18	0.219
	[494.434]	[75.677]	[126.161]	[216.259]	[349.406]	[0.376]
% irrigated area (mean of 3 years)	1,135.062	216.659	135.981	214.131	−16.314	−0.170
	[753.944]	[148.644]	[133.484]	[256.756]	[350.571]	[0.421]
Total canal length (km)	334.437	17.147	8.121	−44.380	−81.431	−0.047
	[137.365]**	[17.422]	[35.798]	[65.720]	[84.406]	[0.114]
Pump repair in 3 years (10^5 FCFA)	−58.193	−8.840	−13.842	−21.570	−33.211	0.032
	[66.552]	[8.633]	[11.223]	[33.092]	[50.437]	[0.045]
Total number of FG members	5.325	0.344	0.297	−1.705	−2.151	−0.002
	[1.504]***	[0.167]**	[0.443]	[1.334]	[1.396]	[0.001]
Year of group formation	−20.05	−5.391	1.375	6.089	9.007	0.010
	[22.722]	[4.083]	[4.132]	[7.744]	[12.003]	[0.013]
Located in Podor (dummy)	−1,085.994	−72.815	−158.055	−979.608	−1,431.452	−0.896
	[557.965]*	[109.025]	[109.971]	[194.995]***	[309.800]***	[0.349]**
CNCAS eligibility (dummy)	NA	NA	NA	NA	NA	0.500
						[0.223]**

(continued)

Table 6.11 (continued)

	Eq. 7	Eq. 8	Eq. 9	Eq. 10	Eq. 11	First stage
Dependent variable	Rice yield (kg/ha)	Rice income per area (10^3 FCFA/ha)	Rice income per HH (10^3 FCFA/ HH)	Profit before harvesting (10^3 FCFA/ha)	Profit after threshing (10^3 FCFA/ha)	Credit for fertilizer purchase (dummy)
Household (HH) level variables						
Credit for fertilizer purchase (dummy) endogenous	997.304	177.381	243.173	−789.158	−1,231.059	NA
	[1,049.881]	[76.379]**	[112.082]**	[191.061]***	[254.071]***	
Age of HH head	−17.133	0.146	−3.373	−2.468	−7.042	−0.009
	[13.234]	[1.934]	[2.582]	[4.268]	[6.273]	[0.007]
Years in education of HH head	−61.869	−8.869	−23.836	15.855	43.944	0.034
	[74.939]	[8.158]	[17.784]	[25.991]	[35.701]	[0.043]
Number of HH members	−48.329	−3.606	20.153	−14.511	−12.382	0.012
	[31.396]	[3.960]	[16.877]	[10.754]	[15.904]	[0.015]
Monogamy HH head (dummy)	−238.219	−96.348	−221.671	−123.627	−91.405	0.140
	[602.246]	[72.406]	[109.256]**	[170.775]	[233.369]	[0.302]
Polygamy HH head (dummy)	124.72	−77.88	−96.419	−319.181	−518.483	0.015
	[693.295]	[87.372]	[134.996]	[185.269]*	[292.089]*	[0.307]
Self-employment (dummy)	−314.104	54.378	−90.913	−261.877	−371.776	−0.510
	[487.127]	[63.532]	[102.073]	[126.739]**	[174.399]**	[0.242]**
Number of months being away home	152.401	18.338	7.592	−3.764	−16.182	−0.094
	[156.270]	[17.401]	[15.871]	[15.268]	[22.352]	[0.045]**
Size of rice plot in question (ha)	−62.983	−3.164	81.354	13.891	25.037	0.015
	[39.272]	[4.482]	[41.532]*	[13.669]	[20.680]	[0.020]
Constant	44,791.445	10,887.076	−2,482.117	−11,610.394	−17,280.162	−19.642
	[45,196.366]	[8,070.768]	[8,301.359]	[15,485.051]	[23,976.406]	[26.942]
Number of Obs.	228	228	228	228	228	228

Standard errors are in parentheses. ***, ** and * indicate statistical significance level of level of 1 %, 5 %, and 10 %, respectively
Each equation (Eq. 7–Eq. 11) is estimated separately, including the dummy variable for the use of credit for purchasing fertilizer. Since this dummy variable is assumed to be endogenous in each equation, the selection bias is controlled for by the predicted probabilities obtained by a first stage probit regression as shown in the last column of the table

Table 6.12 Effect of scheme size on input use in Senegal in the rainy season of 2011

	Eq. 12	Eq. 13	Eq. 14	Eq. 15	Eq. 16	Eq. 17
Dependent variable	Seed cost (10^3 FCFA/ha)	Fertilizer cost (10^3 FCFA/ha)	Other chemicals (10^3 FCFA/ha)	Machine rental cost (10^3 FCFA/ha)	Hired labor cost (10^3 FCFA/ha)	Household labor cost (10^3 FCFA/ha)
Explanatory variables						
Scheme/Farmer Group (FG) level variables						
Large-scale scheme (dummy)	–0.563	3.449	–3.625	29.158	–29.871	–101.889
	[4.092]	[10.026]	[6.429]	[12.799]**	[28.940]	[170.949]
Area managed by the FG (ha)	–0.009	–0.21	–0.269	–0.065	–0.572	–18.574
	[0.082]	[0.188]	[0.094]***	[0.272]	[0.421]	[6.518]***
% irrigated area (mean of 3 years)	8.073	–15.625	18.892	15.47	57.741	379.105
	[5.347]	[15.631]	[10.000]*	[25.305]	[67.078]	[312.733]
Total canal length (km)	–0.080	3.340	–0.372	1.259	7.450	195.099
	[1.793]	[3.183]	[2.672]	[5.965]	[10.189]	[124.552]
Pump repair in 3 years (10^5 FCFA)	–0.402	–0.973	–1.489	–2.626	3.186	21.920
	[0.521]	[1.688]	[0.862]*	[2.635]	[3.926]	[81.996]
Total number of FG members	0.004	0.046	0.055	0.136	0.146	3.275
	[0.023]	[0.036]	[0.022]**	[0.063]**	[0.062]**	[1.351]**
Year of group formation	0.464	0.284	–0.333	–0.422	–0.252	–29.833
	[0.224]**	[0.417]	[0.235]	[0.813]	[0.934]	[14.661]**
Located in Podor (dummy)	–5.365	10.076	–26.407	–16.948	–85.341	1,136.599
	[4.839]	[11.356]	[6.136]***	[16.389]	[55.209]	[301.909]***
Household (HH) level variables						
Credit for fertilizer purchase (dummy)						
Endogenous	–2.078	11.875	0.515	31.261	–0.559	1,412.378
	[8.383]	[21.360]	[17.649]	[33.476]	[72.387]	[584.762]**
Age of HH head	–0.113	–0.054	–0.199	–0.452	–1.426	6.814
	[0.113]	[0.332]	[0.139]	[0.349]	[1.336]	[6.109]

(continued)

Table 6.12 (continued)

	Eq. 12	Eq. 13	Eq. 14	Eq. 15	Eq. 16	Eq. 17
Dependent variable	Seed cost (10^3 FCFA/ha)	Fertilizer cost (10^3 FCFA/ha)	Other chemicals (10^3 FCFA/ha)	Machine rental cost (10^3 FCFA/ha)	Hired labor cost (10^3 FCFA/ha)	Household labor cost (10^3 FCFA/ha)
Years in education of HH head	−0.056	−0.369	−0.253	−0.598	0.453	3.622
	[0.150]	[0.282]	[0.251]	[0.523]	[0.677]	[7.684]
Number of HH members	−0.305	−0.515	0.060	−1.715	4.099	−94.979
	[0.981]	[2.090]	[1.103]	[2.845]	[4.946]	[55.004]*
Monogamy HH head (dummy)	−0.013	0.200	0.634	−1.488	−2.786	17.054
	[0.247]	[0.583]	[0.534]	[0.925]	[2.204]	[17.647]
Polygamy HH head (dummy)	3.322	17.155	1.768	−1.603	19.291	213.726
	[2.373]	[10.582]	[6.807]	[12.888]	[20.896]	[201.292]
Self-employment (dummy)	−1.663	21.757	5.969	15.621	38.927	823.913
	[5.550]	[12.426]*	[8.390]	[17.268]	[42.804]	[309.801]***
Number of months being away home	−7.125 [3.129]**	−3.533 [10.273]	12.784 [7.892]	−7.741 [18.943]	−2.315 [28.118]	38.38 [185.972]
Size of rice plot in question (ha)	−0.285	0.424	0.284	4.197	1.911	72.853
	[0.603]	[1.705]	[0.971]	[3.724]	[4.064]	[33.880]**
Constant	−885.62	−491.754	697.853	1,001.059	555.799	59,168.719
	[443.684]**	[831.057]	[464.852]	[1,613.738]	[1,843.163]	[29,108.605]**
Number of Obs.	147	147	147	147	147	147

Standard errors are in parentheses. ***, ** and * indicate statistical significance level of level of 1 %, 5 %, and 10 %, respectively

Each equation (Eq. 12–Eq. 17) is estimated separately, including the dummy variable for the use of credit for purchasing fertilizer. Since this dummy variable is assumed to be endogenous in each equation, the selection bias is controlled for by the predicted probabilities obtained by a first stage probit regression as shown in the last column of Table 6.13

Table 6.13 Determinants of yield and profit of rice production in Senegal in the rainy season of 2011

	Eq. 18	Eq. 19	Eq. 20	Eq. 21	Eq. 22	First stage
Dependent variable	Rice yield (kg/ha)	Rice income per Area (10^3 FCFA/ha)	Rice income per HH (10^3 FCFA/HH)	Profit before harvesting (10^3 FCFA/ha)	Profit after threshing (10^3 FCFA/ha)	Credit for fertilizer purchase (dummy)
Explanatory variables						
Scheme/Farmer Group (FG) level variables						
Large-scale scheme (dummy)	1,104.471	147.241	–110.023	215.464	249.13	–0.279
	[478.874]**	[65.829]**	[102.104]	[175.022]	[179.373]	[0.409]
Area managed by the FG (ha)	–2.445	0.802	4.699	14.168	19.376	0.008
	[8.642]	[0.919]	[2.450]*	[4.446]***	[6.528]***	[0.008]
% irrigated area (mean of 3 years)	585.995	–7.2	–41.758	–23.64	–386.305	–0.456
	[962.440]	[130.786]	[127.854]	[270.594]	[327.166]	[0.841]
Total canal length (km)	47.687	–5.302	–20.147	–126.517	–200.401	–0.346
	[187.676]	[26.043]	[41.196]	[88.430]	[116.042]*	[0.263]
Pump repair in 3 years (10^5 FCFA)	–99.465	–10.826	–18.085	–16.805	–32.746	0.049
	[96.577]	[11.332]	[20.323]	[43.476]	[78.623]	[0.114]
Total number of FG members	5.142	0.292	–0.469	–2.434	–2.983	–0.003
	[2.350]**	[0.229]	[0.381]	[1.124]**	[1.258]**	[0.008]
Year of group formation	–15.966	–1.85	–0.819	19.776	27.983	0.005
	[31.138]	[3.643]	[3.298]	[10.437]*	[15.133]*	[0.031]
Located in Podor (dummy)	–641.974	39.244	–91.68	–787.197	–1,097.355	–0.921
	[542.837]	[84.936]	[96.461]	[175.694]***	[305.721]***	[0.727]
CNCAS eligibility (dummy)	NA	NA	NA	NA	NA	1.279
						[0.552]**
Household (HH) level variables						
Credit for fertilizer purchase (dummy) endogenous	997.304	177.381	243.173	–789.158	–1,231.059	NA
	[1,049.881]	[76.379]**	[112.082]**	[191.061]***	[254.071]***	

(continued)

Table 6.13 (continued)

	Eq. 18	Eq. 19	Eq. 20	Eq. 21	Eq. 22	First stage
Dependent variable	Rice yield (kg/ha)	Rice income per Area (10^3 FCFA/ha)	Rice income per HH (10^3 FCFA/HH)	Profit before harvesting (10^3 FCFA/ha)	Profit after threshing (10^3 FCFA/ha)	Credit for fertilizer purchase (dummy)
Age of HH head	–22.639	–2.165	–3.146	–3.482	–5.788	–0.008
	[23.614]	[2.205]	[2.648]	[5.796]	[6.998]	[0.013]
Years in education of HH head	–64.968	–10.199	1.44	43.394	84.781	0.154
	[92.617]	[12.154]	[13.173]	[31.097]	[51.528]*	[0.093]*
Number of HH members	–56.377	–3.989	4.779	–19.923	–21.043	–0.005
	[39.456]	[4.037]	[6.490]	[11.920]*	[19.017]	[0.044]
Monogamy HH head (dummy)	–60.706	–47.946	–119.016	–210.798	–261.672	–0.267
	[601.615]	[58.201]	[92.189]	[156.852]	[251.291]	[0.447]
Polygamy HH head (dummy)	591.705	–2.506	–56.458	–423.441	–826.419	–0.568
	[891.227]	[73.356]	[123.488]	[240.307]*	[300.161]***	[0.659]
Self-employment (dummy)	–293.212	–30.774	–92.96	–54.112	–69.154	–0.855
	[815.301]	[76.642]	[99.368]	[153.242]	[246.018]	[1.279]
Number of months being away home	158.98	14.455	9.784	–32.96	–58.398	–0.168
	[112.527]	[17.111]	[13.190]	[23.453]	[39.938]	[0.571]
Size of rice plot in question (ha)	–112.512	–7.919	5.368	30.665	60.316	0.079
	[189.753]	[17.459]	[88.280]	[50.671]	[106.183]	[0.189]
Constant	36,971.93	4,002.959	1,975.773	–38,899.8	–55,165.8	–8.897
	[61,491.132]	[7,219.971]	[6,550.391]	[20,779.864]*	[29,939.373]*	[62.111]
Number of Obs.	147	147	147	147	147	147

Standard errors are in parentheses. ***, ** and * indicate statistical significance level of level of 1 %, 5 %, and 10 %, respectively

Each equation (Eq. 18–Eq. 22) is estimated separately, including the dummy variable for the use of credit for purchasing fertilizer. Since this dummy variable is assumed to be endogenous in each equation, the selection bias is controlled for by the predicted probabilities obtained by a first stage probit regression as shown in the last column of the table size has a significant and positive impact on machine use (Table 6.12) and rice yield (Table 6.13), and this is the same as those in the full sample regression shown in Tables 6.10 and 6.11, respectively. In addition, rice income per hectare is higher in large-scale irrigation schemes than in the small-scale irrigation schemes as shown in Table 6.13. The results are consistent with Table 6.9, implying that large-scale irrigation schemes have certain advantages over village-based small-scale irrigation schemes, even after controlling for irrigation performance.

6.6 Conclusions

In the Senegal River Valley, the average yield of irrigated rice production is much higher than the average throughout the rest of sub-Saharan Africa. Our data show that the overall average in this area is 4.5 tons per ha, and that of the large-scale irrigation schemes is more than 5 tons per ha. In addition to well irrigated conditions, the high yields seem to be due to the high doses of chemical fertilizer applied, i.e., 400 kg per ha on average. It is therefore no exaggeration to argue that as in the Asian Green Revolution, the core of high productivity in rice farming in the Senegal River Valley lies in the adoption of improved "seed-fertilizer" technology under irrigated conditions.

Our main aim was to determine if large-scale irrigation schemes are more efficient than small scale irrigation schemes, or at least that they are as efficient as small ones; because it is widely believed that large-scale irrigation schemes are less efficient due to difficulties in irrigation management. Thus, this study compared the efficiency of rice production between large-scale irrigation schemes and small-scale irrigation schemes using household data collected in the Senegal Ricer Valley. The regression analyses demonstrate that large-scale irrigation schemes are as efficient as small-scale irrigation schemes when we control for the quality of irrigation facilities. That is, the seemingly better performance of large-scale irrigation schemes in the Senegal River Valley mainly comes from better management of irrigation facilities at the scheme level. However, the small-scale irrigation schemes are heterogeneous since they include village-based collective irrigation schemes and private irrigation schemes. If we compare large-scale schemes with village-based small-scale ones only, the former perform better even after controlling for observed advantage. The results imply that village-based small-scale collective irrigation schemes have inherent problems in irrigation management. Thus, we conclude that a part of the reason for the high productivity in rice farming in the Senegal River Valley can be attributed to the advantage of large-scale irrigation schemes over small-scale schemes.

Chapter 7
On the Possibility of a Maize Green Revolution in the Highlands of Kenya: An Assessment of Emerging Intensive Farming Systems

Rie Muraoka, Tomoya Matsumoto, Songqing Jin, and Keijiro Otsuka

Abstract As population pressure on land grows rapidly in Kenya, rural farmers have started to intensify land use, which has led to the emergence of a new maize farming system. The new system is characterized by the adoption of high-yielding maize varieties, the application of chemical fertilizer and manure produced by stall-fed improved dairy cows, and intercropping, especially the combination of maize and legumes. This study aims to explore the determinants of the new maize farming system and its impact on land productivity. We examine not only the impacts of new technologies and production practices but also the impact of the entire new maize farming system by generating an agricultural intensification index based on a principal component analysis. The estimation results show that a decrease in the land-labor ratio accelerates farming intensification, and that the adoption of each new technology and production practice has positive and significant impacts on land productivity. These findings are further supported by the significantly positive impacts of the agriculture intensification index on land productivity.

Keywords Farming system • Agricultural intensification • Population pressure • Maize • Green Revolution • Kenya

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7.1 Introduction

The improvement of agricultural productivity is imperative for poverty reduction in developing countries in general, and in sub-Saharan Africa (SSA), in particular, considering its high rate of population growth, increasingly limited availability of cultivatable lands, and the rise of food prices in the international market (David and Otsuka 1994; Otsuka et al. 2008; Barrett et al. 2010). Asia experienced a rapid rise of agricultural productivity, known as the "Green Revolution," characterized by the adoption of chemical fertilizer and fertilizer-responsive high-yielding varieties in the 1970s and 1980s, along with the expansion of irrigation infrastructure (Kikuchi and Hayami 1978; David and Otsuka 1994; Evenson and Gollin 2003c; Hayami and Godo 2005; Otsuka and Larson 2013b). In contrast, Africa is the only continent experiencing the stagnation of agriculture productivity. Researchers, therefore, continue to look for ways to enhance agriculture productivity in Africa. However, it is widely believed that underdeveloped infrastructure and markets lead to high transaction costs for the purchase of chemical fertilizer and seeds of high-yielding varieties and to poor access to irrigation, and, hence, it is not possible for small farmers to achieve rapid growth in agricultural productivity (Jayne et al. 2003; Kydd et al. 2004; Reardon et al. 1999; Gregory and Bumb 2006).

Yet, under these circumstances, some farmers have begun adopting a new farming system of maize production in the highlands of Kenya characterized by the application of organic fertilizer, i.e., manure produced from improved dairy cattle in addition to the use of hybrid seeds, chemical fertilizer, intercropping with legumes, and crop rotation (Otsuka and Yamano 2005). A typical farmer in this system grows Napier grass, which is a common feed crop for cattle that can also repel pests, feeds it to improved cattle that are raised in stalls, collects manure from the stalls, and applies it on the maize plots, where the intercropping of hybrid maize with nitrogen-fixing--> legumes is practiced. This farming system is similar not only to the Green Revolution in Asia in the 1970s and 1980s whose essence is the application of high-yielding varieties and chemical fertilizer, but also to the agricultural revolution in U.K. in the eighteenth century, which is based on the application of manure produced from stall-fed cattle as well as the production of feeds on crop fields. It may not be unrealistic to assume that this new farming system, which embodies the essence of the two preceding revolutions in agricultural history, will bring about "revolutionary" changes in farm productivity in SSA.

To our knowledge, however, no study has statistically examined the determinants of the adoption and productivity impacts of this emerging farming system in SSA. Therefore, this study aims to identify the determinants of the adoption of this new farming system and to estimate its impact on the productivity of maize, the major staple crop in Kenya, through regression analyses. In addition to estimating the effects of each element of the new farming system on production and productivity, this study attempts to measure the impact of the entire system by creating a single agriculture intensification index that captures this multidimensional input intensification. Our approach will provide insights into the effects of the new farming system on the productivity and profitability of maize farming, which should assist policy makers in constructing new, effective strategies for agricultural productivity improvement in SSA.

The remainder of the chapter is structured as follows. Section 7.2 outlines the background of this study, while Sect. 7.3 describes the data collection method and provides descriptive statistics. Section 7.4 explains how the maize farming system index is constructed, Sect. 7.5 describes our identification strategies, and Sect. 7.6 presents the estimation results. Finally, Sect. 7.7 discusses the conclusions and policy implications of this study.

7.2 Background

In the eighteenth century, the agricultural revolution was realized due to the introduction of the turnip as a feed crop, the stall-feeding of cattle, and the ample application of manure to crop fields (Timmer 1969). This new farming system was based on crop rotation, feed production, stall-fed cattle, and the application of manure, which enhanced crop yields. In contrast to cattle grazing under a three-field system which requires large areas of land but does not require intensive labor use, stall-feeding of cattle is labor intensive as it requires feed crops or feeding grass. The collection of manure from stalls and its application to crop fields is also labor intensive. In addition, the stall-feeding of cattle makes it possible to fully collect manure. Therefore, a farming system based on the stall-feeding of cattle is a more labor-using and yield-enhancing technology than the traditional three-field farming system based on grazing. This method seems to fit with densely populated areas in SSA, which have been experiencing rapid population growth, the shrinkage of cultivatable lands per capita, and declining soil fertility.

Asia has experienced rapid productivity growth mainly in rice and wheat since the late 1960s (David and Otsuka 1994; Hayami and Godo 2005), which is called the Green Revolution. This high growth in agricultural productivity was realized by the application of chemical fertilizer, the adoption of high-yielding modern rice varieties, and the development of irrigation. Farmers used the modern varieties and chemical fertilizer simultaneously because the provision of soil nutrients is necessary to realize the high yield potential of the modern varieties. Therefore, the important lesson from the Green Revolution in Asia is that both the adoption of high-yielding varieties and the application of chemical fertilizer are necessary to increase crop yields significantly (Hayami and Ruttan 1985; David and Otsuka 1994).

However, in a country where infrastructure is underdeveloped, it is difficult for poor farmers in rural area to have access to chemical fertilizer due to its high transaction cost. Moreover, unlike lowland rice farming, which is most sustainable, upland farming requires the maintenance of soil fertility by applying organic fertilizer in addition to chemical fertilizer. Hence, many farmers in the highlands of Kenya apply organic fertilizer which is made from enteruria collected from stall-fed cows as depicted in Fig. 7.1. Farmers grow feed grass such as Napier grass, which

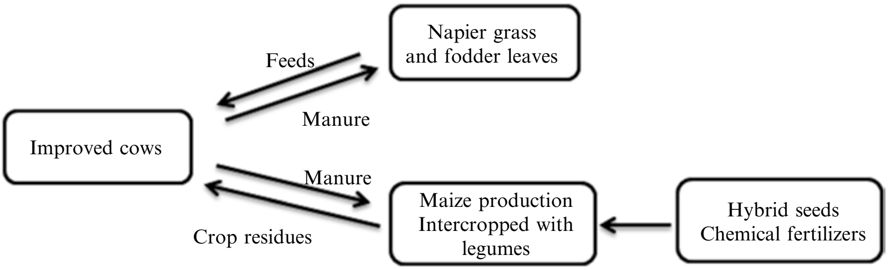

Fig. 7.1 Organic green revolution in East Africa (Source: Revised Fig. 4 from Otsuka and Yamano 2005)

repels pests, and feed it to improved cows in the stalls. Then, farmers collect the cows' enteruria and create manure from it. Many of them plant a hybrid maize variety and apply both manure and chemical fertilizer on the plot. Moreover, they often intercrop maize with legumes that fix nitrogen from the atmosphere, which improves soil fertility. It is important to emphasize that this system combines the technological advantages from two agricultural revolutions, one that occurred in England in the eighteenth century and another that was achieved in Asia in the twentieth century. We hypothesize that the emerging farming system has the potential to boost maize productivity significantly in SSA.

7.3 Descriptive Analysis

7.3.1 Data

In order to analyze the determinants of the adoption of the new maize farming system and its impact on maize and entire crop yields, including the yield of leguminous crops, and milk production, household and plot-level data are taken from a survey called RePEAT. This data set was jointly collected by the National Graduate Institute for Policy Studies (GRIPS), the World Agroforestry Center, and Tegemeo Institute of Agricultural Policy and Development in Kenya. The RePEAT survey is originally based on a survey conducted by the Smallholder Diary Project (SDP) that collected data from more than 3,300 households randomly selected from communities in the Central, Rift Valley, Nyanza, and Western, and Eastern provinces in Kenya by the International Livestock Research Institute, Nairobi. In 2004, the RePEAT survey randomly selected 99 sub-locations, which is the smallest community unit and is equivalent to a village, and up to ten households from each of the selected sub-locations, which results in a sample of 899 households.

Table 7.1 Sample household characteristics in Kenya

	2004		2012		Testing difference in means[a]
	Mean(b)	S.D.	Mean(c)	S.D.	
Number of households	663		663		
Female headed HH (%)	22	(41)	30	(46)	***
Age of the head (years)	56	(14)	61	(14)	***
Head completed primary education (%)	39	(49)	0.42	(49)	
Years of schooling of HH head (years)	6.5	(4.4)	6.8	(4.3)	
HH size	7.0	(3.1)	7.0	(3.2)	
HH members between 15 and 64	4.2	(2.2)	4.4	(2.4)	
Number of dependents	2.9	(2.)	2.5	(1.8)	***
Owned land size (ha)	1.8	(2.8)	1.5	(2.1)	**
Owned land size per HH members between 15 and 64 (ha)	0.6	(0.9)	0.4	(0.7)	***
Value of asset (KSh)	88,068	(238,179)	79,902	(353,745)	
Time to the nearest market by car (min)	21	(20)	15	(12)	***

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

[a] Significance testing of the difference between columns (b) and (c)

The second round of the RePEAT survey was conducted in 2012, which revisited 751 households that were interviewed in 2004. Thus, the attrition rate is 16.5 %.[1] We drop households that did not provide complete answers for the survey and that did not grow maize because our focus is on maize production. To address extreme values or outliers, we drop the households if their outcome variables including the maize yield per hectare, total value of crop harvest per hectare, crop income per hectare, the sum of crop and milk revenue per hectare, or crop and milk income per hectare is more than the 99th percentile of each variable. Eventually, our final sample size consisted of 663 households in 97 sub-locations and 1,750 maize plots. The RePEAT survey includes detailed household information on agricultural activities, land use, demographics, education, assets, nonfarm income, agricultural expenditure, and consumption.

Table 7.1 shows the socioeconomic characteristics of the sample households. According to this table, the proportion of female headed households has increased from 22 to 30 %, and the typical household head has become older by 5 years from 2004 to 2012. Although the household size has not changed much over time, the composition of a typical household has changed as the number of household working age (15–64 years) members increased by 0.2, and the number of dependents has decreased by 0.4 over time. The size of owned land was small already in 2004, i.e.,

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[1] Attrition weights are adopted to control for attrition issues in the estimation.

1.8 ha, indicating that the population pressure was severe in the highlands of Kenya. Farm size has shrunk to 1.5 ha over the 8-year period, which clearly leads to a decrease in the land-labor ratio over time. It is clear that in order to increase maize production, maize yield must be increased. The transportation infrastructure has improved over time in Kenya as evidenced by the shortened time distance to the nearest market by car, which indicates that the accessibility to agricultural inputs and output markets and information could have improved over time.

7.3.2 Maize Production in Kenya

Figure 7.2 traces the change in the quantity of maize production, maize harvested area, and land productivity of maize from 1962 to 2010 in Kenya. All of them are indexed in which all values are converted into 100 in 1962. Although there are upward trends in the quantity of maize production and area harvested, the rate of growth in the land productivity of maize has been negligible over time. It raises a red flag regarding food security in Kenya whose annual population growth rate was still 2.7 % in 2012 and whose potential for area expansion is limited. Therefore, how to boost the maize yield is an urgent issue in this country.

Table 7.2 provides production data in Kenya based on our survey data in 2004 and 2012. The size of the maize plot has shrunk over time, which is consistent with the declining trend in the owned land size. The adoption rate of hybrid maize,

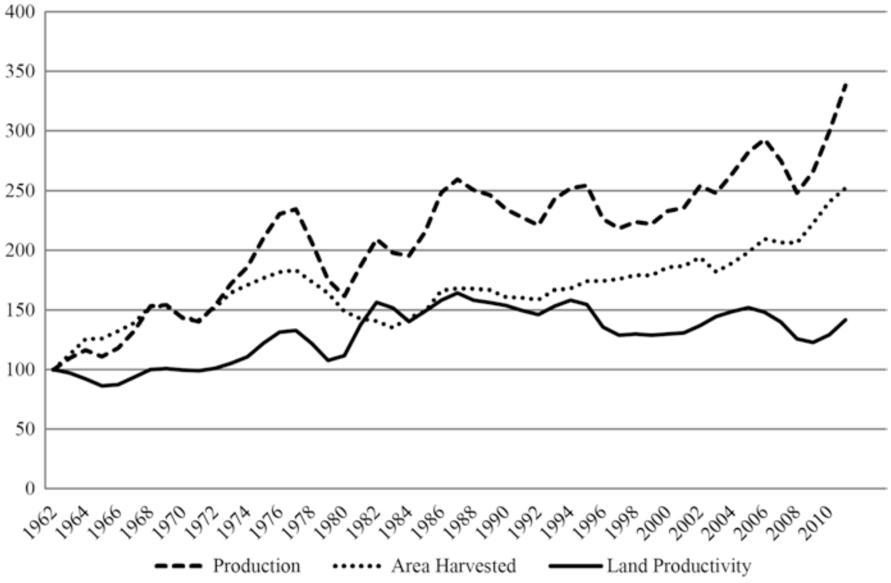

Fig. 7.2 Maize production in Kenya, index (1962= 100) (Source: FAOSTAT Online Database)

Table 7.2 Crop production of the maize plots in the main crop season in Kenya

	2004		2012		Testing difference in means[a]
	Mean(b)	S.D.	Mean(c)	S.D.	
Number of plots	846		904		
Maize plot size (ha)	0.41	(0.40)	0.37	(0.36)	*
Hybrid maize seeds (%)	50	(50)	78	(41)	***
Intercrop with legumes (%)	76	(43)	72	(45)	*
Area planted to Napier grass (ha)	0.05	(0.18)	0.03	(0.14)	
Manure applied (%)	38	(49)	51	(50)	***
Chemical fertilizer applied (%)	68	(46)	76	(43)	***
Quantity of manure (kg/ha)	971	(2,873)	1,578	(3,079)	***
Quantity of chemical fertilizer (kg/ha)[b]	49	(64)	47	(48)	
Cost of other chemical inputs (KSh/ha)[c]	109	(478)	211	(555)	***
Quantity of maize yield (kg/ha)	1,766	(1,595)	2,142	(1,522)	***
Value of harvest from all crops (KSh/ha)	47,520	(43,069)	60,011	(47,465)	***
Crop income from all crops (KSh/ha)[d]	37,869	(39,983)	46,786	(44,362)	***

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

[a] Significance testing of the difference between columns (b) and (c)

[b] Quantity of chemical fertilizer is measured in NPK equivalent

[c] This includes herbicides, pesticides, fungicides, and other chemical input

[d] Crop income is defined as the value of harvest minus the paid costs of chemical and organic fertilizer, other chemical inputs, seed, and hired labor

however, has increased from 50 to 78 %, and expenditures for chemical inputs other than chemical fertilizer, which include herbicides, pesticides, and fungicides, have risen from 109 Kenyan Shieling (KSh) per hectare to 211 KSh per hectare from 2004 to 2012.[2] In contrast, the ratio of intercropping with legumes and the proportion of area planted to Napier grass slightly declined over time. Both the adoption rate of manure and the quantity of manure applied per hectare have risen significantly over time, which resulted from raising stall-fed improved cows and the production of Napier grass. It is also remarkable to observe that the adoption rate of chemical fertilizer significantly increased over time, even though its applied quantity, which is converted into the total weight (in kg per hectare) of primary nutrients in terms of nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O_5) contained in fertilizers (hereafter, NPK), slightly and insignificantly decreased over time. While

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[2] Throughout this chapter, all prices are converted to the real price setting 2009 as a base year. The consumer price index for 2004 is 66.03 and that for 2012 is 103.53.

the maize yield has increased by about 21 %, the value of the harvest from maize and all other intercropped crops of the maize plots has increased by as much as 26 %. Similarly, sample households experienced a growth in their crop income, defined as the total value of harvested crops minus the paid-out costs of chemical and organic fertilizer, other chemical inputs, seeds, and hired labor, by 24 % over time. This indicates that the yield is increasing not only for maize but also for other crops planted in the intercropping system. Since intercropping with maize and other crops, such as legumes, is a common farming practice in Kenya, we may underestimate maize productivity if we look at only maize on the intercropped maize plots. A possible hypothesis about the stagnant maize productivity in Kenya as a whole is that while "effective" maize productivity increased, measured maize productivity is stagnant due to the increasing practice of intercropping.

Table 7.3 shows the amount of fertilizer application and land productivity by the types of maize seeds. The adoption of hybrid maize seeds is associated with a higher yield and value of harvest than that of local seeds by about 55 % and 44 %, respectively. Consistently, the proportion of plots with chemical fertilizer application is higher for hybrid seeds than for local seeds by 32 %, and the quantity of chemical fertilizer applied per hectare is also greater for the hybrid seed parcels than for the local seed by 31 kg per hectare. In contrast to chemical fertilizer use, the proportion of manure used is slightly higher for local seed parcels than for hybrid parcels. However, when we look at the quantity of manure applied per hectare, it is greater for hybrid seeds than for local seeds. This indicates that rural farmers in Kenya know the importance of applying both chemical and organic fertilizer to realize the yield potential of the hybrid seeds.

Table 7.3 Yield and fertilizer application by seed type in the maize plots in the main crop season in Kenya in 2012

	Type of maize seeds			Testing difference in means[a]
	Local seeds (b)	Hybrid seeds (c)	All	
Number of maize parcels	199	705	904	
Maize yield (kg/ha)	1,496	2,325	2,142	***
Value of harvest from all crop (KSh/ha)	44,723	64,326	60,011	***
Manure				
Manure applied (%)	57	50	51	*
Quantity Applied (kg/ha)	1,332	1,648	1,578	
Chemical fertilizer				
Chemical fertilizer applied (%)	51	83	76	***
Quantity applied (kg/ha)	23	54	47	***

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

[a] Significance testing of the difference between columns (b) and (c)

Overall, it is clear that maize farmers in the highlands of Kenya spontaneously began exerting efforts to intensify land use under the increasing population pressure on the limited land resources.

7.3.3 Milk Production in Kenya

It is a mistake to examine only maize fields if we are interested in the impacts of new maize-based farming system because keeping improved dairy cows is an integral part of this farming system. Figure 7.3 depicts the trends in milk production, the number of milking cows, and milk production per cow from 1962 to 2010 in Kenya. All of them are indexed by converting into 100 in 1962. The number of cows and milk production per cow have increased rapidly and concomitantly from 1980 to 1987 and 2000 to 2005. However, the number of cows suddenly dropped since 2006. This is mainly due to an outbreak of Rift Valley fever, a viral disease communicable to animals such as cows, sheep, and goats, in Kenya. It is interesting to observe that milk production per cow has started to slowly rise since 1998, thereby resulting in the increase in total milk production. This is most likely due to the widespread adoption of dairy cows, which are more productive than local cows.

Consistent with the decrease in the number of cows shown in Fig. 7.3, Table 7.4 displays the decline in the number of both local and improved cows from 2004 to 2012 in the RePEAT data, though these changes are not statistically significant. However, the quantity of milk produced per cow by local, improved, and both local and improved cows all increased over time. It is also clear that milk production per

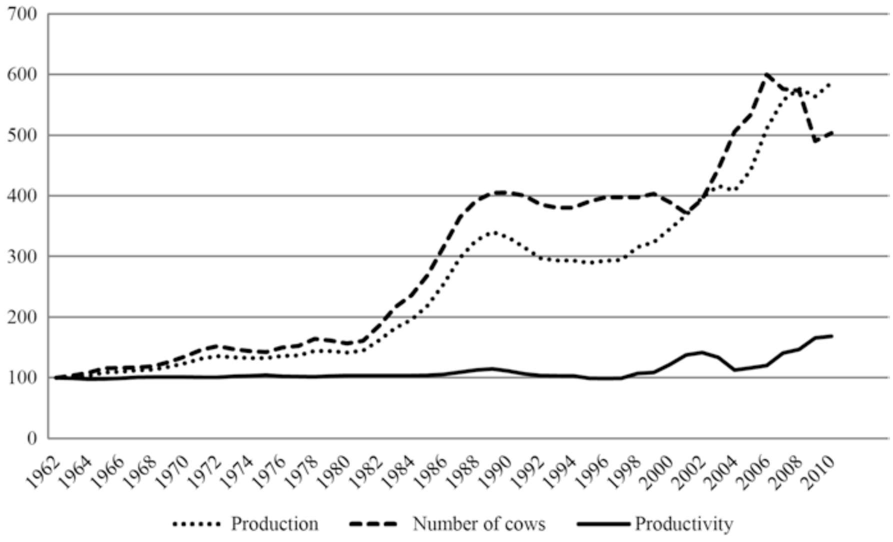

Fig. 7.3 Milk production in Kenya, index (1962= 100) (Source: FAOSTAT Online Database)

Table 7.4 Milk production per household in Kenya in 2004 and 2012

	2004		2012		Testing difference in means[a]
	Mean (b)	S.D.	Mean (c)	S.D.	
Number of households	663		663		
Number of local cows	1.5	(6.1)	1.3	(4.7)	
Number of improved cows	2.0	(2.9)	1.9	(2.5)	
Number of total cows	3.5	(6.4)	3.2	(4.8)	
HH owning improved cows (%)	58	(49)	58	(49)	
Quantity of milk produced per cow for HH owning only local cows (liter/cow)	159	(251)	178	(204)	
Quantity of milk produced per cow for HH owning only improved cows (liter/cow)	705	(608)	855	(671)	***
Quantity of milk produced per cow for HH owning local and improved cows (liter/cow)	326	(275)	369	(261)	
Quantity of milk produced per cow for all HH (liter/cow)	528	(570)	647	(640)	***
Value of milk produced (KSh/cow)	30,658	(36,015)	29,722	(37,419)	
Milk income (KSh/cow)[b]	21,477	(29,280)	23,606	(32,192)	

*** indicates significance at 1 %

[a] Significance testing of the difference between columns (b) and (c)

[b] Milk income is defines as the value of milk produced milk minus all the paid costs of services and feed

improved dairy cow is about four times greater than that of a local cow, which demonstrates the much higher productivity of improved cows over local cows. The use of improved dairy cows is reminiscent of the White Revolution realized in India a few decades ago (Kajisa and Palanichamy 2013).

7.4 The Agriculture Intensification Index

It is difficult to measure the overall effect of the farming system, which consists of multiple changes in input uses and production practices, by simply looking at individual elements of the new farming system separately because their effects on agriculture production could be interactive. In fact, many changes are expected to be complementary. In such a case, if we analyze the impacts of each change on the outcome variables by estimating the production function by using each input and technology separately as an explanatory variable, we could miss the interacting effects of multiple changes. Although it is theoretically possible to specify the general form of production function, such as translog, it is empirically difficult to estimate such a function due to the limited degree of freedom and high correlation among various elements of the new farming system. Therefore, it will be useful to construct a single index that represents the degree of adoption of the new maize farming system. This single index should incorporate the important multiple indicators from each dimension of agriculture intensification in the system.

This study uses principal component analysis (PCA) to construct an index of agricultural intensification. PCA is a variable reduction procedure which decomposes variations in the variables included in the analysis into components (Darnell 1994). A component is a linear combination of weighted explanatory variables, in such a way that the component accounts for a maximal amount of variance in the explanatory variables (Cavatassi et al. 2004). Since the first component captures the greatest proportion of total variation, it will be used as an agricultural intensification index in our analysis. The component is constructed based on the factor scores which are used as weights for each explanatory variable to calculate an index which represents the degree of agricultural intensification. The agricultural intensification index is computed by the following formula (Filmer and Pritchett 2001):

$$AI_{ipt} = \sum\nolimits_{k=1}^{K} F_k [\frac{(x_{kipt} - X_k)}{S_k}], \tag{7.1}$$

where AI_{ipt} is the agricultural intensification index of household i on maize plot p in year t which follows a normal distribution with a mean of 0, F_k is the factor score for the variables k in the PCA model, x_{kipt} is the variable k of household i on the maize plot p in year t, and X_k and S_k are the mean and standard deviation of the variable k. As AI_{ipt} becomes greater, farming is supposed to be more intensified. Dummy variables for hybrid maize seed adoption, the quantity of intercropped legume seeds with maize, the quantity of manure per hectare, and the quantity of chemical fertilizer converted in NPK per hectare are included in the PCA model as these input variables represent agricultural intensification of the new maize farming system. Since the data used for the analysis consist of two rounds of household panel data, it is necessary to create an index which can be compared over time. Therefore, the pooled data from the two rounds of household panel data are used to estimate the intensification index.

Table 7.5 shows the factor loadings of the individual elements accounting for the agricultural intensification index. The principal component explains 34 % of the variance in the four variables. Factor loading, which provides the direction and weight for each variable, shows that hybrid seed adoption and the quantity of chemical fertilizer applied per hectare account for a large part of the agricultural intensification. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy takes a value between 0 and 1, and higher KMO values indicate that the correlation between pairs of the explanatory variables could be explained by the other explanatory variable (Kaiser 1974). The KMO of our analysis is 0.55, and it is usually considered that PCA is acceptable if the value of KMO is more than 0.5. The factor loadings obtained from the pooled samples of the 2004 and 2012 surveys display similar patterns, which indicates that it is acceptable to use an index created from pooled data. The result shows that the agricultural intensification index has

Table 7.5 Factor loading for maize production intensification index of the maize plots in the main crop season in Kenya in 2004 and 2012

	Pooled years	2004	2012
Individual elements	Factor loadings		
Hybrid maize seeds (=1)	0.59	0.59	0.60
Quantity of intercropped legume seed (kg/ha)	0.39	0.36	0.37
Quantity of manure (kg/ha)	0.31	0.19	0.35
Quantity of chemical fertilizer (kg/ha)[a]	0.63	0.70	0.62
KMO	0.55	0.49	0.55
Proportion variation explained	0.34	0.34	0.34
Mean of agriculture intensification index generated from pooled data	0.00	−0.226	0.249

[a]Quantity of chemical fertilizer is measured in NPK equivalence

Table 7.6 Crop production by quartile of the agriculture intensification index in the maize plots in the main crop season in Kenya in 2012

	Quartile of agriculture intensification index			
	1st	2nd	3rd	4th
Hybrid maize seeds (%)	22	93	99	99
Intercrop with legumes (%)	55	65	78	88
Adoption of organic fertilizer (%)	50	51	44	61
Adoption of chemical fertilizer (%)	42	76	90	96
Quantity of manure (kg/ha)	886	1,031	931	3,465
Quantity of chemical fertilizer (kg/ha)[a]	13	25	56	95
Cost of other chemical inputs (KSh/ha)[b]	93	175	227	350
Quantity of maize yield (kg/ha)	1,552	1,948	2,222	2,849
Value of harvest from all crops (KSh/ha)	40,954	50,145	58,205	90,773
Crop income from all crops (KSh/ha)[c]	35,384	39,875	43,329	68,570
Maize plot size (ha)	0.34	0.42	0.44	0.30

[a]Quantity of chemical fertilizer is measured in NPK equivalence
[b]This includes herbicides, pesticides, fungicides, and other chemical inputs
[c]Crop income is defined as the value of harvest minus the paid costs of chemical and organic fertilizer, other chemical inputs, seed, and hired labor

increased from −0.226 to 0.249 from 2004 to 2012, indicating that agricultural intensification has advanced even in the short period of 8 years.

Table 7.6 provides evidence that the agricultural intensification index captures the degree of intensification of each input quite well by looking at the crop production on the maize plots in the main season by quartile in 2012. As shown in the table, there are upward trends in almost all individual input uses as well as in the adoption of new production practices, as the quartile of the agricultural index goes up. Consistently, outcome variables such as maize yields, revenue from all crops, and net revenue increase as the degree of agricultural intensification deepens. These findings indicate that the farmers' effort of agricultural intensification is likely to pay off in rural Kenya. Furthermore, it is interesting to note that households that belong to the greatest quartile of the index have the smallest operated maize plot size, which is consistent with the negative correlation between farm size and agricultural intensification widely observed in SSA in recent years (Larson et al. 2014a, b).

7.5 Estimation Strategy

7.5.1 Determinants of the New Maize Farming System Adoption

Following the literature on agricultural intensification, this study focuses on population pressure as the driving force that accelerates agricultural intensification. Boserup (1965) argues that a rise in population density will change the relative prices of land and labor, which increases the demand for new inputs such as fertilizer, irrigation water, improved seeds, and herbicide in order to intensify land use. This leads to an increase in input use per unit of area, which is regarded as agricultural intensification. In this way, population pressure accelerates the intensive use of labor and other non-land inputs, which facilitates the shift of farming system from extensive, such as slash and burn farming, to intensive, such as sedentary multi-cropping farming with higher agricultural productivity (Otsuka and Place 2001). Similarly, Hayami and Ruttan (1985) argue that changes in relative input scarcities would bring about changes in farmers' behaviors and institutions to adapt to new conditions, which is called the "induced innovation hypothesis." In their hypothesis, it is hypothesized, as in the Boserupian view, that population pressure decreases the wage rate relative to land price, which increases the demand for labor and non-land input use, thereby enhancing land productivity. Empirical evidence shows that population pressure is associated with smaller land size and higher agricultural intensification (Josephson et al. 2014; Muyanga and Jayne 2014; Ricker-Gilbert et al. 2014). Following the existing literature, this study employs the ratio of a household's owned land to family labor as a proxy for population pressure on the land in order to explore its impact on agriculture intensification.

To assess the effect of the land-labor ratio and other household characteristics to explain agricultural intensification, we consider the estimation of the following reduced form equation:

$$I_{lkjit} = \alpha_{lkji} + \beta_1 L_{lkjit} + \beta_2 R_{lt} + \beta_3 X_{lkjt} + \beta_4 P_l + \beta_5 D_t + \beta_6 P_l * D_t + \varepsilon_{lkjit}, \quad (7.2)$$

where I_{mlkjit} is the agricultural intensification index or one of the four agriculture input or practice variables of interest, i.e., manure applied per hectare, the amount of chemical fertilizer converted into the NPK applied per hectare, adoption of hybrid maize seed, and the amount of intercropping legume seed planted. All variables pertain to the main crop season for maize plot i of household j in district k in province l in time t. L_{lkjit} is a ratio of owned land size to the number of working age (15–64) household members. R_{lkt} is a coefficient of variation of rainfall. X_{lkjt} is a vector of household control variables including the number of working age (15–64) household members, a dummy variable for female head, the household head's age, a dummy variable for head with primary education, the value of non-land assets, the time distance to the nearest market by a motor vehicle, and the soil carbon content of the main maize plot which represents soil fertility. Some soil samples were lost or spoiled in the laboratory and thus a dummy variable for no soil information is created and included in the regressors in order to avoid the loss of the observations without soil sample information. P_l and D_t are province and time dummies. a_{lkji} is a household fixed effect that intends to capture farmer management ability, household risk preferences, unmeasured household wealth, and other time-invariant household level factors, that could be correlated with the land-labor ratio and input use simultaneously. The existence of a_{lkji} would cause OLS estimates to be biased. To purge a_{lkji}, we take advantage of the household panel data and estimate Eq. 7.2 using a household level fixed-effects estimation approach. Our main interest is the estimated parameters of β_1.

7.5.2 Impact of the New Maize Farming System on Agricultural Production

To examine the impact of the new maize farming system on agricultural productivity, the impact of each individual element of the new farming system is estimated separately. The following model is used to examine the individual effects:

$$Q_{lkjit} = \gamma_{lkj} + \delta_1 I_{lkjit} + \delta_2 L_{lkjit} + \delta_3 R_{lkt} + \delta_4 X_{lkjt} + \delta_5 P_l + \delta_6 D_t + \delta_7 P_l * D_t + \epsilon_{lkjit}, \tag{7.3}$$

where Q_{lkjit} is one of the three output variables of interest, which are the physical maize yield, the value of harvest of all crops, and the income from the production of all crops, which is defined as the value of the harvest from all crops minus the paid-out costs of chemical and organic fertilizer, other chemical inputs, seed, and hired labor on the maize plot in the main crop season.

In order to measure the impact of the entire farming system, the following equation is employed:

$$\begin{aligned} Q_{lkjit} = \theta_{lkji} &+ \pi_1 AI_{lkjit} + \pi_2 L_{lkjit} + \pi_3 R_{lkt} + \pi_4 X_{lkjt} \\ &+ \pi_5 P_m + \pi_6 D_t + \pi_7 P_m * D_t + \mu_{lkjit}, \end{aligned} \tag{7.4}$$

where AI_{lkjit} is the agricultural intensification index for household i in district j in time t.

Outputs from a new maize farming system accrue not only from crop production but also from milk production. Therefore, the following models are also employed in order to capture the effect of the maize-based farming system on the total value of crop harvested and milk production and income from the crop and milk production:

$$Y_{lkjt} = \vartheta_{lkji} + \rho_1 AI_{lkjt} + \rho_2 L_{lkjt} + \rho_3 R_{lt} + \rho_4 X_{lkjt} + \rho_5 P_l + \rho_6 D_t + \rho_7 P_l * D_t + \varphi_{lkjit}, \qquad (7.5)$$

where Y_{lkjt} is alternately the crop harvested and milk production or income from crop and milk production defined as the revenue from the crop harvest and milk production minus the paid-out costs, including the costs of livestock services and feeds for the main crop season.

With the same reasoning as in the determinants of the adoption model, the unobservable fixed effects ($Y_{lk}j$, θ_{lkji}, *or* ϑ_{lkj}) would cause bias and inconsistent estimates. Thus, the household fixed-effects model approach is used for the estimation of Eqs. (7.3), (7.4) and (7.5) in this study.[3]

7.6 Estimation Results

7.6.1 Determinants of the Adoption of New Maize Farming System

Table 7.7 shows the estimation results of the new maize-based farming system adoption model. In columns (1) to (5), the specifications explaining the quantity of manure per hectare, the quantity of NPK equivalent chemical fertilizer use per hectare, the adoption of hybrid maize seed dummy, the quantity of intercropped legume seeds planted per hectare, and the agriculture intensification index on the maize plot in the main crop season are estimated by the household level fixed-effects. The most important finding is that the land-labor ratio has negative and significant effects on chemical fertilizer use and the agriculture intensification index, which supports our hypothesis that population pressure encourages input use intensification. Households located close to markets and with younger heads are more likely to adopt hybrid maize seeds.

7.6.2 Impact of the New Maize Farming System on Agricultural Production

Table 7.8 shows the impact of individual input use and intercropping on land productivity alternatively measured by (1) maize yield per hectare, (2) value of harvest from all crops per hectare, and (3) crop income per hectare on the maize plot in the main crop season, which are estimated by the household fixed-effect model. The adoption of hybrid maize is found to contribute to a 25 % and 13 % increase in the maize yield and the value of harvest from all crops, respectively. Interestingly, the

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[3] Ideally we should endogenize the technology adoption variables. However, we have failed to find appropriate instrumental variables so far.

Table 7.7 Estimation results of the determinants of input intensification in the main crop season in Kenya (household fixed-effect model, plot level data)[a]

	Manure (t/ha)	Chemical fertilizer (10 kg/ha)[b]	Hybrid maize seeds (=1)	Intercropped legume seeds (kg/ha)	Intensification index
Explanatory variables	(1)	(2)	(3)	(4)	(5)
Log of owned land size per working age member (ha)	−0.000172	−0.484***	0.00197	−0.0614	−0.0597**
	(0.0911)	(0.145)	(0.0118)	(0.0789)	(0.0282)
Log of time to the nearest market by car (min)	−0.333	−0.00773	−0.0808*	0.134	−0.113
	(0.280)	(0.520)	(0.0474)	(0.253)	(0.0988)
Coefficient of variation of rainfall	0.301	3.057	−0.0818	2.063*	0.573
	(1.359)	(2.349)	(0.175)	(1.056)	(0.420)
Female headed (=1)	−0.121	−0.913	0.0480	0.0154	−0.0498
	(0.258)	(0.655)	(0.0588)	(0.285)	(0.129)
Log of head's age	−0.0330	−0.259	−0.212***	0.654	−0.196
	(0.469)	(1.140)	(0.0753)	(0.493)	(0.216)
Head completed primary education (=1)	0.197	0.900	−0.0266	−0.0643	0.0747
	(0.356)	(0.604)	(0.0494)	(0.243)	(0.114)
Log of value of assets (KSh)	0.00688	0.359	0.0278	−0.0774	0.0628
	(0.135)	(0.256)	(0.0195)	(0.111)	(0.0459)
Log of carbon	−0.245	0.430	−0.0224	0.489	0.0694
	(0.466)	(0.697)	(0.0768)	(0.402)	(0.159)
Constant	1.809	−0.209	1.311***	−1.439	−0.256
	(2.622)	(4.985)	(0.413)	(2.298)	(1.043)
Observations	1,750	1,750	1,750	1,750	1,750
R-squared	0.033	0.073	0.236	0.040	0.136
Number of households	663	663	663	663	663

The numbers in parentheses are robust standard errors

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

[a] Interaction terms between year 2012 and provinces, and year 2012, provinces, and no carbon information dummies are included in all regressions

[b] Quantity of chemical fertilizer is measured in NPK equivalence

intercropping with legume dummy is shown to decrease maize yield by 11 %, but this negative effect is more than compensated for by the additional value of harvest and income from other crops, judging from its positive effect on the value of harvest from all crops. This means that although intercropping with legumes on the maize plots decreases the maize yield, farmers can obtain higher revenue and income from the intercropped production of legumes. In addition, as legumes contribute to the improvement of soil nutrients by fixing nitrogen from the atmosphere,

Table 7.8 Estimation results of the effects of input intensification on crop production in the main crop season in Kenya (household fixed-effect model, plot level data)[a]

	Log of maize yield (kg/ha)	Log of value of harvest from all crops (KSh/ha)	Log of crop income[c] (KSh/ha)
Explanatory variables	(1)	(2)	(3)
Hybrid maize seeds (=1)	0.247***	0.130*	0.0330
	(0.0703)	(0.0732)	(0.0900)
Intercrop with legumes (=1)	–0.107*	0.179***	0.0435
	(0.0590)	(0.0667)	(0.0832)
Organic fertilizer (t/ha)	0.0413***	0.0421***	0.0478***
	(0.00967)	(0.0102)	(0.0120)
Chemical fertilizer (10 kg/ha)[b]	0.0331***	0.0295***	0.0128*
	(0.00490)	(0.00537)	(0.00673)
Log of owned land size per working age member (ha)	0.0236	0.0244	0.0208
	(0.0269)	(0.0277)	(0.0357)
Log of time to the nearest market by car (min)	0.177*	0.0607	0.0465
	(0.0993)	(0.0980)	(0.123)
Coefficient of variation of rainfall	–0.318	–0.418	–0.173
	(0.367)	(0.382)	(0.450)
Female headed (=1)	–0.0235	–0.0919	–0.119
	(0.114)	(0.122)	(0.138)
Log of head's age	0.00164	–0.00342	–0.00667
	(0.00374)	(0.00379)	(0.00479)
Head completed primary education (=1)	0.0301	–0.0183	0.0972
	(0.104)	(0.108)	(0.119)
Log of value of assets (KSh)	–0.0107	–0.0176	–0.0290
	(0.0467)	(0.0466)	(0.0535)
Log of carbon	0.00332	–0.0430	0.149
	(0.184)	(0.163)	(0.182)
Constant	6.432***	10.45***	10.41***
	(0.606)	(0.597)	(0.713)
Observations	1,750	1,750	1,750
R-squared	0.206	0.151	0.598
Number of households	663	663	663

The numbers in parentheses are robust standard errors

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

[a] Interaction terms between year 2012 and provinces, and year 2012, provinces, and no carbon information dummies are included in all regressions

[b] Quantity of chemical fertilizer is measured in NPK equivalence

[c] Crop income is defines as the value of harvest minus the paid costs of chemical and organic fertilizer, other chemical inputs, seed, and hired labor

intercropping with legumes could contribute to a gain in the total crop revenue in the longer run. The additional application of organic fertilizer by 1 ton per hectare is expected to increase the maize yield, the value of harvest from all crops, and the income from all crops by about 4.1 %, 4.2 %, and 4.8 %, respectively. Similarly, the additional application of chemical fertilizer by 10 kg per hectare is expected to increase the maize yield, the value of harvest from all crops, and the income from all crops by about 3.3 %, 3.1 % and 1.3 %, respectively.

It may not be possible to capture the whole impact of the new maize farming system only by estimating the impact of an individual effect on agriculture production. Therefore, Table 7.9 attempts to examine the effect of the entire new maize farming system by using the agricultural intensification index as an explanatory variable while using the household fixed-effect model. Estimation results show the positive and consistently positive effects of the agricultural intensification index on all outcome variables. The magnitudes of the impact on the index are smaller for

Table 7.9 Estimation results of the effects of the intensification index on crop production in the main crop season in Kenya (household fixed-effect model, plot level data)[a]

	Log of maize yield (kg/ha)	Log of value of harvest from all crops (KSh/ha)	Log of crop income[b] (KSh/ha)
Explanatory variables	(1)	(2)	(3)
Intensification index	0.266***	0.254***	0.175***
	(0.0273)	(0.0273)	(0.0352)
Log of owned land size per working age member (ha)	0.0173	0.0314	0.0244
	(0.0271)	(0.0271)	(0.0358)
Log of time to the nearest market by car (min)	0.162	0.0620	0.0397
	(0.0993)	(0.0969)	(0.120)
Coefficient of variation of rainfall	−0.480	−0.488	−0.291
	(0.365)	(0.382)	(0.449)
Female headed (=1)	−0.0484	−0.0779	−0.119
	(0.114)	(0.124)	(0.143)
Log of head's age	0.000692	−0.00348	−0.00689
	(0.00372)	(0.00369)	(0.00468)
Head completed primary education (=1)	0.0309	−0.0127	0.0943
	(0.105)	(0.109)	(0.120)
Log of value of assets (KSh)	−0.0134	−0.0207	−0.0379
	(0.0465)	(0.0469)	(0.0537)
Log of carbon	0.0186	−0.0383	0.164
	(0.184)	(0.163)	(0.182)
Constant	6.945***	10.99***	10.81***
	(0.604)	(0.598)	(0.713)
Observations	1,750	1,750	1,750
R-squared	0.210	0.153	0.597
Number of households	663	663	663

The numbers in parentheses are robust standard errors

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

[a] Interaction terms between year 2012 and provinces, and year 2012, provinces, and no carbon information dummies are included in all regressions

[b] Crop income is defines as the value of harvest minus the paid costs of chemical and organic fertilizer, other chemical inputs, seed, and hired labor. A negative income dummy is included in (3)

income than for value of the harvest, which could reflect the fact that agricultural intensification is a costly practice to conduct, and thus the magnitude of the coefficients of the index are smaller for the net outcomes than for the gross outcome. However, even though agricultural intensification is costly, it remains true that crop income would increase significantly with increases in agricultural intensification.

Since the new maize farming system aims to increase output not only from crop production but also from milk production, Table 7.10 illustrates the impacts of agricultural intensification on (1) the total value of all crops harvested and milk production per hectare and (2) the sum of crop and milk income per hectare. Consistent

Table 7.10 Estimation results of the effects of the intensification index on agriculture production in the main season in Kenya (location fixed-effect model, HH level data)[a]

	Log of value from all crops and milk (KSh/ha)	Log of crop and milk income[b] (KSh/ha)
Explanatory variables	(1)	(2)
Intensification index	0.197***	0.129***
	(0.0314)	(0.0426)
Log of owned land size per working age member (ha)	–0.0979**	–0.108**
	(0.0436)	(0.0522)
Log of time to the nearest market by car (min)	0.0622	–0.0508
	(0.100)	(0.138)
Coefficient of variation of rainfall	–0.331	–0.143
	(0.356)	(0.490)
Female headed (=1)	–0.124	–0.244
	(0.112)	(0.166)
Log of head's age	–0.00306	–0.00637
	(0.00378)	(0.00537)
Head completed primary education (=1)	–0.0281	–0.0146
	(0.102)	(0.150)
Log of value of assets (KSh)	0.0298	0.0262
	(0.0493)	(0.0658)
Log of carbon	0.126	0.0928
	(0.158)	(0.215)
Constant	10.77***	10.67***
	(0.617)	(0.780)
Observations	1,326	1,326
R-squared	0.123	0.839
Number of households	663	663

The numbers in parentheses are robust standard errors

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

[a] Interaction terms between year 2012 and provinces, and year 2012, provinces, and no carbon information dummies are included in all regressions, and a negative income dummy is included in (2)

[b] Income form crop and milk defined as the revenue from the crop harvest and milk production minus the paid costs of chemical, organic fertilizer, other chemical inputs, seed, hired labor, livestock services and feeds

with the findings in Table 7.9, the effects of the agriculture intensification are positive and significant on both outcome variables. Similar to the results shown in Table 7.9, the coefficient is smaller in the income regression. An inverse relationship between owned land size and outcome variables is observed in Table 7.10: Doubling owned land size per working age member would reduce the value from all crops and milk and the crop and milk income by 9.8 % and 11 %, respectively. This finding indicates that the maize-based farming system is conducive to both production efficiency and the equity of income distribution.

7.7 Conclusions and Policy Implications

As population pressure grows rapidly in Kenya, rural farmers have started to intensify farming systems by adopting new inputs and production practices, including the adoption of high-yielding maize varieties, the application of organic fertilizer produced by improved dairy cows, and intercropping especially of maize with legumes that could fix nitrogen. Since the phenomenon of the new farming system has failed to receive a lot of attention from researchers, our knowledge of the driving forces and impacts of this system is limited. Hence, this study aims to quantify the determinants of the new maize farming system and its impact on agriculture productivity. To gauge the impact of the new farming system, this study examines the impacts of individual inputs as well as the impact of the new maize farming system by using an agricultural intensification index constructed by PCA.

The estimation results show that the decrease in the land-labor ratio increases chemical fertilizer application and the extent of agricultural intensification. These findings indicate that population pressure accelerates farming intensification, consistent with the Boserupian and induced innovation hypotheses. Furthermore, it is found that the adoption of hybrid maize seed, intercropping legumes with maize, manure application, and chemical fertilizer application have positive and significant impacts on land productivity. These impacts are confirmed and reinforced by the consistent and significantly positive impacts of the agriculture intensification index on land productivity in terms of the value of production and income per hectare.

Therefore, we conclude that the new farming system has already improved the productivity of small-scale farmers in the highlands of Kenya. It is worth emphasizing that the substantial yield gain has already been achieved by this farming system without strong support from the Kenyan government and aid donors. Moreover, to our knowledge, no agricultural research center has undertaken research on the “optimum” farming systems. In all likelihood, this is a serious omission as this farming system is consistent with the British Agricultural Revolution and the Asian Green Revolution as well as the Indian White Revolution. Thus, it can be expected that much more significant increase in the productivity of farming could be achieved if appropriate research is carried out and appropriate technical support and extension services regarding this new maize farming system are provided for small-scale maize farmers in Kenya.

Chapter 8
On the Determinants of Low Productivity in Maize Farming in Uganda: The Role of Markets, Fertilizer Use and Gender

Donald F. Larson, Sara Savastano, Siobhan Murray, and Amparo Palacios-López

Abstract African governments and international development groups see boosting productivity on smallholder farms as a key way to reduce rural poverty and safeguard the food security of non-farming households. Prompting smallholder farmers to use more fertilizer has been a key tactic. Closing the productivity gap between male and female farmers has been another avenue toward achieving the same goal. Our results suggest the two are related. We find that fertilizer use and maize yields among smallholder farmers in Uganda are increased by improved access to markets and extension services, and reduced by ex-ante risk-mitigating production decisions. However, we find that the gender productivity gap, significant in OLS regression results, disappears when gender is included in a list of determinants meant to capture the indirect effects of market and extension access. Consistent with observed risk mitigation production choices, the research confirms the important consequences of unexpected weather outcomes on yields.

Keywords Smallholder farmers • Rural poverty • Market access • Fertilizer use • Maize yield • Green Revolution • Role of gender • Agricultural extension • Uganda

8.1 Introduction

In Africa, many smallholder farmers are reluctant or unable to purchase fertilizer and apply it to the staple crops they grow, despite evidence that doing so would improve their incomes. This is worrisome for policy makers since fertilizer is needed to sustain the fertility of African soils and to take full advantage of the

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potential gains from new varieties of staple crops developed with smallholder farms in mind. What's more, the places where agricultural productivity is low are often also the places where households are disproportionately poor and rely more on agriculture for their livelihoods. The welfare and productivity of smallholder farmers are entwined with future gains in affordable food supplies for many African countries as well. The agricultural sectors of sub-Saharan Africa are largely made up of small farms and there is evidence that the average African farms has become smaller rather than larger in recent decades (Lowder et al. 2014). Consequently, African governments, development organizations, and many NGOs see boosting productivity on smallholder farms as a key way to reduce rural poverty and safeguard the food security of non-farming households (Otsuka and Larson 2013b). In turn, finding ways to prompt African smallholders to use more fertilizer is often a key tactic in rural development strategies.[1]

In this chapter, we examine the role general market participation has for smallholder decisions about fertilizer and the consequences for smallholder maize yields in Uganda. Many smallholder farmers growing maize in Uganda harvest two crops and we exploit a 2009–2010 survey that covers both cropping season to examine how diversification and other ex-ante risk mitigation strategies across growing seasons sets the stage for productivity outcomes.

Recently, some researchers have argued that poorly functioning fertilizer markets constrain smallholder productivity by limiting the availability of fertilizer and keeping its price unreasonably high. With this as preface, we consider an empirical model of productivity in which the choice about using fertilizer is endogenous, but is constrained by market performance and social norms. Controlling for heterogeneous farmgate prices using fixed spatial effects, we use instruments that address the informational, social, and financial constraints that might additionally limit fertilizer demand. The empirical model performs well overall and passes a variety of tests designed to detect problems associated with our choice of instruments.

An important empirical result from our research has to do with gender. In productivity studies, the gender of the farmer, included as an exogenous control, often indicates that women are less productive farmers. We find this as well in simple OLS regressions. However, the measured gender gap goes away once we use variables associated with market and extension interactions that are potentially influenced by traditional gender roles. The model is consistent with the notion that the gender of the farmer per se does not directly affect productivity outcomes, but does affect fertilizer purchases, which affect eventual productivity outcomes. The results indicate that what does matter for productivity outcomes are weather outcomes and related choices about input use and ex ante risk mitigation strategies.

The organization of this chapter is as follows. Section 8.2 reviews the literature on the effects of market access, production risk, and gender on input use and agricultural productivity in developing countries. We describe the characteristics of our study sites in Uganda in terms of access to markets and maize yield variations

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[1] A partial list of organizations promoting smallholder productivity gains as a pathway for rural development includes the World Bank, FAO, IFPRI, AGRA and the Gates Foundation.

in Sect. 8.3, and report regression results on fertilizer use, hired labor use, and maize yields in Sect. 8.4. We conclude by drawing implications for Green Revolution in maize production in sub-Saharan Africa in the final section.

8.2 Markets, Risk and Decisions About Applied Technologies

8.2.1 Role of Market Access

Providing better access to agriculture input and output markets is an often stated policy goal in African countries. The underlying rationale is that input markets provide key productivity-enhancing inputs that farmers cannot produce on their own and that markets are needed to vend surpluses. As a consequence, markets are often seen as a key driver of technology adoption (Boserup 1965; Pingali et al. 1987; Binswanger and Pingali 1989; Rosenzweig and Binswanger 1993). What's more, recent evidence suggests that the intensification of farming systems over much of Sub-Saharan African countries has been more limited and less beneficial to farmers in comparison to tropical areas of Asia and Latin America, and several researchers point to poor access to markets or inefficient markets as root causes (Headey et al. 2013; Binswanger-Mkhize and Savastano 2014).

For example, Dorosh et al. (2012) find out that adoption of high-productive and high-input technology declines with increases in travel time to urban center in sub-Saharan Africa. In northwestern Ethiopia, Minten et al. (2013) found that transaction and transportation costs increased fertilizer prices at the input distribution center between 20 and 50 %; Zerfu and Larson (2010) show that transportation time and other measures of remoteness explain the reduced use of chemical fertilizers by farmers in rural Ethiopia; and Sheahan and Barrett (2014) find a downward trend between fertilizer application levels and distance to major market center in Ethiopia, Malawi, and Nigeria. Another set of studies show how distance from market affects the price and availability of improved seeds in Africa (Smale et al. 1998; Shiferaw et al. 2008; Yorobe and Smale 2012; Headey et al. 2013).

A related area of research investigates the underlying causes of high transaction costs. These studies examine both observable (tangible) costs, such the costs associated with transport, handling, packaging, storage costs and spoilage, and unobservable (intangible) costs, including information asymmetries, search costs, bargaining costs and the costs of enforcing contracts (Cuevas and Graham 1986; Staal et al. 1997; Hobbs 1997; Key et al. 2000; Holloway et al. 2000; Birthal et al. 2005; Jensen 2007).

8.2.2 Risks and Livelihood Strategies

Agricultural productivity outcomes observed in cross-country, farm, and household surveys are highly heterogeneous and this implies that the choices farmers make about applied technologies are heterogeneous as well (Mundlak et al. 2012; Larson et al. 2014a, b). This is partly explained by transaction costs and heterogeneous farmgate prices, but other factors are thought to influence livelihood choices as well. In particular, the pervasive presence of uninsurable risk, poorly functioning labor and credit markets, and high transaction costs have been used to explain the diverse livelihood strategies of rural households, and choices about production technologies (e.g., Norman 1978; Morrison 1980; Feder 1985; Lipton and Lipton 1993; Rosenzweig and Binswanger 1993; Croppenstedt et al. 2003).

Without access to formal markets for risk, poor households implement ex ante risk mitigation strategies, often preferring to invest effort and resources in low-risk-low-return activities and technologies rather than in riskier but potentially more profitable alternatives (Binswanger and McIntire 1987; Rosenzweig and Binswanger 1993; Morduch 2005; Carter et al. 2007; Larson and Plessmann 2009). Key ex-ante mitigation strategies also include farm management practices and crop diversification. This set of actions includes introducing different types and varieties of crops, planting the same crop at different times or on spatially separate plots, investing in soil and water management, and irrigating land (Bezabih and Sarr 2012; Kurukulasuriya and Mendelsohn 2007; Maddison 2007; Nhemachena and Hassan 2007). In addition, mixed crop-livestock farming systems are often used to diversify income, and manage soils and other farm resources (Hoddinott and Kinsey 2001; Yamano et al. 2011; Chap. 7).

Still, risks are not fully mitigated, so many farming households also adopt ex post smoothing or coping strategies, often by reducing consumption, liquidating assets or drawing down savings. It has been shown that these behaviors have short-term negative welfare effects and income instability in the long run (Morduch 1995; Dercon 2004; Dercon et al. 2005; Dercon and Christiaensen 2011; Hoddinott 2006; Kazianga and Udry 2006; Carter et al. 2007; Carter and Lybbert 2012). In addition, while effective in the face of idiosyncratic risks, these informal risk mitigation strategies can fail in the face of repeated or systemic shocks. Consequently, without adequate insurance markets for weather or price risks, households often come to rely on safety nets or periodic disaster relief interventions (Larson et al. 2004; Skees et al. 2005).

8.2.3 Gender and Agricultural Productivity

A fairly consistent finding in the literature is the negative relationship between female-managed agricultural plots and agricultural productivity in sub-Saharan Africa. Estimates of the gender gap in agricultural productivity range from 4 to 40 % across several papers. The finding is pervasive across studies that are quite heterogeneous, with differences in the representativeness of the data, the composition of household, the type of crop considered, model specification, and estimation method (Akresh 2005; Alene et al. 2008; Gilbert et al. 2002; Goldstein and Udry 2008; Peterman et al. 2011; Oladeebo and Fajuyigbe 2007; Quisumbing et al. 2001; Saito et al. 1994; Tiruneh et al. 2001; Udry 1996; Hill and Vigneri 2014; Palacios-Lopez and Lopez 2014; Kilic et al. 2015).

A set of overlapping reasons have emerged for the gender gap in agricultural productivity. These include a reduced tendency to use agricultural inputs and improved technologies; gender-linked barriers to markets and credit; lower investments due to land-tenure insecurity; lower stores of human and physical capital, and informal and institutional constraints (Peterman et al. 2011). Nevertheless, differences in input use by gender is a leading proximate explanations for the gender gap in agriculture, and a focal point for most policy recommendations (Palacios-Lopez and Lopez 2014; Kilic et al. 2015).

The role of input use in explaining the gender gap in agricultural productivity naturally leads to the exploration of gender differences in obstacles faced in agricultural technology adoption. Peterman et al. (2011) provides a comprehensive examination of the gender differences in the adoption of technology drawing from findings in 24 studies. Eighteen of these studies are based on inorganic fertilizer use and they conclude, after controlling for several factors such as differences in land endowment, that access to other relevant agricultural inputs, education, and endowments, the rate of adoption of inorganic fertilizer is similar between men and women. What's more, there is some evidence that technology adoption rates may be higher for females. A recent study by Fisher and Kandiwa (2014) found that the subsidies for seed and fertilizer increases the probability of adoption of improved maize for female headed households in Malawi, thereby reducing the gender gap in the adoption of modern technologies.

8.3 Markets and Productivity in the Study Area

8.3.1 The Geography of Market Participation

Figure 8.1 is a map showing the location of cities in Uganda with more than 20,000 inhabitants and the road network connecting them. The map also reports the average share of agricultural production (by value) that households sell. To be clear, this is not the share of maize sold, but rather the accumulated value of all agricultural goods produced and sold. The shares are calculated for each household and averaged for each enumeration area, the basic area-based unit from the sampling strategy.

In general, the map shows that rural households are clustered around major roads and that market shares are also higher near major roads and cities, although there are exceptions. However, it is almost always the case that enumeration areas where the share of production marketed is less than 10 % are situated in remote places. What is perhaps most surprising is the overall low share of marketed output in Uganda. In most enumeration areas, less than 40 % of output is marketed.

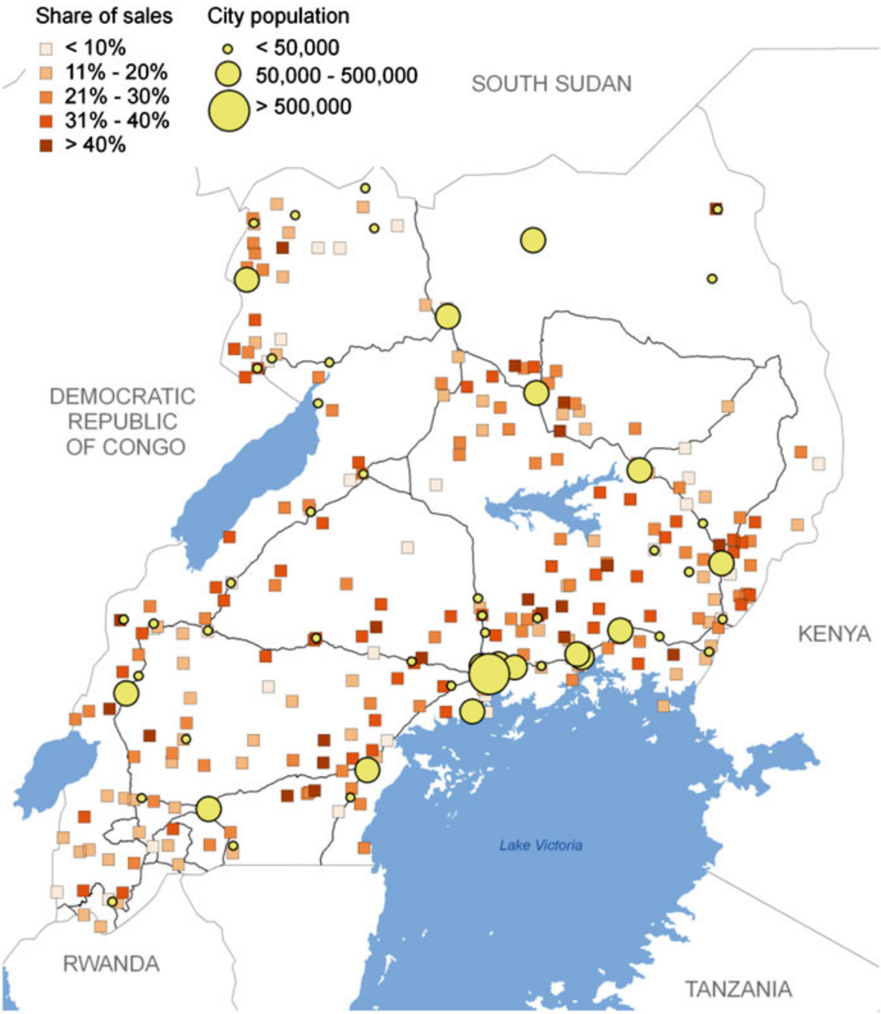

Fig. 8.1 Average share of output sold by enumeration area in Uganda, 2009–2010 (Source: World Bank 2014; Brinkhoff 2014)

8.3.2 Yields and Seasonal Outcomes

Table 8.1 reports sample statistics for the data used in our analysis for the sample as a whole and sub-set averages for male and female-headed households. Maize yields, reported at the top of the table, are production weighted averages. The average yield of 1.2 tons per hectare is lower than the average in SSA, which is more than 1.5 tons per hectare. As discussed, there are two growing seasons for maize in the southern

Table 8.1 Sample statistics by farmers' gender in Uganda

	Male-headed households		Female-headed households		All households	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
Maize yield (tons/ha)	1.22	0.79	1.14	0.73	1.20	0.77
Maize area (combined over all seasons in ha)	4.27	3.32	3.29	2.74	3.99	3.20
Share of agricultural output sold, by value	0.26	0.29	0.21	0.26	0.25	0.28
Extension officer visited	0.24	0.43	0.19	0.40	0.23	0.42
Fertilizer use (kg/ha)	0.38	2.40	0.16	1.07	0.32	2.12
Manure use (kg/ha)	28.70	204.28	6.11	34.89	22.31	174.27
Family labor (days/ha)	65.17	66.35	82.08	136.89	69.95	92.22
Hired labor (days/ha)	4.88	9.48	5.05	9.35	4.93	9.44
Wealth Index (Principal component)	–0.33	1.21	–0.58	1.23	–0.40	1.22
Wage or business income ($US)	0.82	2.73	0.19	0.63	0.64	2.35
Share of maize area in pure stands	0.54	0.33	0.56	0.33	0.55	0.33
Maize area/plots managed	1.02	0.87	0.83	0.65	0.96	0.82
Number of crops managed	5.01	1.88	4.88	1.76	4.97	1.85
Age of household head	45.99	14.45	51.76	14.49	47.62	14.69
Family members, ages 14–60 per ha	1.35	2.09	1.14	1.63	1.29	1.98
Population density (people/sq. meter)	317.28	206.92	336.67	206.68	322.81	206.97
Difference from average rainfall (mm)	87.30	108.13	89.81	114.36	88.01	109.89
Late start for season 1 rains (weeks)	0.67	3.81	0.44	3.82	0.61	3.82
Late start for season 2 rains (weeks)	1.03	1.94	1.05	1.88	1.04	1.92
Market participation (share of households)						
Output sold	0.67	0.47	0.62	0.49	0.66	0.47
Fertilizer used	0.06	0.24	0.04	0.20	0.06	0.23
Improved seeds used	0.30	0.46	0.22	0.41	0.28	0.45
Manure used	0.14	0.35	0.09	0.29	0.13	0.33
Labor hired	0.58	0.49	0.53	0.50	0.56	0.50

Source: Uganda National Panel Survey, 2009–2010

and eastern sections of Uganda. Figure 8.2 shows weather outcomes and the gray area in the right-hand portion of the figure indicates the parts of Uganda that are generally not favorable for a second maize harvest.

The map also shows the spatial variation in moisture, measured in terms of Water Requirement Satisfaction Index at the close of each growing season. The Index is

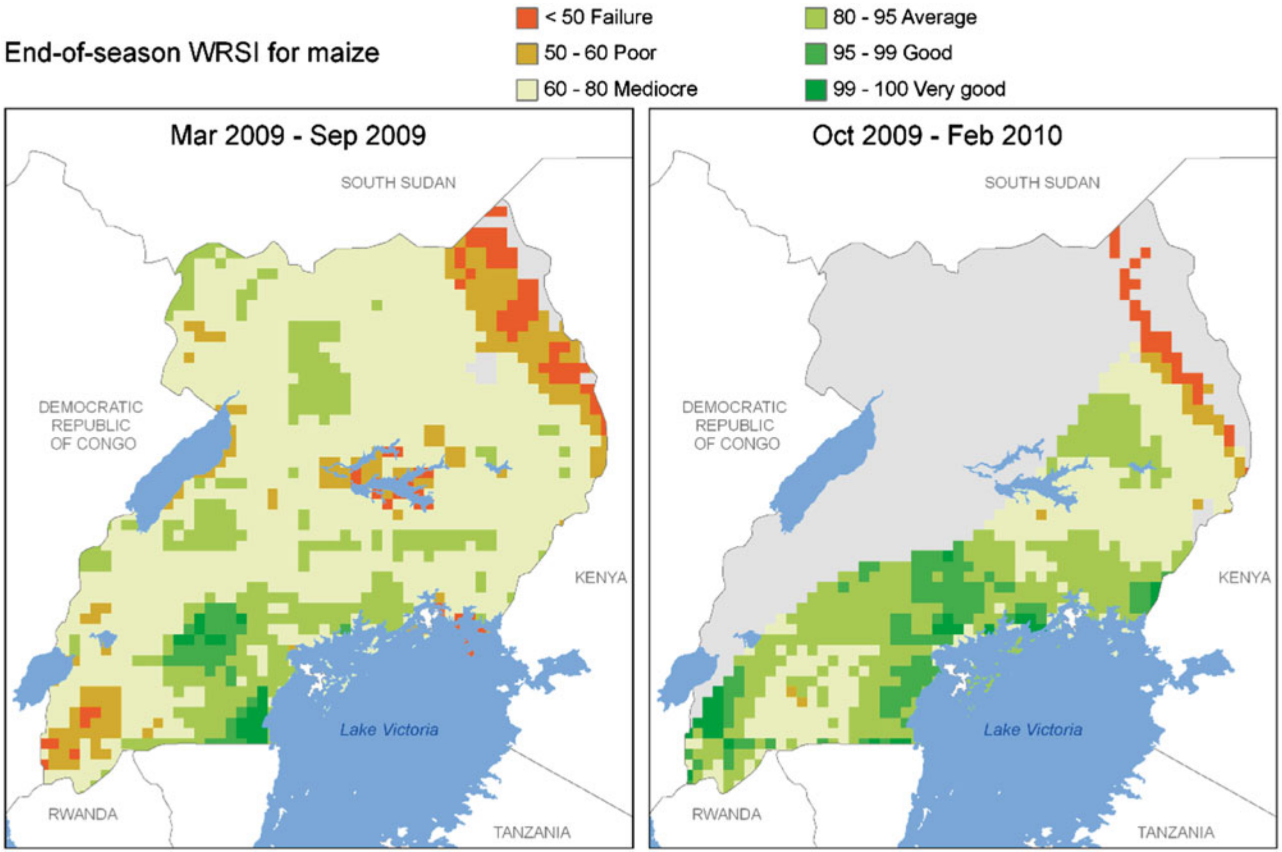

Fig. 8.2 Water Requirement Satisfaction Index for maize growing seasons in Uganda (Source: USGS FEWS Net 2014)

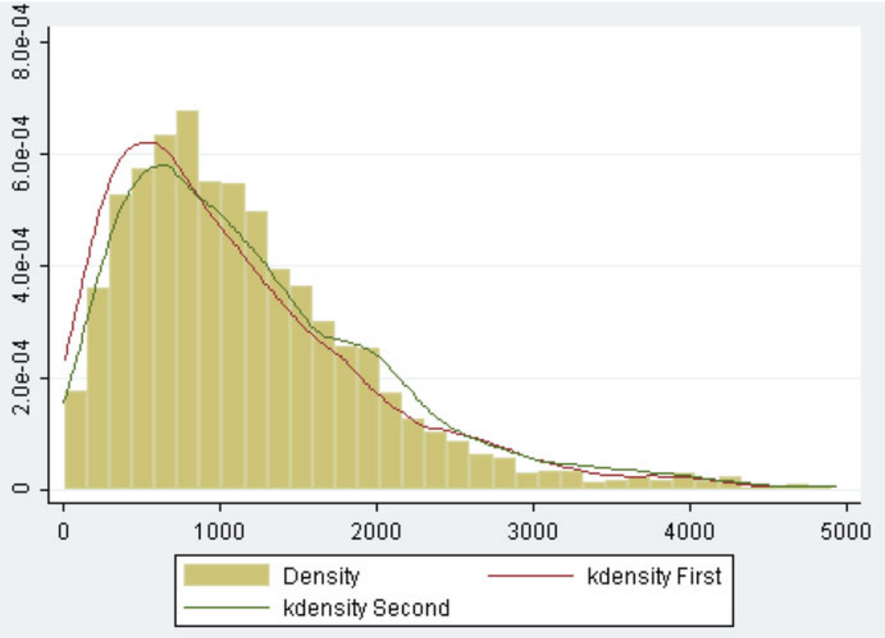

Fig. 8.3 Season 1 and Season 2 yields and weighted average yields in Uganda (Source: Uganda National Panel Survey 2009–2010)

crop specific and, in this case, indicates whether or not the soil moisture is adequate for a healthy maize crop. The map shows that weather conditions were dry during the first season of our sample, with severe weather to the west of Lake Victoria and along the northern section of the Kenyan border. Weather during the second season was much better with average to excellent conditions through the south-western part of the country.

As is frequently the case for smallholder producers in Africa, the seasonal distribution of yield outcomes, shown as thin lines in Fig. 8.3, and the weighted average, shown as a histogram, are skewed toward low-yield outcomes, with a long tail containing higher yields. The first-season distribution is more skewed to the left than the distribution of second season yields, consistent with the relative weather outcomes.

Returning to Table 8.1, there are some differences in the sample averages for male and female-headed farms; however the differences are not compelling in either an absolute or statistical sense. Female farmers obtained slightly lower yields than did male farmers. Most farmers sold very little of what they produced. Few farmers in the sample received visits from an extension agent, and women received fewer visits than men. Female-headed farms used less fertilizer and more family labor. They were slightly less likely to participate in markets – to sell their produce, buy fertilizer, or hire workers than male-headed farms (reported in the lower rows of Table 8.1). They were also less likely to report additional income from wages or a household-owned business. Most farmers did not use improved maize seeds, although men were more likely to do so.

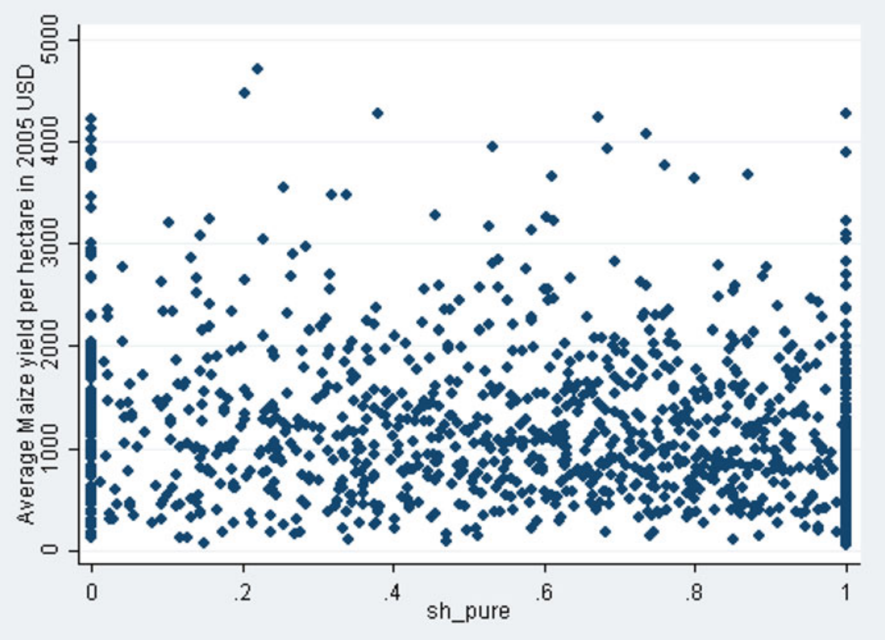

Fig. 8.4 Maize yields by production type in Uganda (Source: Uganda National Panel Survey 2009–2010)

Farmers planted slightly more than half of their maize plots as pure stands, with the rest planted in a mixed crop setting. Additionally, it was not uncommon for the same farmers to devote some plots exclusively to maize while mixing maize with other crops on other plots or switching from pure to mixed stands according to the season. Figure 8.4 plots maize yields against the share of pure-stand plots on each farm. As the graph shows, many farmers used a combination of cropping systems and there was no observable pattern for associated yield outcomes.

The table also reports total area planted with maize for both seasons rather than seasonal average. In general, farms are small (nearly 70 % of the farms planted less than 2 ha to maize per season) and the averages in the table are inflated by a small set of larger farms. Farmers tended to manage multiple crops (an average of about five unique crops across growing seasons) and multiple plots on the same farm. The fragmentation statistic reported in the table gives the ratio of the area planted with maize divided by the number of plots that the farmer managed and is intended to give a notion of overall land fragmentation relative to productions scale. On average there were only minor differences between men and women on the diversification and fragmentation measures.

To finish the comparison, female-headed households were slightly older than their male peers and there were slightly fewer family members. They also had slightly lower stores of wealth. For the year, total rainfall amounts were slightly above the long-run average, and roughly the same for male and female-headed households. On average, the rains came on time, missing the 10-year average start time by less than a week for both seasons.

The maize production system in Uganda is different in key ways from the Kenyan system described in Chap. 7. As in Uganda, pure maize stands are not common in highlands of Kenya and many farmers intercropped maize and beans. However, in contrast, most Kenyan farmers in the Chap. 7 study applied manure and more than three-quarters applied chemical fertilizer; 78 % used improved seeds. As a consequence, the farmers in Kenya achieved yields that were about 75 % higher.

8.4 Estimation Results

The estimation strategy we employ entails two steps. As discussed, few farmers in our sample used fertilizer or hired workers, resulting in a truncated set of observed values populated with many zeroes. To explore why, we used a tobit regression in which observations of fertilizer use per hectare is regressed against the farmer's gender and six additional variables related to markets, household assets, knowledge and social norms participation and household financial and labor resources. Results from the regressions are reported in Table 8.2. The tobit regression results are of interest on their own and are also useful for our estimation strategy, as we use the predicted values from the regressions as instruments in an IV regression to explain maize yields. The approach addresses the endogeneity of the truncated input observations, thereby avoiding the so-called forbidden regression problem.[2]

Table 8.2 Fertilizer and hired-labor demand in Uganda, tobit results

	Fertilizer use		Hired labor demand	
	Coef.	z-score	Coef.	z-score
Market indicators				
Share of agricultural output sold, by value	4.51**	2.28	5.03***	4.17
Population density (people/sq. meter)	0.02***	2.85	–0.01***	–2.97
Liquidity				
Wage or business income ($US 1000)	0.16	0.59	0.37***	2.55
Wealth Index (Principal component)	0.22	0.40	2.56***	7.84
Knowledge/social norms				
Extension officer visited	6.58***	4.19	3.03***	3.53
Female head of household	–4.23***	–2.67	0.84	1.04
Labor assets				
Family members, ages 14–60, per ha	–2.66***	–3.28	–1.19***	–4.28
Constant	–32.30***	–7.48	2.15	1.52

Enumerator-area dummies were included as random effects
*** and ** indicate significance at 1 and 5 %, respectively

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[2] See Wooldridge (2002, p. 236) and Angrist and Pischke (2009, p. 190).

8.4.1 Step One Results

The results in Table 8.2 suggest that farmers who participated in output markets were more likely to use fertilizer and employ workers. There are potentially two channels, since the sales may provide the liquidity needed to purchase fertilizer, and market participation may also provides vent-for-surplus opportunities – the ability to profit from producing more than can be consumed (Myint 1971; Hayami 2001). Higher population densities can lower transaction costs through scale and tighter information channels, providing greater opportunities for farmers. Also according to the Boserupean and induced innovation hypotheses (Boserup 1965; Hayami and Ruttan 1985), higher population density stimulates the adoption of land-saving technology, including the application of chemical fertilizer. The associated coefficient, positive and significant in the fertilizer demand regression, is consistent with this notion. Labor markets are likely more fluid where populations are denser. This can make it harder to find farm workers, since farm wages are usually lower than non-farm wages, an idea that is consistent with the negative and significant coefficient in the hired labor regression.

Surprisingly, coefficients on the two variables that might address liquidity constraints, household wealth and non-farm income had no measurable impact on fertilizer demand. In contrast, the variables helped explain choices about hiring workers significantly, suggesting higher opportunity costs for wealthier farmers and farmers who engaged in other money-making activities.

As mentioned, only 23 % of the households in our sample were visited by extension agents; however, those that were called upon were more likely to use fertilizer and hire workers. This finding is consistent with that on rice production reported in Chaps. 2, 3, 4, 5, and 6, where the importance of extension in improving technology adoption and productivity. The household head's gender mattered for fertilizer use, with women significantly less likely to use fertilizer than men. In contrast, a farmer's gender did not appear to effect worker hires.

8.4.2 Productivity

The estimated yield equation includes five inputs, land, chemical fertilizer, manure, household labor, and hired labor. It also includes additional variables related to risk management, farmer characteristics and weather outcome. The equation's parameters were estimated using a fixed-effect OLS regression and also an instrumental variables (IV) regression with fixed effects. As mentioned, predicted values from the tobit regressions reported in Table 8.2 were used as instruments in the IV regression. Before proceeding to a discussion of those results, it is worth explaining why the remaining inputs were not instrumented.

Maize area: As has become standard practice, the decision about how much area to plant to maize is treated as non-contemporaneous and therefore treated as

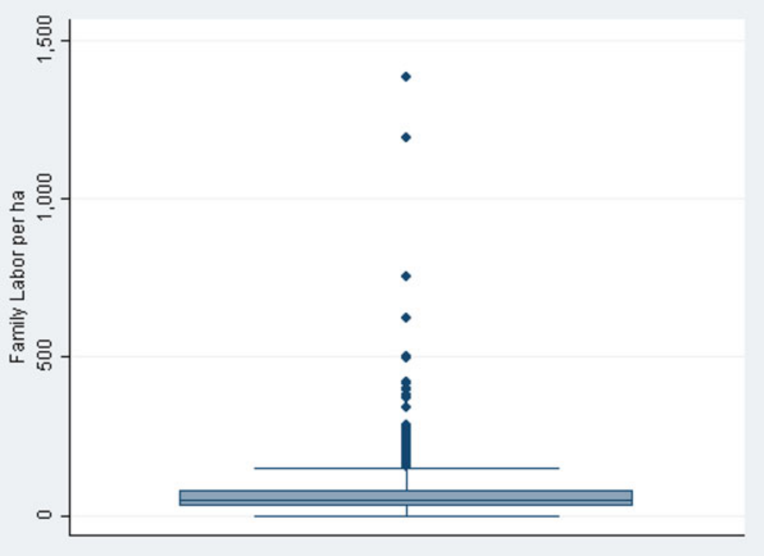

Fig. 8.5 Outliers for family labor measures in Uganda (Source: Uganda National Panel Survey 2009–2010)

predetermined in the regression.[3] The notion here is that cropping decisions are made ahead of choices about inputs. **Manure** is treated as an exogenous household resource, since it is seldom traded. As a consequence, the availability and use of manure depends on a priori decisions about whether or not to include livestock on the farm. In this sense, manure applications are predetermined in a way similar to area planted to maize. **Household labor**: Our survey data on the number of days household members devoted to maize production proved problematic, which ultimately led us to use an exogenous proxy in its place.

To understand this last point better, it is important to note that, household labor measures are notoriously inaccurate, often with a bias toward inflating reported labor days (Beegle et al. 2012). We find indirect evidence of this in our sample, with the distribution of household labor days per hectare skewed by a string of high-valued observations. This is illustrated by the box-plot shown in Fig. 8.5, which condenses key aspects of our sample labor data into a single form. The top of the rectangular box shaded in the figure marks the 75th percentile of the data range, while the bottom "hinge" markets the lower 25th percentile. The "whiskers" extend another 1.5 times the interquartile range of the nearest quartile. The white line marks the median of the data. Intuitively, the range of the box delineates observations that are typical. The whiskers contain values that are somewhat atypical relative to most observations, while the dots mark observations that are extreme. Consistent with the tendency to over-report, the observations contain a number of suspiciously large

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[3] See Antle (1983) and related discussion in Larson et al. (2014a, b).

Table 8.3 Maize yields in Uganda, and mean elasticities from OLS and IV regressions[a]

	OLS regression		IV regression	
	Elasticity	z-score	Elasticity	z-score
Inputs				
Fertilizer use (kg/ha)[b]	0.013***	5.40	0.097***	2.50
Manure use (kg/ha)	0.001	0.61	0.004	1.12
Family labor (available/ha)[b]	0.086***	6.99	0.107***	5.37
Hired labor (days/ha)[b]	0.060***	7.43	0.111***	2.12
Maize area	–0.092***	–3.10	–0.062	–1.44
Risk management				
Share of maize area in pure stands	–0.020	–0.66	–0.083*	–1.73
Maize area/plots managed	–0.057**	–2.06	–0.084**	–2.11
Number of crops managed	0.264***	4.98	0.167**	2.12
Farmer characteristics				
Female head of household	–0.019**	–1.97	0.000	–0.02
Age of household head	–0.034	–0.71	0.043	0.58
Weather effects				
Difference from average rainfall (mm)	–0.056	–0.27	–0.175	–0.50
Late start for season 1 rains (weeks)	–0.040***	–3.29	–0.080***	–3.49
Late start for season 2 rains (weeks)	–0.035	–1.14	–0.063	–1.38

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

[a] Both regressions included 215 fixed location-effects, which were significant in each regression at the 0.01 level

[b] Fertilizer use and hired labor were treated as endogenous in the IV regression. The predicted values from the tobit regressions reported in Table 8.2 and their cross product were used as instruments. Available family labor is measured as family members, ages 14–60, divided by maize area planted. Underlying regression parameters are given in Appendix (Table 8.5)

values. Consequently, we decided to use an exogenous measure, available labor – that is the number of household members between the ages of 14 and 60 – to proxy household labor input, obviating the need to include household labor days as an instrumented variable.

With this as background, mean-valued elasticities from the second-stage are reported in Table 8.3.[4] For comparison purposes, elasticities from a corresponding OLS model are reported as well. In both estimation exercises, enumeration-area dummies were included to account for location effects; the effects are expected to sweep up the effects of any unmeasured differences in relative prices, market conditions, travel times and average soil and climate endowments. The regression suggests that location matters as the location dummies were statistically significant and explained a significant portion in the variation in yields.

Focusing first on the IV estimates, the results show that using fertilizer boosts yields in a statistically significant way. However, the average effect is not large, with an elasticity less than 0.10 evaluated at average values for yield and fertilizer use.

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[4] The estimated parameters themselves are reported in Appendix (Table 8.5).

There is a small, but statistically insignificant impact on yields from manure use. Higher levels of available family labor and hiring farm workers boost yields in a measurable way; at mean levels, the effects are not large and similar to the elasticity for fertilizer. As is often the case with maize in Africa, the elasticity of area is negative, although not significantly so.[5]

In terms of risk management strategies, the results suggest that growing maize in dedicated plots does not boost yields but rather reduces them. It is difficult to say exactly why this is the case, but it is consistent with the fact that very little of the maize grown in Uganda is harvested from pure-stand plots. It is also possible that nitrogen-fixing crops, such as beans, help compensate for low levels of applied chemical fertilizers. As discussed in Chap. 7, this type of intercropping is prevalent in the Kenyan highlands.

The IV results also suggest that farmers who diversify their risks by growing several crops also achieve higher yields, perhaps because they are able to use riskier-but-more profitable production strategies. However, diversification comes at a cost as it also results in fragmentation; the diversification elasticity is estimated at 0.167, while the fragmentation elasticity is at −0.084, suggesting that, in practice, the diversification benefits are partially off-set.

Weather mattered as much as any input for the rain-fed maize farmers in our sample, a finding consistent with observed risk mitigation strategies. Keeping in mind that conditions during the first growing season were dry, the results suggest that a 1 % gain in rainfall would increase yields by 0.08 %. The results suggest that the late arrival of first-season rains had a small but statistically significant negative effect on yields. Average rainfall for the season was near climate averages, and the small differences did not have a measureable impact on yields.

In terms of farmer characteristics, age and gender did not appear to affect yields. The IV estimates suggests that that farmers, male and female, young and old, achieved identical yields, once other factors have been accounted for.

8.4.3 Gender and Estimation Method

As discussed, the lack of a gender-effect in our IV estimates is at odds with results from the OLS model. As Table 8.3 shows, most of the estimated coefficients were robust to the choice of estimation technique; only 3 of the 13 estimated coefficients went from significant to non-significant or vice versa. Two of the changes had to do with the area planted to maize and the share of pure stands planted, and the differences are marginal. In the case of gender, the negative elasticity estimated under OLS is small, but significant at the 5 % threshold. When instruments are used the estimated effect is quantitatively and statistically indistinguishable from zero.

Table 8.4 summarizes a set of tests concerning the validity of our instrumentation choices. The tests and the software used to generate them are described in Baum

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[5] See Larson et al. (2014a, b) for a related discussion.

Table 8.4 Tests related to the instrumental variables in Uganda

Excluded instruments	
Combined instruments	F(1, 1391) = 38.77***
Fertilizer use	F(2, 1391) = 5.89***
Hired labor	F(2, 1391) = 38.77***
Under-identification test	
Combined instruments	Anderson LM $\chi^2(1) = 10.38$***
Fertilizer use	Angrist-Pischke $\chi^2(1) = 10.54$***
Hired labor	Angrist-Pischke $\chi^2(1) = 69.78$***
Weak identification test	
Combined instruments	Cragg-Donald Wald F statistic = 5.18***[a]
Fertilizer use	Angrist-Pischke F(1, 1391) = 10.44
Hired labor	Angrist-Pischke F(1, 1391) = 69.14**[b]
Weak instruments robust inference tests	
Combined instruments	Anderson-Rubin Wald $\chi^2(2) = 29.68$***
Combined instruments	Anderson-Rubin Wald F(2, 1391) = 14.70***
Combined instruments	Stock-Wright LM S $\chi^2(5) = 29.06$***

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

[a] Exceeds Stock and Yogo (2005) 0.15 critical value threshold (when two endogenous regressors are exactly identified) of 4.58 (See Baum et al. (2007) for more on the estimation and interpretation of the tests reported in this table)

[b] Exceeds Stock and Yogo (2005) 0.10 critical value threshold (for a single endogenous regressor) of 16.38

et al. (2007). Overall, the tests indicate that our identification strategy works reasonably well. The hypotheses that the tobit predictions are not relevant can be rejected for both fertilizer use and labor hires individually and taken together. Because two instruments are used to treat the two endogenous variables in our model, the model is exactly identified. The three tests reported in the next panel in Table 8.4 suggests that the hypothesis that this leads to under-identification can be rejected. The next panel shows the results from tests about the strength of the instruments. Here the results are mixed. Overall, the combined instrument test, given by the Cragg-Donald Wald F statistic, signals an adequate level of strength. When this is decomposed, it appears that some weakness is associated with fertilizer use. Nonetheless, the next three test reject the hypothesis that the instrumentation is weak and that this would reverse tests of significance for fertilizer and hired labor in our IV results.

8.5 Conclusion

Fertilizer, more so than other inputs, is considered an entry point for utilizing the improved technologies developed by scientists with smallholder farmers in mind. It is also a key element of the technologies that drove Asia's Green Revolution. However, the data from Uganda show that the production technologies employed by maize farmers are highly varied with farmers sometimes employing a mixture of strategies across seasons and among the separate plots that comprise their farms – farms often smaller than 1 ha. In addition, outcomes from the varied technology choices do not follow the clear relationships between modern production techniques and improved yield found in organized field trials. In particular, it is hard to distinguish performance patterns when yield outcomes are graphed according to decisions taken by farmers to grow maize in pure stands or in mixed-crop settings.

Our study suggests that markets and ex ante risk mitigation strategies in the face of uninsurable risks contribute to this outcome. Social norms regarding gender seem to as well, most likely by influencing female farmers' access to markets and information, which manifest themselves in lower yields.

Maps constructed for this study reveal the propensity of smallholders to locate near cities and transportation corridors and also the propensity of those households with better access to markets to sell more of what they produce. Our estimation results indicate that this also leads households to use more fertilizer when they grow maize.

The results show that weather variations around climatic norms affects yields, as would be expected. Since insurance markets are lacking and the capacity to self-insure or borrow in bad times is limited, nearly all of the farmers in our study diversify production. But because farms in Uganda are small, diversification leads to fragmentation, which reduces yields. At the same time, growing maize in mixed stands, which may also help farmers manage risks, appears to improve yields – albeit at the cost of increased fragmentation given the limited area farmed.

After accounting for a variety of farming decisions, the results show that using fertilizer improves yields; as was the case with most of the studies reported in this volume, extension visits spurred fertilizer use, as did participation in output markets. However, even after adjusting for these factors, women who head farming households are less likely to purchase fertilizer than their male counterparts, which leads to a productivity gap. Using an instrumental variables approach motivated by the assumption that gender roles make it more difficult for women to interact with market agents and to receive extension services, we find that often observed gender-linked productivity disparities between female farmers and their male peers disappear. For policy, this suggests that lowering market and information hurdles for female farmers can directly boost productivity, although the potential gains are small. Still, doing so will benefit a group of farmers that are, on average, disproportionately poor.

More broadly, most of the estimated input elasticities are low for the average set of input values. In addition, the collection of risk-mitigating activities, though likely well justified, have a comparable impact on productivity outcomes. Consequently, there is little in the results to suggest that policy instruments designed to improve input markets will have a transformational impact on farm productivity and farmer welfare via maize production alone. In all likelihood, agronomic research to enhance productivity and profitability of maize-based farming system is badly needed to realize a maize Green Revolution in Africa.

Appendix

Table 8.5 Estimated coefficients used to evaluate the elasticities reported in Table 8.3

	OLS fixed-effects results				Instrumental variables fixed effects results			
	Coef.	Std. Err.	t-score	P>|t|	Coef.	Std. Err.	t-score	P>|t|
Inputs								
Fertilizer use (kg/ha)	48.51	8.97	5.41	0.00	245.71	117.60	2.09	0.04
Manure use (kg/ha)	0.07	0.11	0.61	0.54	0.16	0.17	0.92	0.36
Family labor (days/ha)	80.39	11.46	7.02	0.00	91.09	15.47	5.89	0.00
Hired labor (days/ha)	14.65	1.96	7.46	0.00	23.74	10.79	2.20	0.03
Maize area	−27.65	8.91	−3.10	0.00	−19.56	10.87	−1.80	0.07
Risk management								
Share of maize area in pure stands	−43.17	65.13	−0.66	0.51	−137.58	88.30	−1.56	0.12
Maize area/plots managed	−70.62	34.29	−2.06	0.04	−97.45	41.03	−2.38	0.02
Number of crops managed	63.79	12.79	4.99	0.00	45.49	16.02	2.84	0.01
Farmer characteristics								
Female head of household	−78.71	39.95	−1.97	0.05	−35.32	58.65	−0.60	0.55
Age of household head	−0.85	1.20	−0.71	0.48	0.58	1.56	0.37	0.71
Weather effects								
Difference from average rainfall (mm)	−0.77	2.82	−0.27	0.79	−1.63	3.89	−0.42	0.68
Late start for season 1 rains (weeks)	−78.72	23.88	−3.30	0.00	−115.32	32.22	−3.58	0.00
Late start for season 2 rains (weeks)	−41.04	36.07	−1.14	0.26	−58.84	43.16	−1.36	0.17

Note: Both regressions included 215 fixed location effects, which were jointly significant at the 0.01 threshold. The number of observations for the OLS and IV regressions were 1,662 and 1,617 respectively

Chapter 9
Conclusions: Strategies Towards a Green Revolution in Sub-Saharan Africa

Keijiro Otsuka and Donald F. Larson

Abstract Observing clear upward trend in rice yield in SSA, this volume attempted to explore whether Green Revolution in rice has taken place in irrigated areas in sub-Saharan Africa (SSA), whether it is possible to realize a rice Green Revolution in rainfed areas, and the extent to which technology and management training has been effective in dissemination of Green Revolution technology. We then looked for signs of significant changes in maize yield from farmers' fields, particularly from highly populated highlands of Kenya. To our surprise, many maize farmers in Kenya adopt land-saving and labor-intensive maize-livestock mixed systems, consistent with the Boserupian theory of agricultural intensification. But institutional innovations from the public sector, such as the support for agricultural research on the establishment of new maize-based farming systems and extension, have not taken place, thereby limiting major gains in maize yields in many areas of SSA.

Keywords Rice Green Revolution • Irrigated area • Rainfed area • Technology and management training • Maize Green Revolution • Maize-livestock mixed systems

9.1 Introduction

As we argued in Chap. 1, African agriculture is challenged when compared with Asia, because of the diversity of crops grown in various parts of the continent. Figure 9.1 shows that although maize is clearly the most important cereal among the five major cereals, viz., maize, rice, wheat, sorghum, and millet, in terms of the harvested area, it accounts for only 40 % of the harvested area in recent years. Therefore, in order to increase the productivity of African agriculture as a whole,

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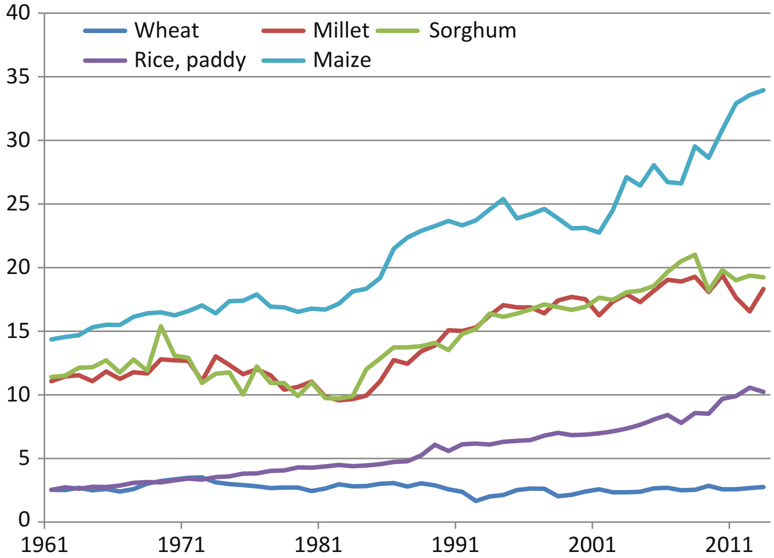

Fig. 9.1 Changes in share of harvested areas of major cereals in sub-Saharan Africa (million hectares) (Source: FAO Stat online)

the productivity of variety of crops must be improved, unlike Asia where single crop, often rice or wheat, dominates food systems throughout the region. It is clearly a challenging task to boost productivity in African agriculture because gains must be made on many fronts.

There are, however, at least two advantages for SSA. In the case of Asian Green Revolution, the aggregate rice production increased considerably due to the widespread adoption of yield-enhancing technology in many countries in Asia, which resulted in large rightward shift of the rice supply curve. Such shift led to sharp reduction in real rice prices because of the inelastic aggregated demand for rice. Thus, rice consumers were clearly made better off, while rice farmers were not, as is clearly demonstrated by Quizon and Binswanger (1983). This implies that productivity growth in agriculture and rural poverty reduction are potentially at odds. This is unlikely the case in SSA, because SSA is a “small country” in each global cereal market so that an increase in production in this region has only negligible impact on cereal prices. In other words, the productivity growth in agriculture and rural poverty reduction can be achieved simultaneously in SSA.

Secondly, being a “latecomer,” clear advantage of African agriculture lies in the transferability of improved technology from Asia. Since both SSA and Southeast and South Asia are tropical, biological and chemical technology transfers between the two continents are easier. As is shown in Fig. 9.2, a huge yield gap is observed for maize and rice between SSA and Asia, which indicates potential to transfer technology either directly or indirectly through adaptive research. As is argued by Otsuka and Larson (2013b) and as has been proven more rigorously in this volume,

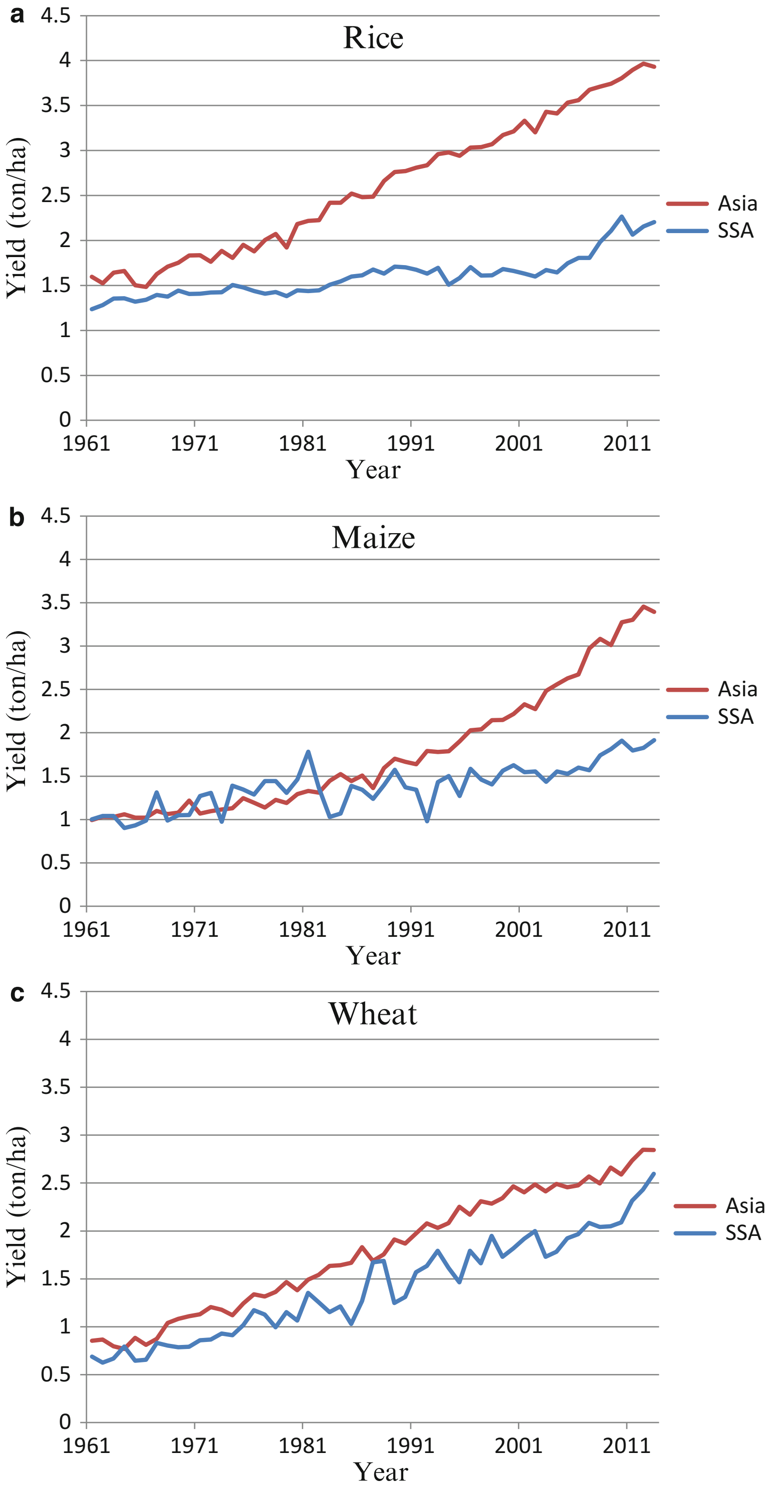

Fig. 9.2 Cereal crop yields in Asia and Sub-Saharan Africa, 1961–2013 (Source: FAO Stat online). (**a**) rice, (**b**) maize, (**c**) wheat, (**d**) sorghum, (**e**) millet

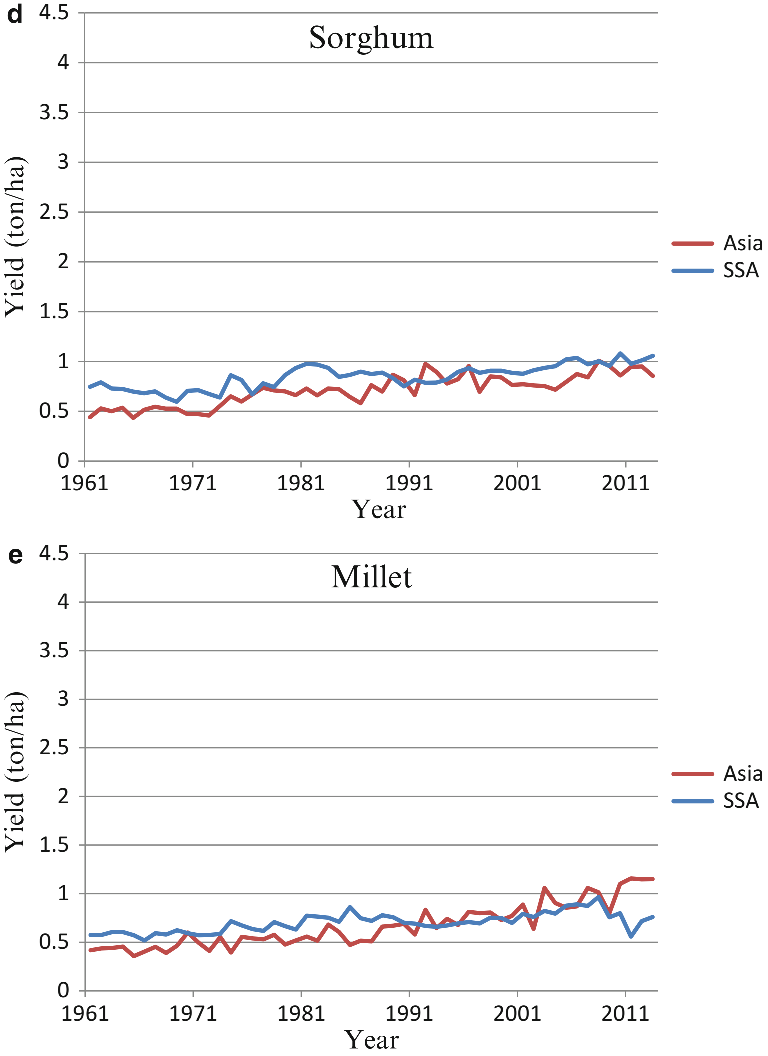

Fig. 9.2 (continued)

rice technology is highly transferable from Asia to SSA. Maize technology seems less transferable but still there is scope for inter-regional technology transfer. The yield gap is much smaller in wheat, because wheat yields have been growing rapidly in SSA, which indicates high transferability of Asian wheat technology. But wheat is grown in the temperate zone and it has limited potential to expand further in SSA. In fact, as is shown in Fig. 9.1, the wheat harvested area is relatively small in SSA. As far as sorghum and millet are concerned, Green Revolution failed to take place even in Asia where physical and market environments are more conducive to growth than in SSA. Indeed, there is no appreciable yield gap in these crops between the two continents. In all likelihood, it will be costly to realize the sorghum and millet Green Revolution in SSA because a new technological breakthrough must be created rather than adapted. Although it is beyond the scope of this study, other crops, such as cassava, plantain, and sweet potatoes, may be more promising than sorghum and millet for SSA (Haggblade and Hazell 2010).

In this concluding chapter, we discuss the possibility of a rice Green Revolution in Sect. 9.2 and that of a maize Green Revolution in Sect. 9.3, based primarily on the review and synthesis of case studies reported in this study. Finally in Sect. 9.4, we consider the strategy towards Green Revolution in SSA.

9.2 Possibility of Rice Green Revolution

In our earlier study (Otsuka and Larson 2013b) we found strong indications that lowland rice is the most promising crop in SSA. This study confirmed that it is in fact possible to realize a rice Green Revolution if effective extension system is in place.

9.2.1 Irrigated Areas

Table 9.1 compares paddy yield per hectare between irrigated and rainfed areas across our study countries. Among them, irrigated and rainfed areas coexist only in Mozambique and Tanzania. In these two countries, paddy yield is significantly

Table 9.1 Comparison of paddy yield per hectare (ton/ha) between irrigated and rainfed areas across study sites[a]

Country (source)	Irrigated area	Rainfed area
Mozambique (Table 2.2)	2.0	1.0
	(2007)	(2008)
	1.6	0.8
	(2011)	(2011)
Tanzania (Table 3.1)	3.7	1.8
	(2009)	(2009)
Uganda (Table 4.3)	n.a.[b]	2.5
		(2009)
		2.3
		(2011)
Ghana (Table 5.4)	n.a.[b]	2.0
Senegal (Table 6.9)	4.5	n.a.[b]
	(2011)	

[a] The numbers in parentheses are production years

[b] “n.a.” means not available

higher in irrigated area than in rainfed areas. Yet, yields of 1.6–2.0 tons per hectare in irrigated areas in Mozambique are low, considering that the average yield in SSA is about 2.0 tons per hectare as is shown in Fig. 9.2. This low yield can be attributed to low-quality irrigation facilities, high fertilizer prices relative to paddy price, the adoption of old modern varieties (MVs) developed in the 1960s and 1970s, and the near absence of the rice production management training program (Chap. 2). In fact, in some portions of the same irrigation area where JICA implemented training program, yields average 2.7 tons per hectare, which is significantly higher than the average yield of 2.0 tons per hectare in 2007.[1] In Doho irrigation scheme in Uganda, where no chemical fertilizer is applied but where more recent MVs are adopted, paddy yield is 3.0 tons per hectare (Nakano and Otsuka 2011).[2] The paddy yield in irrigated area is much higher in Tanzania, where the quality of irrigation facilities is probably better and rice production management training is more actively provided. In Senegal Rive Valley, where climate and soil condition is particularly favorable,[3] paddy yield is as high as 4.5 tons per hectare. In Senegal as well as in Tanzania, Asian-type semidwarf MVs are grown, chemical fertilizer is amply applied, and improved management practices, such as budning and leveling, are widely adopted. This high yield is comparable to yield in irrigated areas in Asia in the late 1980s (David and Otsuka 1994). Furthermore, according to Njeru et al. (2014), paddy yield is as high as 5 tons per hectare in Mwea irrigation scheme in Kenya, even though improved basmati varieties are grown.[4]

As is demonstrated in Fig. 9.3, the functional relationship between paddy yield and fertilizer application in irrigated areas is not significantly different between Asia and SSA, suggesting that the production function parameters are not greatly different between the two continents. The yield, however, is generally higher in Asia than in SSA importantly because fertilizer price relative to paddy price is lower in Asia than in SSA. Thus, there is no exaggeration to argue that the rice Green Revolution has already taken place in some irrigated areas in SSA. Productivity on small-scale irrigated rice farms in SSA can be further boosted, if real price of chemical fertilizer declines.

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[1] Since JICA training area was not chosen randomly, the reported higher yield cannot be solely attributed to the impact of the training program.

[2] This reasonably high yield without application of chemical fertilizer is possible because of the biological nitrogen fixation by micro-organisms in submerged soil (Ladha and Reddy 2003; Buresh 2015).

[3] Climate is fine and dry in this valley, which facilitates photo-synthesis and prevents outbreak of pests. Since it is basin of Senegal River, water is abundant and soil is fertile.

[4] Basmti is high-quality and relatively low-yielding varieties. In some areas of Mwea irrigation scheme where IRRI-type modern varieties are grown, yields are as high as 8 tons per hectare.

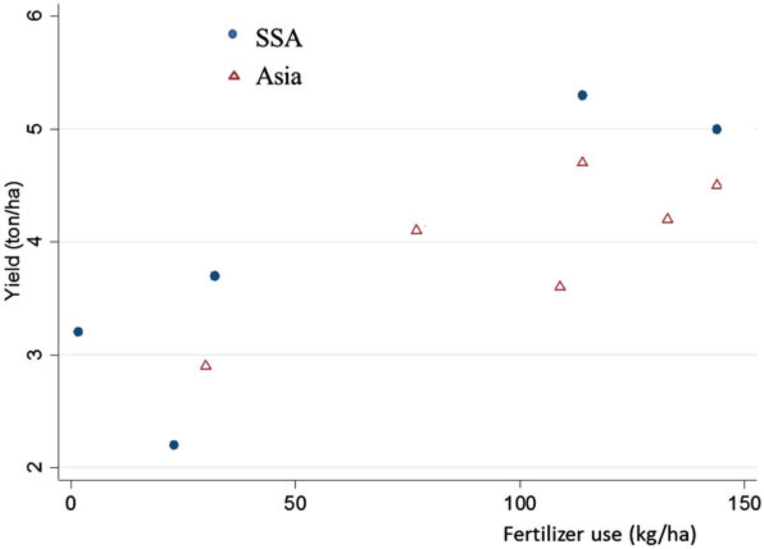

Fig. 9.3 Relationship between paddy yield (ton/ha) and fertilizer use per hectare (kg/ha) in selected irrigation areas in Asia and SSA (Source: Njeru et al. 2014)

9.2.2 *Rainfed Areas*

Yield in rainfed areas ranges from 0.8–1.0 ton per hectare in Mozambique to 2.3–2.5 tons per hectare in Uganda (Table 9.1). The average yield of 2.0 tons per hectare in Ghana is not so low. It is important to note that rainfed areas in Uganda and Ghana include areas where management training programs were implemented. Our hypothesis is that the yield gap between Mozambique and other countries can be attributed largely to the implementation of rice production management training programs in our study countries other than Mozambique.

In order to examine this hypothesis, Table 9.2 shows paddy yields by the adoption status of rice production management practices in rainfed areas in Uganda and Ghana. In training villages in Uganda, yields are low and comparable to Mozambique when improved management practices are not adopted, but yields improve as the adoption of the number of improved management practices increases. In non-training villages in this country, yield is not only low in general but also uncorrelated with the number of improved management practices adopted, which indicates that proper management practices are not adopted without management training. In rainfed areas in northern Ghana where one-third of 60 survey villages are covered by management training programs, yield is merely 1.5 tons per hectare without any improved management practices but becomes 2.6 tons per hectare with the adoption of all recommended management practices, including MVs and chemical fertilizer application.

Table 9.2 Paddy yield (ton/ha) and adoption of improved technology and management practices in rainfed areas in Uganda and Ghana

	Uganda[a]		Ghana[b]
	Training villages	Non-training villages	
All practices[c]	3.7	0.8	2.6
Almost all practices[d]	3.0	1.5	2.3
One practice only	2.1	1.6	1.7
No practices	0.8	1.0	1.5

[a] Yield is average of the two villages shown in Table 4.4

[b] The data source is Table 5.4

[c] Four management practices are considered in Uganda, i.e., buding, leveling, proper timing of transplanting, and transplanting in rows, whereas five production practices are considered in Ghana, i.e., adoption of MVs, chemical fertilizer, buding, leveling, and dibbling

[d] "Almost all practices" refers to three practices in Uganda and to four practices in Ghana

It is worth noting that paddy yield was on average 2.5 tons per hectare in rainfed areas of Asia in the late 1980s where rice Green Revolution took place or MVs were adopted (David and Otsuka 1994). Thus, there seems to be little exaggeration to say that rice Green Revolution took place in some rainfed areas in SSA. Considering that 85 % of lowland field in SSA is rainfed (Balasubramanian et al. 2007), this finding is highly significant.

9.2.3 Impact of Training

Although we have not applied the randomized control trial to assess the impact of management training program, we attempted to make rigorous assessment of the impact of management training programs in Tanzania, Uganda, and Ghana as much as possible (Chaps. 3, 4, and 5). In the cases of rainfed areas in Uganda and Ghana shown in Table 9.2, as management improves, paddy yield increases. This is highly suggestive of the positive impact of production management training on rice yield. Indeed case studies in Chaps. 4 and 5 more rigorously demonstrated that the implementation of the training program is positively associated with the adoption of improved management practices.

More convincing case was provided by Chap. 3 which assessed the impact of JICA management training program in irrigated villages in Tanzania, in which selected key farmers were trained by rice production extension specialists; each key farmer is supposed to train five "intermediate farmers," and ordinary or other farmers are expected to learn from key and intermediate farmers. Changes in yield of three types of farmers are shown in Table 9.3, which is a summary of Table 3.7. Even before key farmers were trained in 2008, they were more productive than other farmers. The yield of key farmers increased appreciably after they received the training program. The yield of intermediary farmers gradually increased, even though it remained lower than that of key farmers. Finally, the yield of ordinary

Table 9.3 Changes and differences in paddy yield (ton/ha) over time by training status in rainfed area in Tanzania[a]

	2008	2010	2012
Key farmers	3.1	4.8	4.7
Intermediary farmers	2.5	2.8	3.9
Ordinary farmers	2.6	2.5	3.7

[a] Data are taken from Table 3.7

farmers also increased and almost caught up with intermediary farmers. Such changes strongly suggest that rice production management knowledge was infused to the village firstly through key farmers and gradually diffused to all other farmers.

According to our ongoing study on the impact of modified System of Rice Intensification (MSRI) training program offered by large private company to small-scale farmers in Kilombero Valley in Tanzania (Nakano et al. 2015),[5] the average yield of MSRI plot of the trainees is as high as 5.1 tons per hectare, which is roughly twice as high as non-MSRI plots of trainees and plots of non-trainees, which are on average 2.8 tons and 2.6 tons per hectare, respectively. This example also indicates that the management training is effective in increasing rice yield.

There is no evidence, however, that the circulation of guidebook on how to produce lowland rice properly is effective in improving rice yield in Uganda (Chap. 4). It is likely that there is no easy substitute for face-to-face management training programs.

It is worth emphasizing that substantial yield gains have been achieved in some areas in SSA, primarily by introducing new technologies and management practices, even without accompanying major market reforms, new credit programs, and improved infrastructure including irrigation systems.[6] In other words, the provision of management training program should be the entry point towards Green Revolution, as far as lowland rice is concerned.

9.2.4 Is It Time for Rice Green Revolution?

From the viewpoint of the induced innovation theory (Hayami and Ruttan 1985), labor-intensive and land-saving technology will be induced to be developed and disseminated when population increases relative to land resources. At present, population pressure is a major concern in many countries in SSA. Given unstable food production and occasional food shortages, African farmers are keen to increase

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[5] Kilombero is rainfed and flood-prone area due to runoff water from nearby mountain range, and the soil is very fertile.

[6] Note that cheap credit was provided to participants in the training program in Ghana initially as well as in Kilombero Valley at present.

cereal production per unit of land, which may be reflected in recent increase in cereal yields in this region (Fig. 9.2).

One way to assess whether it is time for rice Green Revolution in SSA is to examine the profitability of improved rice farming technology and management practices compared with the traditional system. Although profit per hectare is the preferred measure of the profitability, it is difficult to impute the cost of family owned resources, particularly family labor, because of the underdevelopment of labor and other input markets. Thus, Table 9.4 shows both income and profit per hectare, except in Uganda where the imputation of family labor cost was found to be difficult. As would be expected, both income and profit per hectare are positive and significantly higher under irrigated than rainfed areas in Tanzania. More relevant is the comparison between training participants and non-participants in Uganda and between full technology adopters and non-adopters in Ghana. It is clear that both income and profit are significantly higher for training participants than non-participants, and for full adopters, who are undoubtedly training participants, than non-adopters, majority of whom are non-training participants.

Although we did not compute the cost and net benefit of rice production management training programs, it seems clear that the provision of training program is socially desirable, given considerable differences in income and profit between training participants and non-participants and between full adopters and non-adopters of improved technology and management practices.

Table 9.4 Income and profit per hectare of rice cultivation (USD/ha) by status of irrigation, management training participation, and technology adoption

	Income per ha[a]	Profit per ha[b]
Tanzania[c]:		
Irrigated area	1,011	590
Rainfed area	453	153
Uganda (rainfed)[d]:		
Training participants	1,327	n.a.
Non-participants	905	n.a.
Ghana (rainfed)[e]:		
Full adoptors	374	260
Non-adoptors	228	59

[a] Income is defined as the value of production minus paid-out costs

[b] Profit is defined as income minus imputed costs of owned resources including family labor

[c] Data are taken from Table 3.2

[d] Data are taken from Table 4.A2

[e] Data are taken from Table 5.4. Full adoptors are those who have adopted MVs, chemical fertilizer, budning, leveling, and dibbling

Table 9.5 Comparison of maize yield and technology adoption between Kenya and Uganda

	Kenya[a]		Uganda[b]
	2004	2012	2009/2010
Maize yield (ton/ha)	1.8	2.1	1.2
Chemical fertilizer use (kg/ha)	49	47	0.3
Manure use (kg/ha)	971	1,578	22
Share of intercropped fields (%)	76	72	45
Adoption of hybrid maize (%)	50	78	30

[a] Data are taken from Table 7.2

[b] Data are taken from Table 6.1

9.3 Possibility of Maize Green Revolution

Maize yields are substantially higher in Kenya than in Uganda (Table 9.5). Such a gap can be explained importantly by differences in chemical fertilizer and manure use, the frequency of intercropping with nitrogen-fixing leguminous crops, and the adoption of hybrid maize. This indicates that in order to realize maize Green Revolution, the intensification of maize-based farming system is required.

The ongoing intensification of maize-based farming system in Kenya, however, is not enough. Maize yields of roughly 2 tons per hectare are not different from the average maize yield in SSA and well less than one-half of the average yield in Asia (Fig. 9.2). A part of the reason for relatively low maize yield in Kenya is the planting leguminous crops on maize field, which improves soil quality and maize yields in the long run, but decreases maize yield in the short run. We are not sure, however, why maize yields are so low in Kenya where maize-based farming system has been clearly intensified. What is clear is that, unlike the case of rice, high-yielding maize production systems have not been established and disseminated.

It may well be that the quality of hybrid maize needs to be improved. We would also like to point out that we know neither the "optimum" amount or extent of chemical fertilizer application, manure or compost use, intercropping, dairy cows, and production of feed crops nor the best combination of chemical fertilizer, manure, and nitrogen fixed by leguminous crops. As far as maize is concerned, productive and profitable technologies have not yet been established and, hence, entry point towards the Green Revolution is investment in public-sector research on germplasm improvement and the establishment of desirable farming systems. Extension system must be strengthened, once profitable maize-based farming system is established.

9.4 Strategy Towards Green Revolution

Johnston and Cownie (1969) is probably one of the earliest studies that used the term "seed-fertilizer revolution" to refer to the Green Revolution in Asia. We conjecture that it would have been correct and relevant for Asian agriculture in the

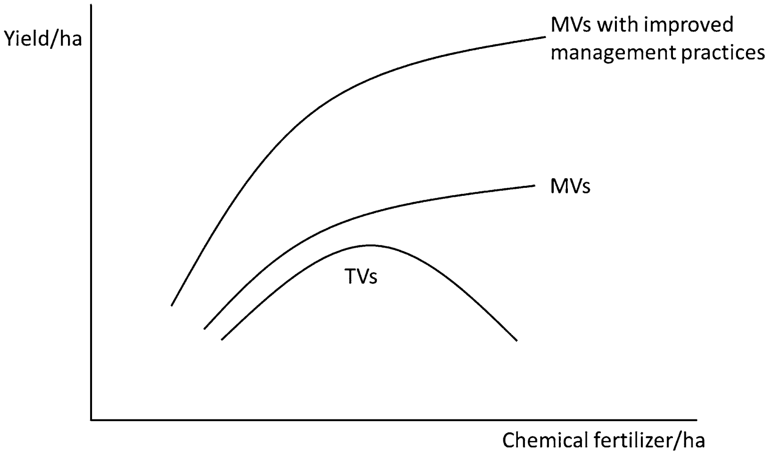

Fig. 9.4 Yield curves of traditional varieties (TVs) and modern improved varieties (MVs) with and without improved management practices

1960s and 1970s, as the advent and diffusion of MVs coupled with increased application of chemical fertilizer resulted in revolutionary changes in rice and wheat yields. We believe, however, that the term "seed-fertilizer revolution" is incorrect or even misleading to realize a Green Revolution in SSA. The main message of this study is that not only new improved seeds and chemical fertilizer but also improved management practices are required to realize a Green Revolution in SSA.[7]

This point is graphically illustrated by Fig. 9.4, which shows yield functions of traditional varieties (TVs) and improved modern varieties (MVs) with and without improved management practices against the application of chemical fertilizer. Consistent with the findings of this study, response of crop yield to the application of fertilizer improves not only with the use of improved varieties but also with the adoption of improved management practices, including the management of water and soil. In other words, productive farming system in SSA ought to be management intensive.

The second most important message of this study is that improved management practices can be introduced to African agriculture by the management training program, judging from the experience of rice production management training. We would like to conclude this study by pointing out that Green Revolution in SSA can be realized if we duely recognize that appropriate Green Revolution technology for SSA is not only "seed-fertilizer intensive" but also highly "management intensive."

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[7] Although evidence is weak, rice farmers in Asia seem to have known the importance of bunding and leveling of paddy fields even before the Green Revolution. Straight-row transplanting, however, was disseminated with the introduction of MVs in the 1970s.

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