Chapter 5
Toward a Green Revolution in Sub-Saharan Africa: Farm Mechanization in the Mwea Irrigation Scheme

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Abstract Governments in Sub-Saharan Africa (SSA) have made concerted efforts to improve farmers' adoption of modern technologies in their farm operations to realize a rice Green Revolution, improve food security, and alleviate poverty. However, smallholder farmers' access to farm mechanization in SSA remains constrained due to supply-side and demand-side challenges. On the supply side, the market for agricultural machinery services is often underdeveloped. On the demand side, the smallholders with inadequate knowledge of improved rice cultivation practices have limited demand for mechanized services despite increasing wage rates. This study analyzes the mechanization process of rice farmers in the Mwea Irrigation Scheme, Kenya. The Mwea Irrigation Scheme is the most advanced rice production area in SSA, with farmers familiar with improved rice cultivation practices, well-functioning input credit markets, and millers adopting modern milling technologies, enabling local rice to compete with imported Asian rice. Analyzing original data collected in 2011, 2016, and 2018, we found that most farmers in Mwea implemented rotavation using tractor services provided by farmers' cooperatives, while they implemented leveling using draft animals. Non-cooperative members reduced tractor use and adopted draft animals to implement both harrowing and leveling, implying the importance of a well-developed mechanization service market.

5.1 Introduction

Sub-Saharan African (SSA) countries and international organizations have been making concerted efforts to facilitate farmer adoption of modern farming technologies to realize the rice Green Revolution, improve food security, and alleviate

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poverty. These technologies include appropriate productivity-enhancing and labor-saving farm-level technologies, such as farm mechanization. In the case of Asia, population pressure on farmland has induced rice farming intensification since the 1960s (Hayami and Ruttan 1985). Farmers implemented intensive land preparation using draft animals, which facilitated the adoption of proper rice cultivation practices and seed-fertilizer technologies during the rice Green Revolution (David and Otsuka 1994). As the farm wage and cost of draft animals increased, farmers adopted farm machinery, like tractors (Binswanger 1978).

But farming intensification and the adoption of tractors have been slow in SSA. Farmers are less familiar with intensive land preparation because of the little use of draft animals in rice farming due to the prevalence of the tsetse fly-transmitted sleeping sickness (trypanosomiasis) (Alsan 2015), coupled with deteriorating animal health services and recurring droughts (Takeshima et al. 2015, 2013). In Cote d'Ivoire, farmers that intensively prepared land using two-wheel tractors more intensively applied fertilizer and used more labor to carefully implement proper agronomic practices, such as straight-row transplanting (Mano et al. 2020). However, few studies examine the use of tractors in the adoption of cultivation practices, productivity, and profitability from rice farming in SSA.

This study attempts to fill this gap in the literature by analyzing the adoption of tractors and other farm machinery in rice farming in the Mwea Irrigation Scheme in Kenya, using original data collected in 2011, 2016, and 2018. We studied rice farming in the Mwea Irrigation Scheme because it is a leading rice production area in terms of technology adoption and productivity in SSA (Njeru et al. 2016; Kikuchi et al. 2021; Mano et al. 2022). The Japan International Cooperation Agency (JICA) introduced small horsepower mechanized inputs coupled with other yield-enhancing technologies in 2014, and our data in 2011 and 2016 allows us to examine farm mechanization over the critical period. We explored which type of farmer was more likely to mechanize. This study also analyzed the possible complementarity between mechanization and other modern agricultural technologies. We draw vital policy implications to promote mechanization and improve food security in Kenya, in particular, and SSA in general.

The rest of this chapter is organized as follows. Section 5.2 explains the development of rice farming in the Mwea Irrigation Scheme in Kenya. We also briefly introduce the three studies we conducted in the Mwea Irrigation Scheme with Professor Keijiro Otsuka. Section 5.3 describes the original data used in this study, and Sect. 5.4 provides descriptive analyses. Section 5.5 concludes the paper.

5.2 Mwea Irrigation Scheme

This paper analyzes the development of rice farming and mechanization in the Mwea Irrigation Scheme, Kenya's leading rice production area, situated 90 km northeast of Nairobi. This scheme has 8,500 ha of irrigated paddy area and grows primarily

improved Basmati rice[1] with two crop cycles (Njeru et al. 2016; Kikuchi et al. 2021). The Mwea Irrigation Scheme is the oldest[2] and largest among the four major gravity-based irrigation schemes and produces 80% of the paddy rice produced in Kenya. The scheme previously consisted of five sections (Mwea, Tebere, Thiba, Karaba, and Wamumu) and gradually expanded. The government retains land ownership in the irrigation scheme, with farmers being allocated land with transferable use rights. Farmers were initially given four 1-acre parcels (equivalent to 1.6 ha [ha]) per household, but some farmers have divided and bequeathed land (use rights) to their offspring. Currently, the average farm size is 1.2 ha.

The authors of this chapter are former students of Professor Keijiro Otsuka who are fortunate to have had opportunities to continue working with him and pursue the possibility of the rice Green Revolution in SSA by examining the development process of rice farming and related sectors in the Mwea Irrigation Scheme. We have investigated the effect of credit on input application and rice productivity (Njeru et al. 2016), the economic viability of the Mwea Irrigation Scheme (Kikuchi et al. 2021), and the technology improvement in the rice milling sector toward the development of rice value chains and the quality and price of local rice to compete with imported rice from Asia (Mano et al. 2022). Because the Mwea Irrigation Scheme is the leading rice production area in SSA, we have learned many important lessons that may contribute to realizing the rice Green Revolution in SSA.

More specifically, Njeru et al. (2016) examined the efficiency of the input credit market in Mwea by comparing the fertilizer application and rice production performance among farmers borrowing from different sources and non-borrowers. After the liberalization of the rice farming system in the Mwea Irrigation Scheme in 1999,[3] a farmers' cooperative, the Mwea Rice Growers Multipurpose Co-operative Society (MRGM), started providing farm inputs on credit. MRGM charged a monthly interest rate of 1% on the value of credit advanced to farmers. Farmers were only required to deliver paddy enough to cover their credit and allowed to sell the remaining harvest to any buyer.[4] To fill the credit demand of farmers who could not access credit from MRGM, many rice traders started to also provide credit to farmers in the early 2000s. The number of farmers receiving credit from traders has increased even though the interest rates were as high as 100% for three months. This is mainly because of the high perceived risks influenced by their history of defaulting on MRGM credit. The

[1] Improved Basmati is a cross-breed between Basmati and high-yielding modern varieties and is widely grown in India and Pakistan. It is of lower quality but is higher yielding than original Basmati rice. A small amount of other rice varieties are produced solely for farmers' domestic consumption.

[2] Mwea Irrigation Scheme was established in 1954.

[3] Similar to the inefficient state management usually seen in managing local commons, such as large-scale irrigation schemes in Asia (e.g., Ostrom 1990; Bardhan 2000; Bardhan and Dayton-Johnson 2002), the state management suffered several shortcomings, such as inefficient water distribution, and overexploitation of water by head users (Abdullahi et al. 2003). In addition, returns to rice farming for farmers were very low as the price of paddy offered by the state was far below the market price.

[4] This new system faced potential challenges (Njeru et al. 2016). First, farmers were not paid immediately after delivery. Second, farmers could receive prices far below the market price.

contract between farmers and traders is that the trader provides cash at the beginning of the season, while farmers will repay in kind (i.e., a predetermined amount of paddy at the market price) at the end of the season. Njeru et al. (2016) found that fertilizer application and rice yield are not significantly different among borrowers from MRGM, borrowers from rice traders, and non-borrowers. Although a potential disadvantage to farmers may arise from the strong monopoly power of traders over farmers (Bell et al. 1997), our finding suggests that the input credit market functions efficiently in Mwea. The contract between the farmers and traders is likely to be competitive as there are hundreds of traders and thousands of farmers. The market is liberalized, with the traders competing with larger institutional buyers, such as MRGM, to purchase paddy from farmers. The successful development of the rice input credit market is likely to reflect the complementarity between the seed-fertilizer technology and the well-managed irrigation scheme.

To see the economic viability of the Mwea Irrigation Scheme, Kikuchi et al. (2021) calculated the costs and benefits of establishing the irrigation scheme under the assumption that the Mwea Irrigation Scheme was constructed as a brand-new project. Unlike the high construction and management costs of many other large-scale irrigation schemes established in SSA during the twentieth century, the Mwea Irrigation Scheme's construction and management costs were modest and comparable to the successful cases in Asia.[5] Furthermore, farmers in the irrigation scheme are likely to be well-trained and adopt seed-fertilizer technologies and proper rice cultivation practices. Although the Mwea Irrigation Scheme can be considered a successful irrigation project, its investment returns were not high. This low investment return is likely due to the low global prices of Asia rice, suggesting the importance of efforts to improve the quality and price of local rice.

Mano et al. (2022) explored technology adoption in the Mwea Irrigation Scheme's rice milling sector and its associated rice value chain development toward improving the quality and price of local rice compared with imported rice from Asia. Liberalization of the Mwea Irrigation Scheme's irrigation management allowed the entry of input retailers, rice traders, and rice millers into the market. The millers in Mwea focused on milling services by operating traditional milling machines, and millers and traders used to hire casual workers to manually remove small stones and other impurities from milled rice. In the early 2010s, several entrepreneurial millers in Mwea visited China. They learned about modern milling technologies, such as the destoner module, which removed small stones and other impurities automatically and thoroughly. Although a limited number of millers initially adopted the large-scale modern milling machines, smaller modern milling machines were introduced and widely adopted in the late 2010s. The adoption of modern milling machines improved the quality and price of Mwea's milled rice and facilitated rice value chain transformation, in which Mwea's rice was sold to urban supermarkets and consumers.

[5] The construction and management cost of Mwea Irrigation Scheme per hectare is slightly higher than the average cost of successful irrigation schemes in the twentieth century (Kikuchi et al. 2021). Its size is relatively small among the category of large-scale irrigation schemes, which prevents it from exploiting the economies of scale.

The rice milled by these millers is of higher quality and successfully competes with imported rice from Asia in urban markets, including in Nairobi. In December 2018, we observed supermarkets in Nairobi selling improved Basmati rice from Mwea at KES 140–200 per kilogram (kg), compared with Pakistani long grain at KES 100–120 per kg.[6] These observations indicate that African rice can compete with Asian rice if improved milling machines are introduced to the SSA.

During the irrigation scheme development, the farmers received training on seed-fertilizer technologies and proper rice cultivation practices (Kikuchi et al. 2021). We will investigate their technology adoption and rice farming performance in the sections that follow. In particular, we analyze the adoption of tractors and other farm machinery for different activities as well as fertilizer application and rice productivity.

5.3 Data

The data used in this study comes from three rounds of original household surveys conducted by the authors in 2011, 2016, and 2018. For the baseline in 2011, stratified random sampling was employed, which followed the zoning of the Mwea Irrigation Scheme. The scheme used to consist of five sections in 2011. Scheme Area 1 (SA1) covers the Tebere section, and Scheme Area 2 (SA2) covers the Mwea, Thiba, Wamuru, and Karaba sections. The 2011 survey covered all the sections in both SA1 and SA2. From each section, seven (or eight) units were randomly selected for a total of 36 units (out of 59 units).[7] The next stage was to choose a feeder canal in each of the units selected. After randomly selecting a feeder canal in each unit, the list of registered farmers for the scheme was used to randomly select eight farmers along each feeder canal. If a feeder canal had fewer than eight farmers, all the farmers along that feeder canal were interviewed. In 2011, 259 farm households were interviewed.

In 2016, the scheme added two new sections for a total of seven sections. Outgrower Area 1 (OG1) covers one additional section, and Outgrower Area 2 (OG2) covers the other section. Because we wanted to compare farmers' situations outside the irrigation scheme to those cultivating rice within the irrigation scheme, the 2016 survey covered SA2, OG1, and OG2, but not SA1 due mainly to the budget constraint. In SA2, a subsample of farmers visited in 2011 were randomly selected and interviewed, maintaining the key sampling structure used in the 2011 survey. First, three units out of all the sample units in each of the four sections in SA2 (i.e., Mwea, Thiba, Wamuru, and Karaba) were randomly selected. All farmers in the selected units interviewed in 2011 were interviewed again in 2016. Furthermore, 25 farmers

[6] In 2019, Pakistan accounted for 67% of imported rice to Kenya, followed by Thailand with 25%, Republic of Korea with 3%, and India with 2% (KNBS 2021). The Pakistani rice is not Basmati, but a type of long-grain nonaromatic rice. According to our informal interviews with local rice traders, some sellers blend Mwea rice with imported rice from Pakistan, and they sell this as 'Mwea rice.' However, note that consumers prefer high-quality Asian rice. For example, Jasmine rice from Thailand retailed at KES 350 per kg while Mwea rice was sold at KES 140–200 per kg.

[7] We selected eight units in the Karaba section because two units shared the same feeder canal.

were randomly selected in each of the four units in OG1, and 15 farmers were selected in each of the seven units in OG2. In total, 314 farmers were interviewed across SA2, OG1, and OG2.

In 2018, all the 51 sample farmers in SA1 in 2011 were interviewed to complement the 2016 survey, in which the farmers in SA1 were excluded from the sample. In addition, using the sampling methodology used in 2011, seven units were randomly identified, and eight farmers in each unit were interviewed for the first time. In total, 107 farmers were interviewed in SA1 in the 2018 survey.

We interviewed these sample rice farmers using structured questionnaires about their rice farming practices for the cropping season. Other information collected included: (1) household demographics and nonfarm occupation, (2) characteristics of land holdings, (3) input and output for rice, (4) source and amount of credit, and (5) agricultural assets held.

5.4 Descriptive Analyses

Table 5.1 presents the sample farmers' basic characteristics in 2011. The average age of the household head is 56, with extensive rice farming experience. The average household consists of 4.5 members, including 1.7 men and 1.5 women of working age (15–64 years old), who are lowly educated. The average sample farmers cultivate 1.17 ha of rice fields and pay the rental value of USD 341 per hectare. Their rice field is located 0.63 km from the intake on average, and there are 16 plots of fellow farmers along the feeder canal. Most sample farmers belong to MRGM and borrow USD 371, while non-members of MRGM borrow USD 144 from rice traders per season.

Figure 5.1 shows the trends in agricultural wages in Kenya. Using data from the Tegemeo Institute panel survey and our original survey data, the average wage rate has more than doubled over the past two decades. A fundamental hypothesis in supporting the adoption of mechanization is that mechanization helps substitute for labor as it becomes more expensive (Binswanger 1978). The rising wage rate is an indicator of scarcity. During peak periods of crop development, the wage rate will likely be higher, and fewer workers face diminishing returns to their productivity.

Table 5.2 presents the use of four-wheel tractors and draft animals across the three survey rounds. Almost all farmers use a tractor and draft animals. The high proportion of farmers using tractors is due to the rice farming experience under the National Irrigation Authority (NIA) (formerly National Irrigation Board [NIB]) and MRGM, where these services were provided on credit. In 2011, tractor services were primarily used for plowing, while draft animals were used mainly for leveling, which equalizes the water level in the rice field and facilitates the even growth of rice plants. Almost all households had this combination, with 98% reporting using both a tractor and a draft animal. This finding contrasts with rice farmers' widespread use of two-wheel tractors for plowing and leveling in Cote d'Ivoire (Mano et al. 2020). According to the Cote d'Ivoire study, intensive land preparation facilitated

Table 5.1 Household characteristics of sample farmers in 2011

Characteristics	
Age of household (HH) head (years)	55.80 (14.73)
Female-headed HH (%)	18.9 (39.2)
% of HH heads who started rice farming after 2000	29.7 (45.8)
HH size (number of members)	4.5 (1.9)
Number of working-age men (15–64 years old)	1.67 (1.21)
Number of working-age women (15–64 years old)	1.46 (0.99)
Highest education attainment of non-head HH members	3.3 (1.2)
Cultivated farm size (ha)	1.17 (0.6)
The rental value of land (USD/ha)	341 (81)
The average distance from intake to plot (km)	0.63 (0.37)
Number of farmers along the feeder canal	16 (6)
Value of assets (USD)	263 (433)
Dropout from MRGM (%)	30.5 (46.1)
Credit from MRGM (USD) per season	371 (188)
Credit from traders (USD) per season	144 (176)
N	259

Notes Standard deviations are in parentheses. Dropouts are farmers who were members of MRGM in 2000 but were no longer members at the time of the survey. The rental value of land, assets, and credit are in USD (the exchange rate was USD 1 = KES 84.21). Assets include small livestock, such as goats, sheep, poultry, and light farm equipment

the adoption of labor-intensive rice cultivation practices, and it was also the case in the Mwea Irrigation Scheme, where almost all the farmers adopted transplanting in rows (not shown in the tables here). In 2011, rotary weeders were yet to be adopted, and no farmer interviewed reported the adoption of the rotary weeders. Similarly, there was no use of mechanized services for harvesting.

In 2016, there was a reduction in the proportion of farmers reporting the use of tractor services, which can be attributed to the newly-added sample farmers in OG1 and OG2. The farmers in these areas were initially not served by NIB and therefore had to access services from private sector suppliers. When they were formally recognized as sections, they joined MRGM and continued to receive mechanized services. Also, a much lower proportion of farmers reported using tractors in the first plow, but more reported using tractors to harrow after the first plow. Similar to 2011, draft animals were mainly used for leveling, although more farmers reported using draft animals to transport produce from the farm. In 2016, a small proportion of farmers had started using rotary weeders, reflecting the sharp rise in farm wages (Fig. 5.1). In

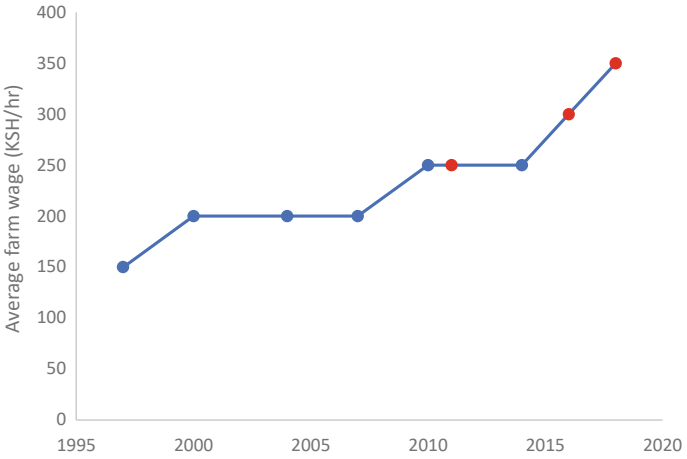

Fig. 5.1 Trends in agricultural wages in Kenya (Tegemeo Institute data in triangles [1997–2010, 2014] and survey data in round dots [2011, 2016, and 2018])

Table 5.2 Use of mechanized inputs and activities

	2011		2016		2018	
	Oxen	Tractor	Oxen	Tractor	Oxen	Tractor
% of farmers using activities (%)	99.6	98.0	97.3	82.2	98.8	41.5
Rotavation	0	98.0	0	16.3	0	32.9
Harrowing	2.4	0.4	8.1	65.5	97.6	1.2
Leveling	99.6	0	93.0	0	97.6	0
Transport	2.9	0	15.5	3.1	0	15.9
Harvesting	0	0	0	38.8	0	3.7
Used mechanical weeder (%)	0		8.1		19.5	
N	245		258		82	
Sample	SA1, SA2		SA2, OG1, OG2		SA1	

addition, more than one-third of the farmers reported using mechanized harvesting of rice.

In 2018, tractor use was further reduced and mainly used for plowing. A higher proportion of farmers reported using tractors for transporting produce from the farm. Draft animals were utilized for harrowing and leveling. Although mechanized harvesting was very low, a much higher proportion reported using rotary weeders. The low use of mechanized harvesting services can be attributed to constraints in access. Although mechanized service providers have increased, they were first provided by MRGM only. More farmers from the Tebere section (SA1) exited MRGM following challenges faced after liberalization and lost access to machinery service on credit,

Table 5.3 Fertilizer application and rice yield

	2011	2016	2018
NPK per ha (kg/ha)	139.28 (57.36)	86.76 (236.21)	66.54 (28.56)
Yields (tons/ha)	4.96 (1.52)	5.36 (3.71)	6.19 (1.45)
N	259	256	82
Sample	SA1, SA2	SA2, OG1, OG2	SA1

Note Standard deviations are in parentheses

explaining the reduced adoption of tractors and slower adoption of mechanized harvesting.

Table 5.3 presents fertilizer application and the rice yield of the sample farmers. The farmers applied, on average, 140 kg of NPK (nitrogen, phosphorus, and potassium) fertilizer per hectare in 2011, which is more intensive than many agricultural countries in Asia, such as India, the Philippines, Bangladesh, Thailand, and Nepal (see Fig. 1 in Njeru et al. 2016). Fertilizer application declined over the sample periods as farmers left MRGM and lost access to input credit. However, the average rice yield increased from 4.96 tons/ha in 2011 to 6.19 tons/ha in 2018. We do not know precisely why the rice yield increased over time. However, rice production was low from 2008 to the early 2010s due to unfavorable rainfall (Kikuchi et al. 2021), while the improved rice yield may be due to the enhanced water access in the Mwea Irrigation Scheme. The Water Management Development Project of the World Bank was improved between 2007 and 2013, while JICA has implemented a modernization-rehabilitation project since 2017 (Kikuchi et al. 2021).

Furthermore, the price of Mwea rice increased following the rice millers' adoption of improved rice milling technologies during this period (Mano et al. 2022). The farmers may have been encouraged to more carefully implement improved rice cultivation practices, such as threshing and drying, to improve the paddy quality. We will investigate these possibilities in our future projects.

5.5 Discussion

Under the leadership of Professor Otsuka, we investigated the possibility of the rice Green Revolution in SSA by closely examining the case of the Mwea Irrigation Scheme in Kenya from diverse angles in the past ten years. As opposed to popular demand for input credit intervention, the farmers in the Mwea Irrigation Scheme can receive credit from the farmers' cooperative and rice traders, enabling them to apply fertilizers properly (Njeru et al. 2016). The liberalization of irrigation management enhanced the rice farming performance and the returns to irrigation investment, making the Mwea Irrigation Scheme one of the successful large-scale

irrigation schemes in SSA (Kikuchi et al. 2021). The liberalization also facilitated the entry and development of related sectors. In particular, the rice millers adopted modern milling machines, improving the quality and price of milled rice produced in the Mwea Irrigation Scheme (Mano et al. 2022). This chapter further explored the technology adoption of rice farmers and found that the farmers used four-wheel tractors for rotavation and oxen for leveling the rice field, facilitating the adoption of labor-intensive rice cultivation practices. The farmers achieved a high rice yield of 6 tons/ha, exceeding the performance of prosperous rice-producing countries in Asia. However, the development of the machinery service market is still limited in the Mwea Irrigation Scheme, and there is still room for improvement. All these findings strongly suggest that the rice Green Revolution is occurring in the Mwea Irrigation Scheme.

Recollections of Professor Keijiro Otsuka

We are former students of Professor Keijiro Otsuka. He taught us the importance of visiting the fields and learning the reality from farmers, entrepreneurs, traders, and workers. We are fortunate to have opportunities to continue working with him and pursuing the possibility of the rice Green Revolution in SSA by examining the development process of rice farming and related sectors in the Mwea Irrigation Scheme. We have examined the effect of credit on input application and rice productivity (Njeru et al. 2016), the economic viability of the Mwea Irrigation Scheme (Kikuchi et al. 2021), and technology improvement in the rice milling sector toward the development of rice value chains and the quality and price of local rice to compete with imported rice from Asia (Mano et al. 2022). Because the Mwea Irrigation Scheme is the leading rice production area in SSA, we have learned many important lessons that may contextualize and improve our understanding of the rice Green Revolution in SSA. We are currently thrilled to prepare for the upcoming survey in Mwea to explore the adoption process of rice cultivation practices and the complementary roles of land preparation using draft animals and power tillers in the process of the rice Green Revolution.

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