

博士論文

**Adoption and Diffusion of New Rice Technologies in Tanzania: Prospects and
Challenges**

(タンザニアにおける稲作新技術の採用と拡大：可能性と課題)

マゲジ ユスタデュース フランシス

MAGEZI Eustadius Francis

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Summary

Rice cultivation is emerging as the most important staple crop in Sub-Saharan Africa (SSA) due to its growing demand. In efforts to improve rice production and productivity, several initiatives have been implemented. These include introducing the high-yielding modern varieties developed in Asia, promoting the use of agro-chemicals, and improved agronomic cultivation methods. However, despite their high potentials, these technologies are not widely adopted in SSA. Several constraints, including the lack of access to credit, the lack of training on rice cultivation, and labor shortage during cultivation seasons, are identified as possible reasons for the low adoption rate. Yet, it is still an empirical question if the adoption of technologies and productivity would increase if these constraints are relaxed. This study focused on two aspects: microcredit and mechanization of rice cultivation.

Regarding microcredit, adopting new agricultural technologies is often labor-intensive, and the initial costs tend to be high. While credit access can reduce this constraint, many smallholder farmers in SSA lack the collateral required to secure loans from formal financial institutions, such as commercial banks. When microfinance institutions (MFIs) arrived in Africa in the 1990s, they were regarded as a solution in ensuring the provision of financial service to the poor due to their low levels of interest rates and collateral-free loans. While microcredit's impact on the investment in non-farm activities has been widely discussed, there is a limited number of empirical studies evaluating the impact of microcredit on the adoption of agricultural technology and productivity. Lack of reliable evidence on the impact of microcredit on agricultural production weakens the efforts of enhancing financial inclusion, especially in rural areas where the majority of the potential clients are farmers.

Turning to mechanization, agricultural production in SSA has mostly continued to rely on manual and animal power, as mechanization in the region remains to be the lowest in the world. The past initiatives to promote mechanization, particularly tractors in the 1960s and 1970s, failed to materialize due to poor management and lack of adequate demand. There was also a growing concern that tractors will encourage large-scale farmers to expand their farms and displace smallholder farmers. This resulted in the perception that mechanization is not a suitable tool for agricultural development, which led to a further decline in SSA tractors. In the past two decades, however, the interest in mechanization began to emerge again in SSA, partly due to the rise of global food prices in 2008 and the arrival of new suppliers of machinery and repair services. Despite the recent increase in the use of four-wheeled tractors and power tillers among rice farmers, studies on the effects of mechanization on rice production in SSA remain scant.

This study explores the role of microcredit and mechanization in improving rice productivity using data collected in Tanzania, one of the major rice-producing countries in SSA. Specif-

ically, this study aims to: (i) Assess rice technologies promoted in Tanzania and their recent adoption trend. (ii) To evaluate the impact of microcredit on the adoption of rice technologies, rice productivity, and overall household income. (iii) To examine the effects of mechanization on the expansion of the cultivated area, land productivity, and labor productivity. We explore these objectives in Chapters 3, 4, and 5.

Chapter 3 discusses various efforts to improve rice production, including introducing different rice technologies such as MV, chemical fertilizer, and improved agronomic practices. We applied the household-level data to descriptively show how the adoption of these technologies has changed over time. The descriptive results show that adoption rates for these technologies have gradually increased from 2009 to 2018. But the adoption pattern varies across agro-ecological zones. Irrigated areas appear to have high adoption rates and relatively higher yields, indicating the possibility of rice Green Revolution in irrigated lowlands. However, only a small proportion of the total rice area is under irrigation, undermining the potential influence of such yield on country-level productivity. Our results show a similar pattern to previous studies that empirically examined factors associated with the adoption of rice technologies in Tanzania. Our results suggest that to achieve the rice Green Revolution in Tanzania, policies that aim to increase irrigation infrastructures and those seeking to improve productivity in rainfed remains essential.

Chapter 4 analyzes the impact of microcredit on technology adoption and land productivity. We use data from the randomized control trial (RCT) of the microcredit intervention conducted in Tanzania. In the intervention, we offered microcredit to randomly selected farmers and investigated its impact on adopting technologies such as high-yielding modern varieties, chemical fertilizer, other agronomic practices, and land productivity. We first estimate the intention-to-treat (ITT) effect of farmers eligible to borrow credit from the program. In addition to ITT, we estimate the local average treatment effects (LATE) of the program, using eligibility status as an IV. We also apply the ANCOVA approach to increase estimation power. Overall, we do not observe any significant impact on technology adoption or increased paddy yield, profit, or household income. Lack of significant effect of credit on fertilizer use or paddy yield is consistent with the previous studies, which found that credit use did not increase chemical fertilizer or paddy yield.

We explore further by conducting sub-sample analyses comparing borrowers and non-borrowers in the irrigation scheme with better access to irrigation water and extension services against those without better access to irrigation water and extension services. Our results show that those farmers in the irrigation scheme with good access to water and extension services have applied a relatively high amount of chemical fertilizer, which is near the recommended level, even without credit use. Therefore, even after some of them borrowed credit, they did not increase chemical fertilizer use. On the other hand, farmers without better access to irrigation water and extension

services usually do not apply a high chemical fertilizer quantity. Therefore, when they borrowed credit, they significantly increased chemical fertilizer. However, the increased use of fertilizer did not increase yield or profit for these farmers. Although this is not conclusive, low rates of yield response to an application of chemical fertilizer can be one of the possible reasons. If this is the case, our results support the argument that emphasizes the importance of the extension services before the input and credit market development. Our results suggest that it is crucial to understand clients' characteristics and their socioeconomic environment when MFIs design their loan products targeting clients in agricultural communities. Additionally, our findings suggest that credit access may not be the only constraint on rural households.

Chapter 5 examines the effects of mechanization on expanding cultivated area, land productivity, and labor productivity. We use three-year panel data from two regions of Tanzania. We focused on the use of four-wheeled tractors (TR) and power tillers (PT) for land preparation activities in rice plots. Descriptive results show that in recent years, mechanization has been increasing in Tanzania and gradually changed how farmers prepare their rice plots. We applied the multinomial endogenous treatment effect (METE) model accounting for unobservable household heterogeneity to analyze the effects of mechanization.

In our empirical estimations, we found that TR contributes to the expansion of area under rice cultivation both within a plot and household level but does not increase paddy yield. On the other hand, PT users adopt yield-enhancing agronomic practices more often and apply a more chemical fertilizer, insecticides, and herbicides, resulting in high paddy yield, revenues, and profit per hectare. Our results are partially consistent with previous empirical studies, which report the positive relationship between agricultural mechanization and intensification, although we do not observe such a tendency for large-scale mechanization. Despite these differences, we find that both PTs and TRs significantly reduce labor use, resulting in increased labor productivity. We also find evidence suggesting that the labor force freed from rice cultivation was reallocated to the cultivation of other crops, resulting in high household income among PT users. Our results would contribute to the recent policy debates that aim to promote mechanization among small-scale farmers in SSA.

The research topics covered in this thesis provide empirical evidence to support future policies aiming to improve agricultural production and productivity through the adoption and diffusion of new agricultural technologies in developing countries.

List of Acronyms and Abbreviations

ACG	Agricultural Growth Corridors
AGRA	Alliance for a Green Revolution in Africa
BRN	Big Results Now
CAADP	Comprehensive Africa Agriculture Development Program
GDP	Gross Domestic Product
IITA	The International Institute of Tropical Agriculture
IRRI	International Rice Research Institute
ITT	Intention To Treat
IV	Instrumental Variable
JICA	Japan International Cooperation Agency
LATE	Local Average Treatment Effect
MATI	Ministry of Agriculture Training Institution
METE	Multinomial Endogenous Treatment Effects
MFIs	Microfinance Institution
MVs	Fertilizer responsive high-yielding modern varieties
NAIVS	National Agriculture Input Voucher Scheme
NEPAD	New Partnership for Africa's Development
NERICA	New Rice for Africa
OLS	Ordinary Least Square
RCT	Randomized Controlled Trial
SACCOs	Savings And Credit Cooperative Organizations
SAGCOT	Southern Agriculture Growth Corridor of Tanzania
SDGs	Sustainable Development Goals
SSA	Sub-Saharan Africa
TShs	Tanzanian Shillings
UNDP	United Nations Development Programme
WARDA	West Africa Rice Development Association
2SLS	Two Stage Least Square

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Chapter 1.

Introduction

1.1 Background of the Study

In recent years, Sub-Saharan Africa (SSA) has made progress in reducing poverty and food insecurity, but some challenges remain. First, the population has continued to grow rapidly at an annual average rate of 2.55 percent, making it the fastest-growing region in the world ([United Nations, 2019](#)). Second, while poverty in SSA shows a declining trend, the number of the poor has increased ([UNDP, 2019](#)). Third, food insecurity in SSA has declined by 31 percent between 1992 to 2015, yet about 32 percent of undernourished people in the world in 2019 were in SSA ([FAO, IFAD, UNICEF, WFP and WHO, 2020](#)).

Although there are many factors linked to poverty and food insecurity in SSA, the under-performance of the agriculture sector explains the largest part of the problem. Agriculture is an essential sector for most of the countries in the region. According to [Alliance for a Green Revolution in Africa \(2014\)](#), on average, agriculture contributes about 15% of total GDP, although the figure ranges from below 3% in Botswana and South Africa to more than 50% in Chad. Agriculture employs more than half of the total labor force in SSA. In rural areas, it is a source of livelihood to smallholder farmers who cultivate about 80% of the total of all farmland in SSA.

Over the past decades, agriculture did not change sufficiently enough to keep up with the rapid pace of growing population, or help those in rural areas escape poverty. The late 20th century's Green Revolution that transformed agriculture in Asia and some parts of Latin America bypassed much of SSA, and most areas are still in subsistence state ([Todaro and Smith, 2015](#)). The large part of agricultural production in the region relies on rainfall. By 2007, only about 4 percent of arable land in SSA was irrigated in contrast to 39 percent of South Asia ([World Bank, 2007](#)), and little has changed since then ([Sheahan and Barrett, 2017](#)). Therefore, improving

agricultural production through technological transformation remains a key agenda in addressing issues related to poverty and food insecurity in the SSA.

Several initiatives have been implemented in SSA, including the introduction of the high-yielding varieties for major staple crops, promoting the use of agro-chemicals, and improved agronomic cultivation methods (Otsuka and Larson, 2013, 2016; Jayne and Rashid, 2013; Binswanger-Mkhize and Savastano, 2017). However, these technologies are not widely adopted, and therefore, agricultural productivity remains to be low (Larson et al., 2016; Matsumoto and Yamano, 2013; Nakano et al., 2013; Sakurai, 2016). Among the reasons for low adoption rates is that farmers in SSA are constrained by factors such as lack of access to credit, labor shortage, lack of knowledge on new technologies, and poor access to input and output markets (Foster and Rosenzweig, 2010; Takahashi et al., 2020; Moser and Barrett, 2006). To address some of these challenges, this study focuses on two aspects, namely microcredit and mechanization.

1.1.1 Microcredit

Access to credit is considered one of the significant factors in enhancing farmers' ability to adopt new agricultural technologies, which are often labor-intensive, and their initial costs tend to be high. Except for a few financially capable farmers or those with external sources of funds, most smallholder farmers require credit access to pay for direct production costs. While such a problem could be solved by issuing credit, many smallholder farmers in SSA lack the necessary collateral to secure loans from formal financial institutions, such as commercial banks (Ledgerwood, 1999). Even for those who own substantial collateral such as land, property rights are often poorly defined, which makes commercial banks reluctant to serve them due to high transaction costs and imperfect information (Ghatak, 1999; Giné, 2011). As a result, many farmers rely on informal loans offered by local money lenders, which typically have high interest rates and are associated with high risks since they are not regulated (Conning and Udry, 2007).

When microfinance institutions (MFIs) arrived in Africa in the 1990s, they were seen as a solution in ensuring the provision of financial service to the poor due to their low interest and collateral-free loans (see Subsection [1.4.1](#) for detailed definition). The success of MFIs in South Asian countries, especially Bangladesh, where they originated, encouraged small and medium-scale enterprises in SSA to use their services ([Robinson, 2001](#)).

Despite their increasing popularity in developing countries, there is a growing debate on whether services offered by MFIs, including microcredits, can be used as tools to alleviate poverty. Several studies have been conducted to examine the impact of microcredit. The recent studies based on randomized controlled trials (RCT) show that in general, microcredit has a positive impact on the business investment but has no impact on their income ([Angelucci et al., 2015](#); [Attanasio et al., 2015](#); [Banerjee et al., 2015a](#); [Karlan and Zinman, 2010](#); [Tarozi et al., 2015](#)). However, most of these studies focus on how investments made by small and medium-scale enterprises (SMEs) can have impact on income, business expansion and other livelihood indicators such as education and medical expenditures, thus are not directly linked to agriculture.

While the impact of microcredit on the investment in non-farm activities has been widely discussed, there is a limited number of RCT studies evaluating the impact of microcredit on adoption of agricultural technology and productivity. Lack of reliable evidences on the impact of microcredit on agricultural production weakens the efforts of enhancing financial inclusion, especially in rural areas where the majority of the potential clients are farmers ([Bauchet et al., 2011](#)).

On the lender's side, MFIs are expected to undergo several adaptations to succeed in rural areas. This is because like any other financial entities, they need to find solutions to potential challenges such as adverse selection (what client you should lend to), ex-ante moral hazard (what economic activities of the borrower are eligible for the loan), limited liability (can the borrower ensure repayments) and ex-post moral hazard (how to enforce repayment). Therefore, in deciding what kind of loan products should be offered, MFIs are expected to consider the production

environment and the distribution of farmers' income to avoid default loans ([Meyer, 2014](#)).

On the borrowers' perspective, farmers are expected to assess beforehand the potential risks in their production environment and make a rational decision on whether to applying for the loan or not. Their propensity to use credit is also likely to be influenced by lenders' policies, such as what measures are taken to support clients' investment decisions and what happens if the investment fails.

Understanding the challenges both sides face is essential for the success of the MFIs and for the betterment of farmers using their services. For example, farmers' income is often concentrated in few months after harvest, which is in contrast to clients making non-farm investments, who tend to have recurring revenues derived from sales ([Beaman et al., 2013](#); [Takahashi et al., 2017](#)). Another challenge to be addressed is that farmlands are often sparsely located, which could undermine conventional practices of MFIs such as client visits and weekly meetings (which are MFIs measures to address ex-ante moral hazard).

Furthermore, some farmers grow crops in areas prone to unpredictable risks, such as droughts or floods, which are likely to affect production and thus, loan recovery ([Miranda and Vedenov, 2001](#)). Even though it is considered that if microcredits are offered and insurance would help address the problem ([Farrin and Miranda, 2015](#); [Karlan et al., 2014](#)), it remains unclear because studies on that matter remain limited. Therefore, as MFIs continue to expand their operations to rural areas, it remains essential to examine the impact of their services on crop production and farmers' livelihood.

1.1.2 Mechanization

Agricultural production in Sub-Saharan Africa (SSA) has mostly continued to rely on manual and animal power, as mechanization in the region remains to be the lowest in the world. The past government-sponsored initiatives to promote mechanization, particularly tractors in the 1960s and

1970s, failed to materialize due to the lack of adequate demand and poor management ([Pingali, 2007](#)). In the past three decades, however, the interest in mechanization began to emerge again in SSA partly due to the rise of global food prices in the late 2000s and the increase of new suppliers of machinery and repair services ([Cossar, 2019](#); [Kirui and Braun, 2018](#)). Reflecting on the past failure of the government-led initiatives, recent attempts of agricultural mechanization emphasize the importance of private sectors ([Diao et al., 2020](#); [Kormawa et al., 2018](#)).

Despite this growing attention, the literature on agricultural mechanization in SSA remains relatively scant, and two empirical questions require a thorough investigation. First, conditions under which agricultural mechanization occurs among small-scale farmers are not broadly investigated. Several studies have argued that the potential demand for agricultural machinery is becoming high even in SSA ([Adu-Baffour et al., 2019](#); [Houssou et al., 2013](#); [Takeshima et al., 2013](#)). However, only a few rigorous empirical studies examine the determinants of the use of agricultural machinery among small-scale farmers ([Diao et al., 2014](#); [Takeshima and Lawal, 2018](#)).

Second, it remains unclear how mechanization can be beneficial to smallholder farmers. Mechanization of land preparation activities is considered to have the potential of expanding the household's cultivated area (extensification). Previous studies suggest that mechanization can lead to the extensification of farming area ([Pingali, 2007](#); [Pingali et al., 1987](#)). On the other hand, [Takeshima et al. \(2013\)](#) found that mechanization leads to extensification in northern Nigeria but not in the south.

Mechanization is also expected to affect land productivity (intensification) and labor productivity. Several studies have attempted to examine the effects of mechanization in SSA on land and labor productivity, but their findings are far from being conclusive. For example, some studies found that mechanization reduces labor demand and positively affects labor productivity ([Berhane et al., 2017](#); [Mano et al., 2020](#)). Furthermore, it is argued that mechanization induces intensive application of chemical fertilizer and other yield-enhancing agronomic practices, resulting in high

land productivity ([Adu-Baffour et al., 2019](#); [Baudron et al., 2019](#); [Mano et al., 2020](#)). On the other hand, other studies could not find distinguishable effects of mechanization either on labor productivity ([Adu-Baffour et al., 2019](#); [Houssou and Chapoto, 2015](#); [Kirui, 2019](#)) or land productivity ([Benin, 2015](#); [Berhane et al., 2017](#); [Houssou and Chapoto, 2015](#); [Kirui, 2019](#)). These studies, however, examine the association rather than causal relationships, adding to the importance of rigorous analyses on the effects of agricultural mechanization. It should also be noted that comparison between small- and large scale-mechanization is missing in the previous literature. Given that the promotion of small-scale mechanization is becoming popular in the policy debate, it is important to investigate if there are any differences in the impact of small-scale and large-scale mechanization on land and labor productivity ([Kormawa et al., 2018](#)).

1.2 Objectives and significance of the study

To examine the role of microcredit and mechanization, this study focuses on lowland rice cultivation. This is because, among major staples grown in SSA, rice is increasingly becoming the most important crop in SSA. Its demand has been growing rapidly, mainly due to urbanization and consumer preferences towards rice. The rice consumption in SSA increased threefold, from 9.2 million metric tons of milled rice in 1990 to 31 million metric tons in 2018 ([USDA, 2020](#)). Currently, rice is the second-largest source of caloric intake after maize, and its consumption will increase further due to rapid urbanization in SSA, which has resulted in a shift in consumer preference in favor of rice.

Besides, most of the countries in SSA relies on both domestically produced and imported rice from Asia. As the demand continues to increase, countries in SSA are advised to reduce their dependence on imported rice ([Larson et al., 2014](#); [Larson and Otsuka, 2016](#)). Because as the wage rates in Asian countries continue to increase rapidly, rice production costs will also increase, particularly labor costs, resulting in high rice imports from Asia. In efforts to improve

rice production in SSA, technologies such as high-yielding modern varieties originated in Asia, transplanting in rows, and improved agronomic practices have been introduced. Studies that examined how new technologies are being disseminated and adopted reveals that adopters were able to increase rice yield, suggesting the possibility of the rice Green Revolution in SSA ([Nakano et al., 2018a,b](#)).

1.2.1 Objectives

The main objective of this study is to explore the role of microcredits and mechanization on improving rice productivity using data collected in Tanzania, one of the major rice-producing countries in SSA. Specifically, this study aims to:

- (i) Assess rice technologies promoted in Tanzania and their recent adoption trend.
- (ii) To evaluate the impact of microcredit on: (a) the adoption of rice technologies; (b) rice productivity; (c) overall household income.
- (iii) To examine the effects of mechanization on: (a) the expansion of area under rice cultivation; (b) land productivity; and (c) labor productivity.

1.2.2 Significance of the study

This study aims to contribute to the literature on rice cultivation in SSA in two ways. First, to evaluate the impact of microcredit using RCT data. As explained earlier, only a limited number of studies rigorously examine the impact of microcredit on agricultural production. To the author's knowledge, the only two studies that examine the direct impact of microcredit on agricultural technology by using RCT are [Hossain et al. \(2019\)](#) conducted in Bangladesh and [Beaman et al. \(2013\)](#) in Mali, who found a positive impact on the input use but little or no impact on income. Unlike the previous microcredit studies, this study is unique because: (i) it examines the impact of

microcredit not only on modern inputs such as chemical fertilizer and improved modern varieties, but also on the improved agronomic practices; and (ii) the microcredit intervention in the RCT was specifically designed to match the income distribution of the agricultural household as we will explain later.

The second contribution of this study is to examine the role of mechanization on rice production. In many countries in SSA, strategies for the transformation of the rice sector primarily focus on the adoption of biological and chemical technologies, which led to an increasing number of studies that examine their impacts, while studies on mechanization in SSA remain scant, despite the recent increase in the use of four-wheeled tractors and power tillers among rice farmers.

In this study, we investigate under what conditions agricultural mechanization among small-scale farmers occur. A seminal work by [Pingali et al. \(1987\)](#) argues that mechanization is the sequential process that occurs as the population density increases and the expansion of the cultivated area becomes necessary for food production. If this is true, agricultural mechanization will occur where the population density is high. On the other hand, the theory of induced technological innovation developed by [Hayami and Ruttan \(1985\)](#) argues that new technology would emerge to save a factor of production that becomes scarce and whose price increases. This theory suggests that agricultural mechanization would occur where labor is scarce either because of low population density or increased labor demand in the non-agricultural sector and thus predicts that the mechanization occurs in the area with low population density.

Furthermore, we contribute to the debate regarding whether agricultural mechanization contributes to the extensification or intensification of agricultural production. Specifically, we separately estimate the impact of TRs, PTs, and draft animal use. As far as the author knows, only [Mano et al. \(2020\)](#) directly examine the impact of mechanization on rice production, using the cross-section data collected in Cote d'Ivoire. In their study area, draft animals' use is not common due to the prevalence of trypanosomiasis (sleeping sickness). They found that rice farmers who

use tractors for land preparation apply fertilizer more intensively and use more labor to implement proper agronomic practices carefully, and therefore raising productivity. In contrast to Cote d'Ivoire, trypanosomiasis has been largely eliminated in many parts of Tanzania (Franco et al., 2020), making it possible for draft animals to be widely used in rice production as in tropical Asian countries.

Therefore, unlike Mano et al. (2020), this study: (i) examines the role of mechanization by using a three-year panel data, allows us to control for household-level unobserved heterogeneity; (ii) covers farmers growing rice in both irrigated and rainfed lowlands; and (iii) take into different tillage options available for rice farmers, including handheld tools such as hand hoe, draft animals, four-wheeled tractors and power-tillers.

1.3 Data Sources

The study uses data from multiple sources to address each of three specific objectives. The study uses a three-year panel data collected during extensive rice household surveys (ES) in Tanzania in 2009, 2012, and 2018 to assess rice technologies promoted in Tanzania and their recent adoption trend. The data sets of the first two rounds of surveys were acquired from Nakano Yuko (Ph.D.)¹ who conducted the surveys as the part of JICA Research Institute's project, namely An Empirical Analysis of Expanding Rice Production in Sub-Sahara Africa. The author conducted the last round of the survey in 2018 under the same project. Each survey covered 76 villages that were randomly selected from six districts of three regions, namely Mbeya, Morogoro and Shinyanga. The regions represent three major rice agro-ecological zones, and the data set is therefore considered to be the national representative on the state of rice cultivation in Tanzania.

To evaluate the impact of microcredit, we use data collected in two irrigation schemes,

¹Nakano Yuko (Ph.D.) is the Associate Professor at the Faculty of Humanities and Social Sciences, University of Tsukuba. Along with the academic advisor, their invaluable contribution and support to this study are highly recognized as mentioned in the acknowledgment.

namely Ilonga and Chanzuru in Morogoro region. Three rounds of household surveys were conducted there in 2010, 2011, and 2012. The baseline information was collected in 2010. Another survey was conducted in 2011 along with the implementation of microcredit intervention, and the endline survey was carried out in 2012. The complete data set was acquired from Nakano Yuko (Ph.D.), but the author visited the study sites in 2016 to conduct the focus discussion with some of the studied farmers, village representatives, and officials of the microfinance institution which collaborated in the intervention. Although the data set is in the panel structure, our analyses mainly use the 2012 observations while controlling for baseline household characteristics.

Furthermore, we use a part of ES data to examine the effects of mechanization because some areas do not use mechanization or do not use mechanization to a large extent. Therefore, we only use data from 34 villages located in three districts: two in Morogoro region and one in Mbeya region. In each chapter, we offer detailed information regarding sampling strategy and the number of observations.

1.4 Definitions of selected terminologies

1.4.1 Microfinance and microcredit

The definition of microfinance has been changing over time to include services that were not part of it when it started as a series of small-scale lending experiments in the villages of Bangladesh in the 1970s. [Ledgerwood \(1999\)](#) defines microfinance as a development approach that provides financial and social intermediation. Financial intermediation includes the provision of savings, credit, and insurance services, while social intermediation involves group formation, development of self-confidence, training in financial literacy, and management capabilities among members of a group.

[Robinson \(2001\)](#), defines microfinance as the small-scale financial services (primarily credit and savings) provided to people who farm or fish or herd; who operate small enterprises or micro-

enterprises where goods are produced, recycled, repaired, or sold; who provide services; who work for wages or commissions; who gain income from renting out small amounts of land, vehicles, draft animals, or machinery and tools; and to other individuals and groups at the local levels of developing countries, both rural and urban. The definition by [Karlan et al. \(2011\)](#) refers to microfinance as the provision of small-scale financial services to people who lack access to traditional banking services. In their definition, they added that microfinance implies a very small amount of loans provide to low-income clients for self-employment, often with the simultaneous collection of small amounts of savings.

In this study we defines microfinance as the institution providing a wide range of small-scale financial services to people who lack access to traditional banking services. These services include but are not limited to collateral-free microcredits, micro-savings, and microinsurance. Institutions that provide such financial services are known as microfinance institutions (MFIs), which may also offer other services as a part of their initiatives of improving the ability of its clients to utilize financial services. We also define microcredit as a small number of loans for entrepreneurial activities to people who lack access to services offered by traditional financial institutions such as commercial banks.

1.4.2 Agricultural mechanization

Agricultural mechanization is defined by [Kormawa et al. \(2018\)](#) as the manufacture, distribution, and operation of all types of tools, implements, machines, and equipment for agricultural land development and farm products for harvesting and primary processing of agricultural produce. This study focuses on the first stage out of six stages of agricultural mechanization (as shown in Table 1.1) and defines mechanization as the process under which mechanical power (tractors) are applied to perform land preparation activities, as a substitute of human power and draft animal power. Human power refers to applying tools and implements such as hand hoe, which use human

Table 1.1: Stages of agricultural mechanization

Stage	Description	
Stage 1:	Power substitution.	draft animal power substituting human power, or mechanical power substituting human and draft animal power.
Stage 2:	Mechanization of the human control functions.	Activities such as hand weeding are replaced by mechanized weeding. Or manual rice threshing and winnowing are replaced by the combined harvester, etc.
Stage 3:	Adaptation of the cropping system to the machine.	For example, transitioning from broadcasting of seeds to mechanized in-rows transplanting, which suits criteria for subsequent operations that are also performed by machines, such as weeding and harvesting.
Stage 4:	Adaptation of the farming or livestock system to facilitate mechanization.	In this stage, the entire production environment are adjusted to suit the use of advanced mechanization. For farming systems, this may include land clearance to facilitate the use of large farm machinery, mono-cropping and crop rotation, and minimum tillage or zero tillage.*
Stage 5:	Adaptation of crops or livestock to the mechanization system.	Involves plant and animal breeding to facilitate mechanization of production activities. For example, rice breeding to allow easy threshing during harvesting, or fruits breeding to allow easy peeling during processing.
Stage 6:	Automation of agricultural production.	The highest level of agricultural mechanization which is also part of precision agriculture. In this stage, many production operations (e.g., feeding animals, fertilizer and herbicides applications) are automated.

Source: Adapted from [Kormawa et al. \(2018\)](#).

* For zero tillage at this stage, no farm implements are used to turn over the soil. Instead, weeds and/or purpose-planted cover crops are controlled by the application of desiccant herbicides before planting. A specialized planter or seed drilling machine cuts through the desiccated cover and residues accumulated on the soil surface, slotting seed (and fertilizer) into the soil with minimal disturbance.

muscles as the main power source, while draft animal power refers to implements and equipment powered by oxen. The use of tractors to perform farm activities is referred to as tractorization, thus it is associated with the use of any type of tractor to perform land preparation activities. The study also categorizes tractors into two groups, regardless of their power rating. These groups are

(i) Four-wheeled, two-axle tractor (denoted as TR); and (ii) Single axle, two-wheel tractor, also called power-tillers (denoted as PT).

1.5 Structure of the thesis

The rest of this thesis is organized as follows. Chapter 2 offers general information about Tanzania, agriculture sector and gives a brief overview on rice production and consumption in the country. Chapter 3 gives a detailed discussion on rice technologies that are being promoted and how they are adopted in major rice-growing areas across the country. Chapter 4 focus on the impact of microcredit on the adoption of rice technologies, productivity, and overall household income. The impact of mechanization on rice production is presented in Chapter 5 followed by a general conclusion in Chapter 6.

Chapter 2.

Tanzania: Country profile, agriculture sector and rice cultivation

2.1 Country profile

Tanzania is located in East Africa, bordering Uganda and Kenya in the north, Indian Ocean in the east, Mozambique, Malawi, and Zambia in the south, and Democratic Republic of Congo (DRC), Rwanda and Burundi in the west. The country's capital city is Dodoma. Tanzania is the union of Tanganyika (referred as mainland) and Zanzibar which consists of two islands in the Indian ocean, namely, Pemba and Unguja (Figure 2.1). The country has a land area of 881,289 square kilometers (km²) in the mainland and 2,460 km² in Zanzibar. The additional area of about 59,100 km² is covered by lakes. The physical terrain comprises plains along the coast, a plateau in the central area, and highlands in the north and south. The northern highlands consist of Mount Kilimanjaro (the tallest mountain in Africa with an elevation of 5,895m) and Mount Meru (4,565m). Southwards is the central plateau reaching elevations above 2,000m.

The climate varies from tropical along the coast to temperate in the highlands. There are two types of rainfall distribution: The “unimodal” type, where rainfall is usually from October or November to April, found in the central, southern, and southwestern highlands; The “bimodal” type, is distributed into two seasons: the short rain season (*Vuli* rains) fall from October to December, while the long rains season (*Masika* rains) fall from late mid-February to June. This type occurs in the coastal areas, the northeastern highlands, and the Lake Victoria zone. In most of the regions, the annual rainfall varies from 500mm to 1,000mm. However, the northeast of the Lake Tanganyika basin and the Southern Highlands have the highest annual rainfall of 1,000mm to 3,000mm. Zanzibar and the coastal areas are hot and humid, where the average daily temperatures are around 30°C. October–March is the hottest period. Sea breezes, however, moderates the

region's climate. June–September is the coldest season, with the temperatures falling to 25°C in coastal areas. In the northern regions around Kilimanjaro, temperatures vary from 15°C in May – August to 22°C in December–March.



Figure 2.1: The map of Tanzania showing its administrative regions

Source: Author, 2020

Note: In 2016, Mbeya region was divided to form Songwe region and Mbeya region. The GIS data of the border between two regions are not yet available disclosed to public.

Like most of the countries in SSA, Tanzania has high rates of population growth. Between 1990 to 2012, the population grew at 2.9 percent annually (IFAD, 2015). According to the national

census of 2012, the population was 45 million and is estimated to reach 100 million by 2050 (PHC, 2012). In the past decades, urban growth continues to grow steadily, but a large part of the population (70 percent in 2012) still lives in the rural area. The average population density is 56 inhabitants/km², with the vast majority of the population living inland, than coastal area.¹ Dar es Salaam has the largest urban population of 4.3 million in 2012, followed by Mwanza (2.7 million), and Arusha (1.6 million).

Tanzania was ranked 152th out of 187 countries in the 2013 Human Development Index (UNDP, 2016). The average life expectancy at birth improved over the years up to 59 years in 2012 compared to 50.6 in 1990. The maternal mortality rate was at 460 per 100,000 live births, and the under-five child mortality rate at 54 per 1,000 live births. Regarding Sustainable Development Goals (SDGs), the country is doing well in addressing eight out of 17 goals, which are goal number 2 (zero hunger); 3 (good health and well being); 4 (quality education); 5 (gender equality); 6 (clean water and sanitation); 8 (decent work and economic growth); 10 (reduced inequality) and 16 (peace, justice, and strong institutions) (United Nations, 2020).

The large part of Tanzania's economy depends on services and agriculture (Figure 2.2). In the past decade, Tanzania has sustained relatively high economic growth. According to official statistics from NBS (2019) annual GDP in has been growing at an average rate of 6.7 percent from 2014 to 2019. Inflation has declined from 5.6 percent in 2015 to 3.4 percent in 2019. In 2018, the basic needs poverty rates declined from 35 percent in 2000 to 26.4 percent in 2018. Although the country's poverty rate has declined, the absolute number of poor citizens has not, primarily due to the high population growth rate.

¹Tanzania conducts Population and Housing Census (PHC) once in every 10 years. The last census was conducted in 2012, and the next one is scheduled in 2022. Therefore, most of the available data on population and demographics are based on the 2012 census.

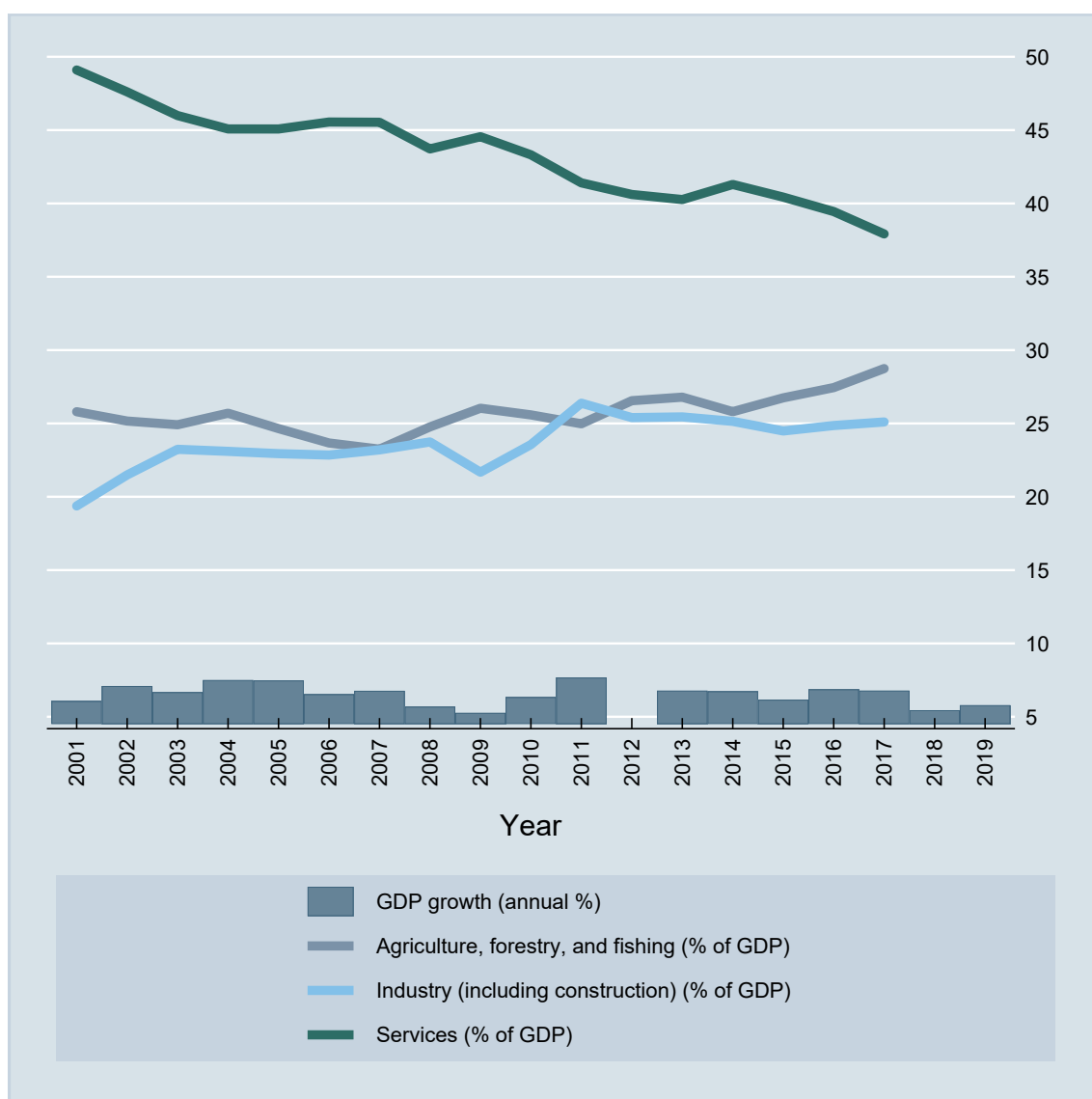


Figure 2.2: Contribution of Agriculture, Industry and Services to GDP
Source: Author, 2020

2.2 An overview of agriculture sector

Tanzania is referred to as a dual-agricultural economy consisting smallholder subsector and the commercial/large-scale. In 2012, 70 percent (31 million) of Tanzania's population was living in the rural area with high dependence on agriculture for a large portion of their income (PHC, 2012). Smallholder farmers account for about 85 percent of the total area under cultivation. Out of the total land area, only 51 percent is suitable for crop cultivation; 21 percent is currently being

cultivated. About 85 percent of arable land is used by smallholders who cultivate about 0.2 ha of land; and agro-pastoralists who keep an average of 50 heads of cattle. It is estimated that the average landholding per capita is only 0.12 ha.

Although large part of the population is employed in agriculture, the sector's contribution to countries economy is the second after services. In the past five years, on average agricultural products accounted about 27 percent of total GDP (Figure 2.2), and nearly 23 percent of the total earnings from major exportable products (Table 2.1). In the past decade, the share of agriculture (including forestry and fishery) to GDP increased from 25.6 percent in 2010 to 28.7 in 2017. The increase is somehow contributed by the growing number of industries for processing primary products and improving market conditions.

Table 2.1: Major exports in (billion TShs) and the share of agricultural products

	2015	2016	2017	2018	2019
Coffee	309.7	224.2	282.4	334.5	351.0
Cotton	79.7	100.5	80.3	155.5	210.0
Sisal	340.2	32.3	57.7	73.7	79.9
Cashew nuts	497.3	756.9	1200.5	245.1	808.3
Cloves	5.9	22.5	121.2	0.8	20.9
Diamonds	65.6	164.3	143.0	185.2	185.9
Gold	2717.2	3072.7	3418.9	3452.7	5069.6
Tobacco	428.0	783.8	434.5	612.0	335.3
Tea	91.0	96.9	109.0	103.6	104.6
Total	4534.6	5254.1	5847.5	5163.1	7165.5
Share of agricultural products (%)	27.19	21.63	29.79	15.68	20.52

Source: [NBS \(2019\)](#).

Tanzania has adopted different policies and strategies to support agriculture development

and the livelihood of millions supported by the sector. The country shifted from the previous paradigm of Agricultural Sector Development Program (ASDP) of 2005 to focus on specific geographical areas rather than on the entire territory and on specific commodities rather than on the whole sector.

In the past decade, two major initiatives are Southern Agriculture Growth Corridor of Tanzania (SAGCOT) launched in 2010, and the Big Results Now (BRN) in 2013. SAGCOT is a part of Agricultural Growth Corridors (AGC), a wider strategy for achieving Africa's Green Revolution. The basic idea of the AGC is to catalyze the development of rural areas by fostering sustainable agricultural development through value chains by (i) forming agricultural clusters alongside the existing roads and railways infrastructures; (ii) establishing transformable public-private partnerships; and (iii) using catalytic financing to attract capital from domestic and international, public and private sources. BRN followed the example of a program that was implemented by the Malaysian government. It focused on six priority areas: energy and natural gas, agriculture, water, education, transport, and mobilization. BRN had specific goals for agriculture, and it focused on maize, rice, sugarcane. It aimed to commercialize the agricultural sector by 2025 to ensure national self-sufficiency and food security. However, the program was discarded in 2015, after the new president came into power.

2.2.1 Crop and livestock sub-sectors

Crop subsector

Farmers in Tanzania grow three groups of crops: staple crops such as maize and rice; high-value crops such as fruits, vegetables, and flowers; and traditional bulk export crops such as coffee, cashew nut, tea, cotton, tobacco, and sisal. The domestic demand for high-value crops and traditional bulk export is relatively weak because of low-income and less-developed manufacturing sectors. Some of the cash crops, such as coffee (marketed as Kilimanjaro Coffee) and cashew

nuts, are performing moderately in the world market, but their share is relatively small. Major food crops are maize, rice, sorghum, millet, cassava, sweet potatoes, bananas, pulses, and wheat. Tanzania prioritizes three staple crops: maize, rice, and cassava due to their demand. These crops account for about 54 percent of cultivated area.

Table 2.2: Production of selected food crops in Tanzania mainland (2015-2019)

Crop	2015	2016	2017	2018	2019
Maize ('000 tons)	5,903	6,149	6,681	6,273	5,652
Paddy ('000 tons)	1,937	2,229	1,594	2,220	2,063
Wheat ('000 tons)	72	76	50	57	63
Sorghum ('000 tons)	1,007	1,003	1,064	988	1,117
Cassava ('000 tons)	1,962	2,205	1,342	2,791	2,728
Beans/Legumes ('000 tons)	1,808	1,959	2,318	1,823	1,888
Bananas ('000 tons)	1,195	1,061	845	1,132	1,135
Sweet potatoes ('000 tons)	1,090	1,044	2,008	1,608	1,644
Cotton (tons)	203,312	149,445	164,709	222,039	352,405
Tobacco (tons)	87,737	60,692	85,861	45,245	68,147
Sugar (tons)	304,007	293,075	556,522	303,752	359,219
Tea (tons)	35,750	32,629	41,495	34,010	37,193
Chrysanthemum (tons)	6,050	2,011	2,151	2,400	2,014
Coffee (tons)	41,674	60,921	47,693	50,522	79,087
Sisal (tons)	39,204	42,314	36,533	40,635	33,271
Cashew nuts (tons)	197,933	155,416	265,238	313,826	225,053

Source: [NBS \(2019\)](#)

Tanzania has achieved self-sufficiency in grain production in some years, including 2011, when the country produced between 5 to 19 percent more than national aggregate food requirements for basic cereals (i.e., rice and maize) ([MAFC, 2014](#)). However, it remains unknown

whether such periodical self-sufficiency is because of an increase in grain's total production, productivity, or reasons related to trade policies such as export ban for maize and rice.² Food export ban in Tanzania and other countries in SSA are usually driven by domestic production shortfalls or high prices in international or neighboring countries' markets. In most cases, farmers or crop traders are unlikely to benefit from such measures but more evidence on this issue is needed. For example, the export ban imposed in 2008 was reported to cause price depression and farmers' incomes (Diao et al., 2016). Another trade incident that significantly led to the depression of paddy price is the duty-free policy for rice imported from Asia in 2012. The policy was in response to reportedly low-levels of domestic rice production. It turned out that the policy was based on wrong estimates and agents responded by exporting the rice imported from Asia to other countries in East Africa.

Livestock subsector

Regarding livestock resources, Tanzania is the third among countries with the largest livestock population in SSA after Ethiopia and North Sudan (NBS, 2017). According to 2017 estimates, there were about 30.6 million cattle concentrated in central regions of Tanzania (Figure 2.3). The livestock industry accounts for 3.8 percent of the GDP, 30 percent of it is derived from dairy products. Several measures have been implemented to improve animal health services, given a large proportion of livestock. However, the lack of commercialization limits the economic potential of the livestock industry. For example, it is estimated that only about 4 percent of cow milk produced goes through formal processing (IFAD, 2015).

² Tanzania has periodically imposed an export ban on major staple crops, especially on maize, since the 1980s. The earliest was imposed in the 1980s and remained active until it was lifted in 1999. It was later succeeded with another ban imposed in 2003 and lifted in January 2006 only for two months to allow cereal traders to sell their surpluses.

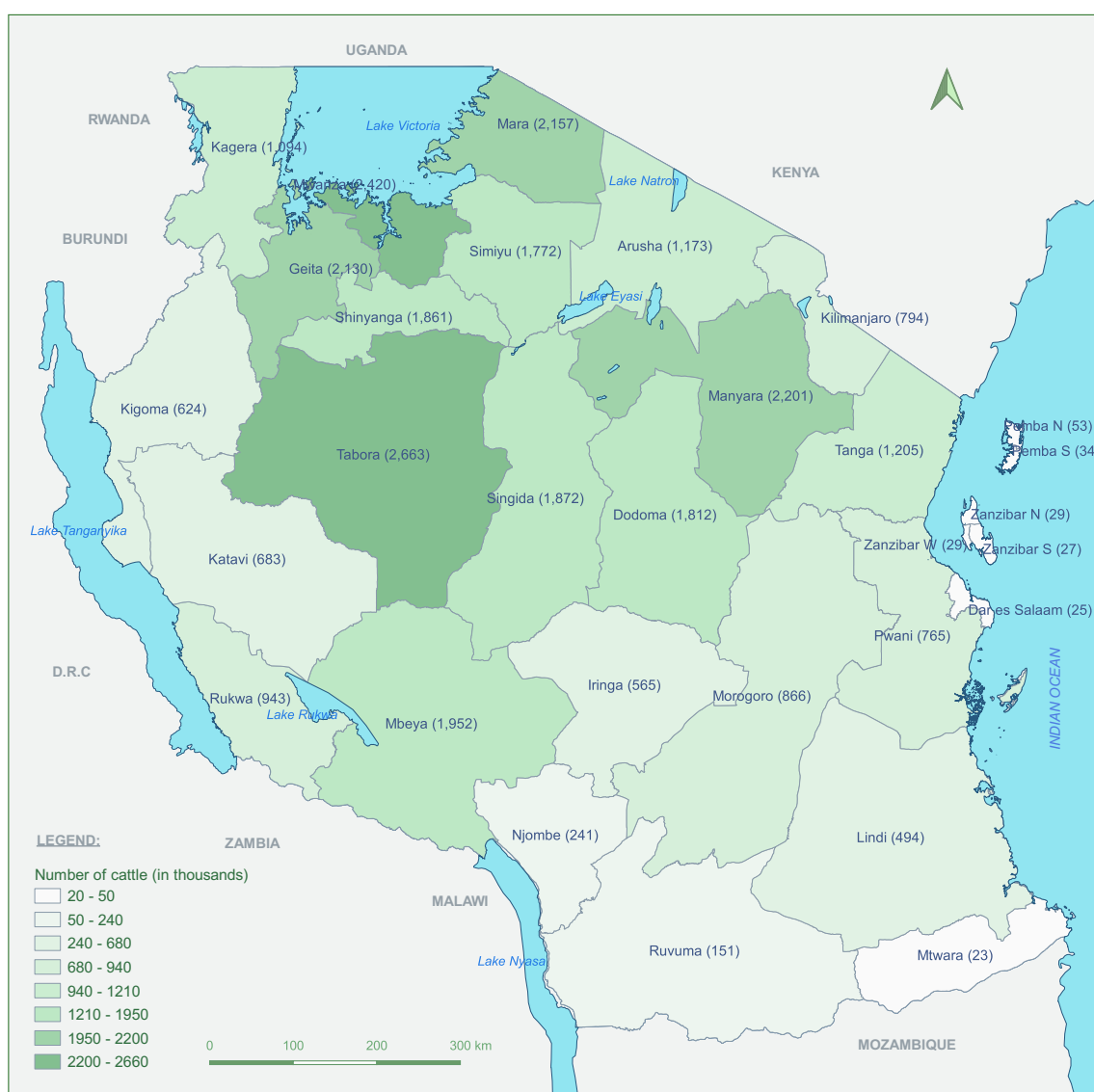


Figure 2.3: Cattle Population (in thousands) by Region in Tanzania (as of 2017)

Source: Author using data from [NBS \(2017\)](#)

2.3 Rice cultivation

Rice is the second most important crop after maize in terms of consumption and area planted. It is also the third food crop in terms of production volume, after maize and cassava. Rice area accounts for about 8% (nearly 1.4 million hectares) of the total area under cultivation in the country. It is grown by nearly 17% of agricultural households and it is among the major sources of income and employment in rural areas. As a commodity, rice is less formalized commercially,

with smallholder farmers accounting large part of production.

Rice is mainly cultivated in three agro-ecological zones, namely the Eastern Zone, the Southern Highland Zone and the Lake Zone. Major rice producing regions in each zones are Morogoro and Pwani (Eastern Zone), Tabora and Shinyanga (Lake Zone) and Mbeya (Southern Highlands Zone). Historically, rice has been cultivated in these regions for many years, but in recent years, the number of rice-growing regions has increased. For example, during 2017, about

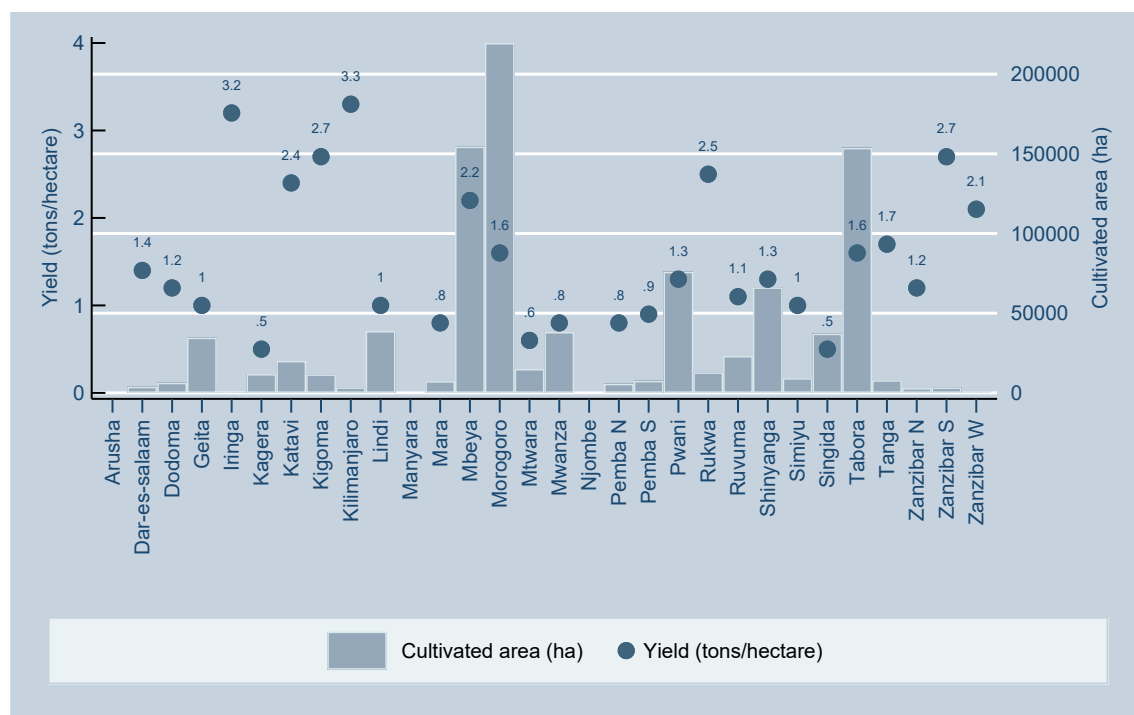


Figure 2.4: Area under rice cultivation and yield by regions (2017)

Source: Author using data from [NBS \(2017\)](#)

954,000 hectares across the country was under rice cultivation (Figure 2.4). Morogoro, Mbeya and Tabora had the largest area share. The average paddy yields in many region were below 2.5 tons per hectare, and regions that reported higher yield are those with small areas under cultivation. Most of rice in Tanzania is produced in five regions Morogoro, Mbeya, Tabora, Pwani and Shinyanga. In 2017, the five regions produced a total of 966,470 tons of paddy, equivalent to 70% of the total production at country-level (see Figure 2.5).



Figure 2.5: Total paddy production by region (2017)

Source: Author using data from [NBS \(2017\)](#).

* denotes data withheld to avoid disclosing data for individual operation. - denotes insufficient data.

2.3.1 Production and consumption trend

Unlike many countries in SSA, most of rice consumed in Tanzania is produced domestically, thus increasing its production volume is highly prioritized. This is because rice demand is expected to increase along with the population growth, improvement of economic conditions, and increased urbanization. These factors are expected to cause changes in consumption patterns towards rice. Furthermore, while rice demand gap could be met through import, there is a concern about the

foreign currency drain, because of poor trade balance. Therefore, Tanzania aims to attain rice self sufficiency to avoid the foreign exchange loss and the influence of unstable global market on local rice prices. In addition, not all countries in SSA can produce rice (Otsuka and Kijima, 2010), there is an opportunity for exporting surplus in the regional market.

Production trend

Rice production trend is presented in Figure 2.6. It shows the low production between 1960s and 1970s, with a slight increase from 1980 to late 1990s. From 2000 onward, there is a significant increase of the total production. Basically, the amount of rice produced follows a trend similar to the size of the cultivated area. Between 2003 and 2013, rice production doubled from 0.9 million tons of paddy to about 2.1 million tons. The cultivated area also increased from 0.62 million hectares in 2002 to 0.93 million hectares in 2013. This indicates that the increase in production depends largely on the increase in cultivated area, and not on the increase in productivity.

There are a number of factors that have led to an increase of cultivated area over time. Some of these factors include the introduction of rice farming in regions that previously did not grow rice, as well as new farmers who shifted from other crops and to rice farming.³ The sharp increase between in 2008 to 2011 might have been contributed by up-scaling of a fertilizer subsidy program (National Agriculture Input Voucher Scheme, NAIVS) which raised yields and production significantly. In 2000s there were several changes in agricultural policies that might have contributed to the upward trend in the following years. We discuss these initiatives in Section 3.2.

Consumption trend

Tanzania has the highest levels of rice consumption East Africa region, with per capita consumption averaging 25 kg, followed by Kenya with a per capita rice consumption of 9 kg. Per capital

³Ngailo et al. (2007) mentions that the increase in production between 2000 and 2005 might have been contributed by farmers who shifted from cotton after experiencing significant loss due to decline in world's cotton prices.

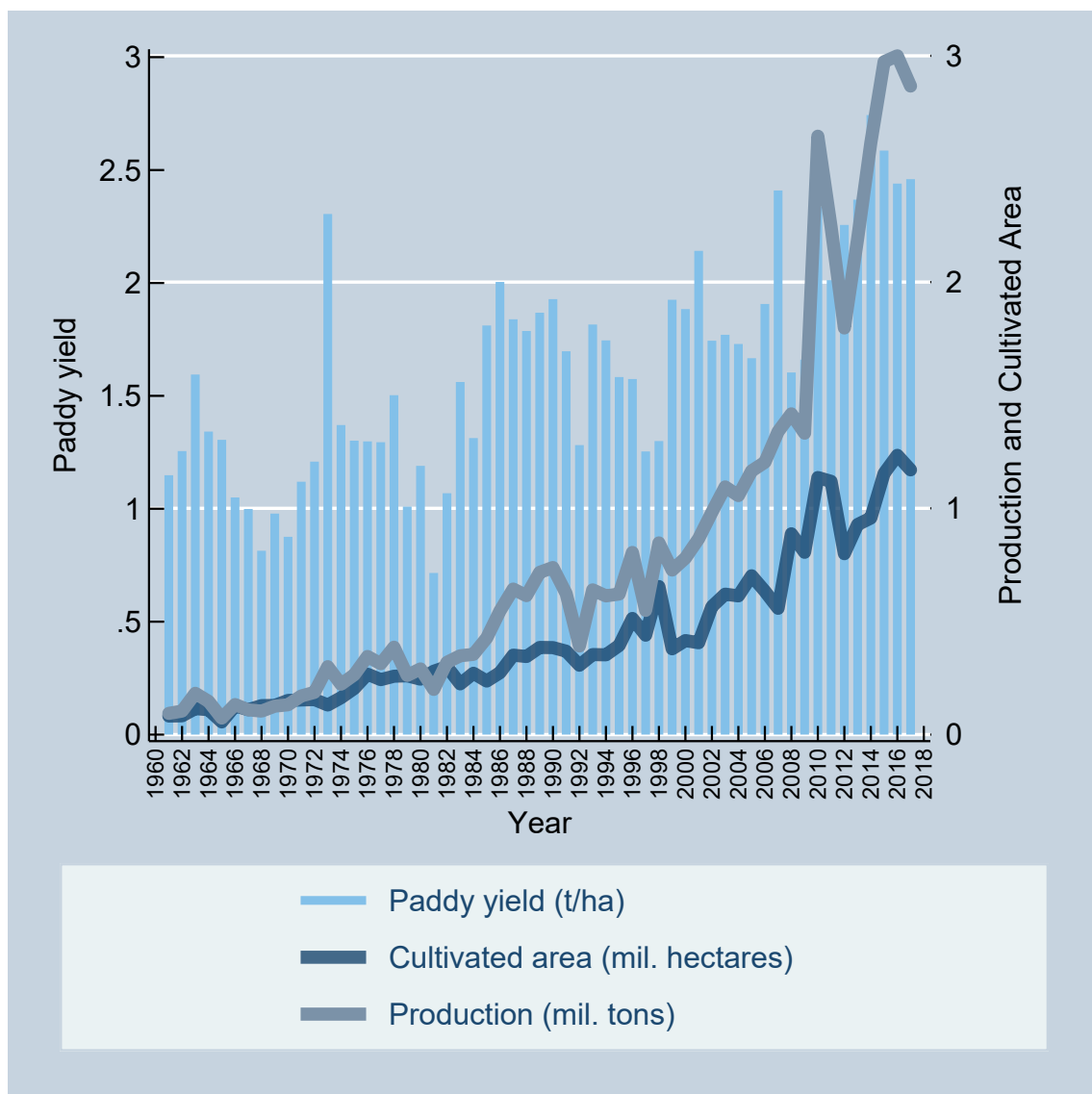


Figure 2.6: Rice Production Trend in Tanzania (1961-2017)

Source: Author using data from [FAO \(2020\)](#)

consumption increased by more than 26%. In comparison with other staple crops, it is estimated that the average consumption is about 200.21kcal per capita per day. That makes rice the third source of caloric intake after cassava (208.57 kcal/capita/day) and maize (553.96kcal/capita/day). However, the consumption pattern is different for rural and urban. Most of urban residents prefer rice over other staples, possibly because of their busy lifestyle and relatively high levels of income. Dar es Salaam city and its surrounding suburban areas are the major market of rice, accounting

about 60% of the national consumption. Mbeya and Morogoro regions are the main supply sources for Dar es Salaam market, while Tabora and neighboring regions are the main supply sources for Mwanza market.

Although Tanzania can meet most of the demand for rice depending on domestic production, it still imports a small amount from Pakistan, Thailand, and other countries. For some years, it also export rice to neighboring countries such as Kenya, Uganda, and Rwanda, where Tanzanian rice is highly prized for its aroma. But this measure is highly dependent on the level of production.

Table 2.3: Rice Production, Supply and Distribution (2018 - 2020)

	2017/18	2018/19	2019/2020
Area Harvested ('000 hectares)	1200	1200	1205
Production ('000 tons of paddy)	3100	3100	3106
Production ('000 tons of milled rice)	2046	2046	2050
Imported ('000 tons)	260	230	250
Total supply ('000 tons)	2306	2276	2300
Exported amount ('000 tons)	40	50	40
Total consumption ('000 tons)	2266	2226	2260

Source: [NBS \(2019\)](#)

2.4 Conclusion

In this chapter, we highlighted Tanzania's general profile and role of agriculture sector to the country's economy. We have also highlighted the importance of the rice sub-sector in ensuring food security. According to macro statistical data, rice production has been increasing over the years. The amount of rice produced in Tanzania doubled in the period between 2003 and 2013. But the increase has been largely contributed by an increase of the total area under rice cultivation rather than productivity.

Chapter 3.

Rice technologies and adoption trend

3.1 Introduction

This chapter discusses efforts to improve rice production in Tanzania, explicitly highlighting technologies recommended to rice farmers in Tanzania and how they are adopted. We descriptively show the country's adoption pattern, using country representative data collected from 76 villages in three agro-ecological zones. Section 3.2 highlights efforts to improve domestic cereal production, including rice, followed the discussion on types of technologies in Section 3.3. Section 3.4 descriptively shows how adoption patterns have changed over time, followed by chapter conclusion in Section 3.5.

3.2 Efforts to improve domestic cereal production

Efforts of promoting rice production and maize began in the early 1960s after Tanzania received its independence, but there have been several variations over time to adapt to the changing economic environment. From 1967 to 1980s was the period of nationalization of private sectors, where industry and agricultural market including fertilizer importation and distribution were run by government (Coulson, 1982). Following the economic crisis of the 1980s, efforts to revive Tanzania's economy started in 1986, involving several economic reforms such as liberalization of prices and foreign exchange rate, ending state monopolies, agricultural market liberalization, and privatization. During the reforms, fertilizer subsidy programs remained but were phased out between 1991 to 1994, causing a decline in fertilizer consumption (Putterman, 1995).

In the early 2000s, other initiatives that positively contributed to domestic rice production, including the Comprehensive Africa Agriculture Development Program (CAADP). Africa's Heads of State declared CAADP in 2003, and it aimed at reducing food insecurity by increasing support

to agriculture from 5% up to 10% of states' annual budgets and other measures. To meet targets set by the CAADP framework and further development agenda, the government attempted to reduce the cost of fertilizer acquisition in eligible remote regions by introducing the fertilizer transport subsidy. Under the program, the government managed the physical flow of fertilizer introduced fixed margins and prices to ensure support reached the farmers. The program stayed active from 2003 to 2007. Similar to previous government-controlled input programs, many criticized the fertilizer transport subsidy for discouraging private sector participation, lack of transparency, limited outreach, and adding a burden on the government's budget.

Therefore, in 2008 the government introduced the National Agricultural Input Scheme (NAIVS), which took a different approach from the preceding programs. NAIVS was targeted to smallholder farmers who are cultivating not more than 1.0 hectare of land. However, the priority was given to female-headed households and households that did not use any or little fertilizer and improved seeds for targeted crops over the past five years. The difference of NAIVS from the previous interventions include: (i) NAIVS intended to stimulate the private sector, rather than to displace it; (ii) NAIVS program had only selected farmers in selected districts; (iii) NAIVS offered three input vouchers, which are one for a bag of UREA, one for a pack of DAP/*Minjingu*, and one for improved maize or rice seed. Voucher worth 50% of price, so 50% co-financed by farmers (MAFC, 2014). NAIVS program was operating at high costs, which brought questions about its feasibility for continuation. In 2014 the Ministry of Agriculture announced suspended the NAIVS and proposed introducing a subsidized credit scheme.

Additional initiatives by international organizations such as the Japan International Cooperation Agency (JICA) offered rice training to farmers across the country. JICA also worked with local experts to create the national rice strategy. Even though these efforts have successfully contributed to the increased interest in rice production, the adoption of modern varieties, and improved agronomic practices such as transplanting, the average yield in Tanzania remains as low as

2.5 tons/hectare.

3.3 Rice technologies promoted in Tanzania

There is a total of thirteen rice technologies that are identified by the ministry of agriculture in Tanzania. The list include: (i) fertilizer responsive high-yielding modern varieties (MV); (ii) rice seed preparation; (iii) raising seedling in wet nursery bed; (iv) bund construction; (v) puddling; (vi) leveling; (vii) chemical fertilizer; (viii) transplanting in rows; (ix) weed control using cultural methods; (x) weed control using herbicides; (xi) water management; (xii) timely harvesting and timely threshing; and (xiii) processing machines (seed cleaning, destoning, dehusking, polishing and grading) ([Ministry of Agriculture, 2009a](#)).

Since traders and agricultural enterprises mainly process rice, the processing technologies are not primarily meant to be adopted at the household level. As we mentioned earlier, JICA deserves most of the credits for promoting most of these technologies by training extension officers and crop researchers working under the ministry of agriculture in Tanzania. This section discusses the most common technologies, which are fertilizer responsive high-yielding modern variety (MV), chemical fertilizers, and a selection of improved agronomic practices. Besides, some other improved agronomic practices are being taught to rice farmers during rice training but are not widely adopted. We summarize these practices together with weed management methods in Appendix.

3.3.1 Modern Varieties

Tanzania collects rice germplasm (genetic material) from the best performing and high-quality local varieties and stock obtained from other areas, including West Africa and Asia. By 2009, Tanzania had a stock of rice germplasm of about 400 genotypes collected within the country and IRRI, IITA, and WARDA ([Ministry of Agriculture, 2009b](#)). Even though there are some

cases when private seed companies import improved modern varieties from neighboring countries, domestically produced MVs are developed by crossing selected the local varieties with germplasm obtained from other regions. Therefore, only a few breeding programs pass field performance evaluations and yet, succeed in maintaining desirable quality preferred by the consumer in the rice market.

One of the successful cases is the lowland high-yielding variety TXD 306 released in 2001 and is currently marketed as SARO 5. The SARO 5 is a cross of one variety from Korea called *Subrimati* and a local variety called *Super*. SARO 5 was developed to increase rice productivity while partially maintaining local rice aroma and cooking quality, desirable characteristics preferred by most rice consumers. Some of the important features of SARO 5 include; (i) It can be grown in both rain-fed and irrigated ecosystems, but it performs better in the irrigated ecosystem; (ii) It has high tillering ability with a range of 30 to 50 tillers, which gives a high yielding potential to produce 8 to 10ton/ha at the research stations and 4 to 6.5ton/ha at farmer's field, while local varieties produce ten to fifteen tillers that give 1.8ton/ha; (iii) It takes 120 days to mature compared to local varieties that take up to 180 days; and (iv) It is semi-aromatic, characteristics that have led to its preferred by consumers than other high yielding imported varieties ([Ministry of Agriculture, 2009a](#)).

3.3.2 Chemical Fertilizer

Fertilizer recommendations tend to vary depending on varieties planted, soil nature, and agro-ecological zone. However, in general, it requires a combination of phosphate (P_2O_5) and nitrogen-based (N) fertilizers such as UREA for optimum rice growth. In livestock keeping areas, the use of livestock manure is common, but manure's bulkiness limits the application. Thus the applied amount is insufficient to meet the plant's nutrients requirement. For a farmer growing SARO 5 in the irrigated ecosystem, the recommended amount of fertilizer to deliver a high yield is 40kg/ha

of Phosphate and 80kg/ha of nitrogen-based fertilizer. Phosphate are basally applied before early crop establishment, which facilitates the early stages of root development. Nitrogen application (top dressing) should be applied in two rounds, which are 14 days and 35 days when the field water level is 3-5 cm. Topdressing fertilizers increases productive tillers, spikelets, and influences grain filling (large grain size) hence high quality and high yield.

3.3.3 Improved Agronomic Practices

Improved agronomic practices include farming techniques that have been proven to be effective in increasing productivity or in facilitating other production activities, such as weeding and harvesting. The highly recommended practices include:

Bund construction

Bunds are the soil structures constructed around the rice plot. Traditionally, bunds are made using hand hoes except for few places where draft animal power and modern agricultural machines like tractors and power-tillers are used. The purpose of bunds varies widely depending on the production environment. In irrigated lowlands, bunds have been proven to be effective in water management as they allow the paddy field to be flooded and dried depending on the plant's growth stage. They also play a role in preventing drainage of applied agrochemicals, resulting in loss of nutrients in the farm and contamination of water sources. In rainfed areas, farmers often use bunds to harvest rainwater. Since the amount of water harvested should be used for almost the entire cropping season, the size of bunds in rainfed areas tends to be higher and thicker than those in the irrigated area. However, there are some areas where bunds cannot be used. For example, farmers (in rainfed lowlands) who cultivate rice along the rivers often do not construct bunds. One of the reasons is their fields get water after the rivers overflow. Therefore, if there are bunds, it means that water will not enter the fields. Another possible reason is that depending on soil type

(e.g., clay or sand), bunds constructed along the river are likely to erode and eventually be washed away.

Leveling

This is the process of moving soil from raised to lower parts of the paddy field while making sure that the topsoil is evenly distributed. Leveling can be done manually using hand-hoes, spades, pulled-levelers, or mechanically using powered levelers or ox-pulled rectangular-shaped log of wood. Leveling facilitates uniform water and nutrient distribution in rice basins and allows even water distribution in paddy fields. Hence, it results in a consistent crop stand and maturity.

Transplanting in rows

This is usually done by using transplanting strings at a spacing of 20cm by 20cm. Transplanting if done with proper spacing, it results in optimum plant population/density and yield increase. Also, transplanted rice plants produce many tillers, which is an indicator that has a direct relationship with yield. Transplanting in rows also allows seedlings to compete for nutrients and moisture against weeds at their emerging stage. It also facilitates other crop management practices like weeding, fertilizers application, and harvesting.

Practices such as transplanting in rows and improved bunds¹, and leveling was already in use in Asia even before the Green Revolution in the 1960s. However, they started to be applied widely in Tanzania in the early 2000s following rice training programs conducted by JICA and the Ministry of Agriculture.

¹ Improved bunds are those constructed using the specified dimensions. Farmers were taught this technique during rice training are gradually becoming common in irrigated lowlands.

3.4 Adoption trend of key rice technologies in Tanzania

3.4.1 Study Site and Data

To descriptively show the adoption trend of rice technologies, we use household-level data during three rounds of extensive rice surveys (ES) in 2009, 2012, and 2018. The ES surveys were conducted in three rice growing zones, where one region was chosen from each zone. Chosen regions are Morogoro (Eastern Zone), Mbeya (Southern Highland Zone), and Shinyanga (Lake Zone). Therefore, we may regard that the resulted data set on rice cultivation as nationally representative. In each region, two major rice-growing districts were selected based on the amount of rice produced. These districts are Kilombero and Mvomero in the Morogoro region, Kahama and Shinyanga Rural in Shinyanga region, and Mbarali and Kyela in Mbeya region. Farmers in our sample grow rice in irrigated and rainfed lowlands. Therefore, sample villages were randomly selected based on the number of rice farmers growing rice in irrigated and rainfed. To facilitate the selection process, information from the 2002-2003 agricultural census were used in each region. In all three regions and six districts, a total of 76 villages were selected.

Within each village, ten rice-growing households were randomly selected, resulting in a total number of observations of 760 at the baseline survey conducted in 2009. Same sample households were revisited again in 2012 and 2018. We interviewed a replacement household if the original household at the baseline was missing in the following surveys. During data cleaning, we dropped outliers and some observations that had missing values in key variables. As a result, we obtained unbalanced, three-year panel data with the total number of 2,159 households. We asked farmers to identify the most important plot for rice production (hereafter called sample plot) and asked in detail about technological adoption, production costs, and rice productivity. In addition to household-level surveys, we also conducted interviews with village-leaders in all 76 villages. During these interviews, village leaders answered structured questions regarding rice cultivation

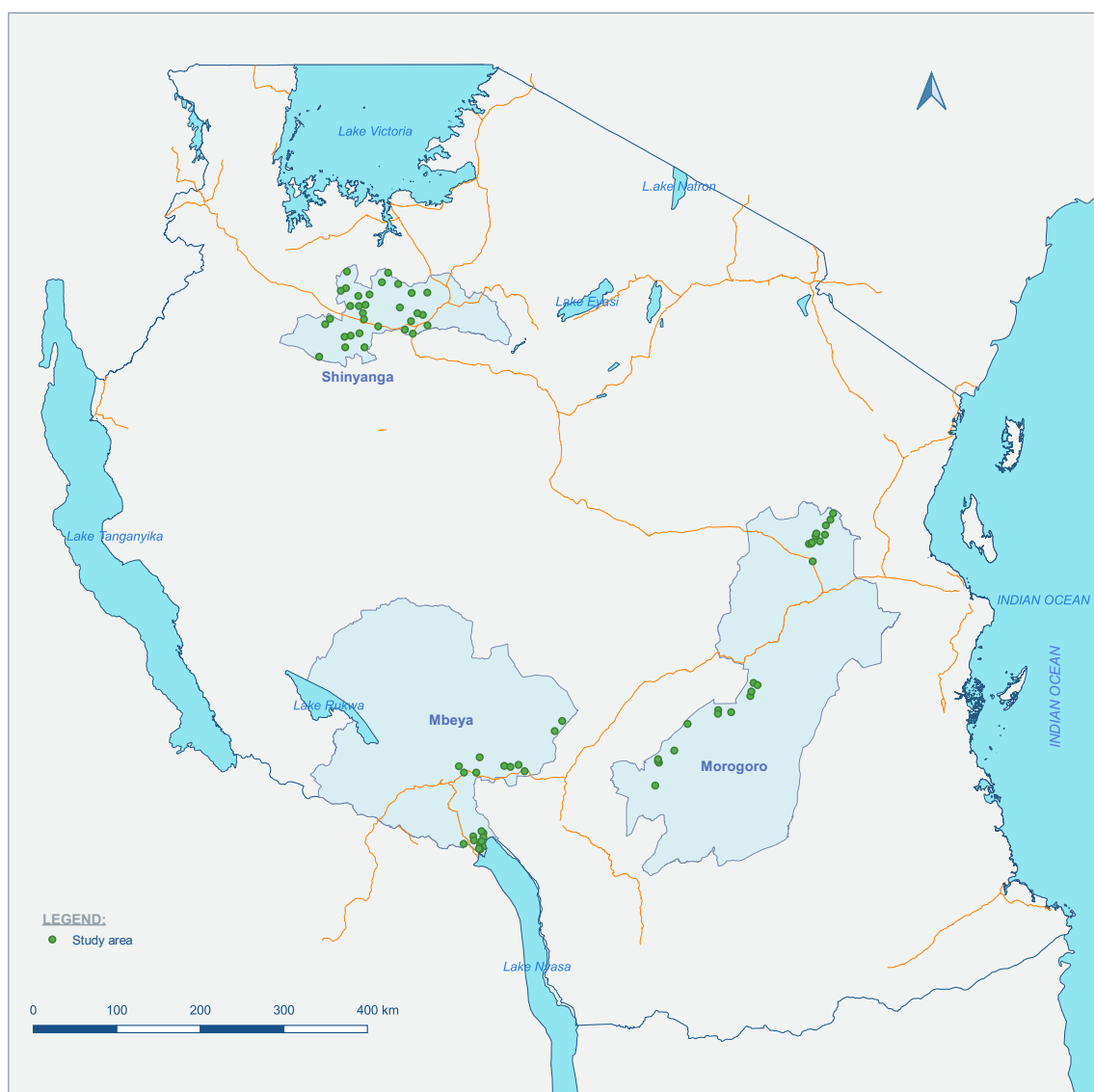


Figure 3.1: Map of Tanzania showing the study site for extensive rice surveys (ES)
Source: Author, 2020

and their villages' overall situation.

3.4.2 Descriptive Results

Table 3.1 shows the changes in the adoption of rice technologies in three regions from 2009 to 2018 among farmers that were interviewed during extensive surveys. Regarding access to irrigation, of about 20 percent of sample farmers in Morogoro region had irrigated plots in 2009. But this number increased to about 30 percent in 2018, following the construction of new irrigation

infrastructure in some villages. Mbeya region had the highest share of irrigated plots in 2009 and 2012. However, access to irrigation water has gradually declined in some villages in the region because of ongoing conservation initiatives that reduce the use of water reserves in the wetland for agricultural purposes. Sample farmers in Shinyanga region had the lowest share of irrigated farms, standing below five percent in all survey years.

Regarding paddy yield, sample farmers in Mbeya and Morogoro regions had the highest yield at 2.5 tons per hectare in 2009, which increased to around 3 tons per hectare in 2018. Morogoro region seems to have the highest use of MV. One of the possible reasons is that many agricultural research institutes and private and public seed companies are based in Morogoro region. MV use among sample farmers in Morogoro region increased from 36 percent in 2009 to 43 percent in 2018. Adoption of MVs increased from 1.9 percent in 2009 in Mbeya region to 25 percent in 2018. The application of chemical fertilizer also appears to follow the same pattern as MVs. In 2018, about 34 kilograms of chemical fertilizer per hectare were applied to the rice plots in Morogoro, compared with 84 per hectare in Mbeya and 4.5 per hectare in Shinyanga. These chemical fertilizer applications are low compared to the country's recommendations of about 120 kilograms per hectare (i.e., 40 kg/ha of Phosphate and 80 kg/ha of Urea). They are also low compared to some parts of SSA, such as Kenya where [Njeru et al. \(2016\)](#) reported almost 150 kilograms per hectare, or Cote d'Ivoire where [Mano et al. \(2020\)](#) reported that some farmers apply up to 200 kilograms per hectare.

In terms of bunds construction, sample farmers in Shinyanga region have the highest percentage. This is true in many parts of the Lake Zone, including Geita, and Tabora region. Many farmers in the lake region rely on rainwater harvesting to grow rice. This is in contrast to farmers in Southern Highlands and Eastern Zone, who primarily grow rice along rivers. Mbeya region has the second-highest percentage of plots with bunds, with about 50% of all plots. This is because most of the sample farmers in Mbeya region grow rice in irrigated areas. For them, the purpose of

the bunds is to control the amount of water entering and leaving the field, which is in contrast to the purpose of bunds for farmers in Shinyanga region. In addition, a large percentage of sample farmers seem to have already been transplanting rice before 2009. However, transplanting in rows was not common as it was only practiced by about 13 percent of sample farmers in Morogoro and Mbeya regions in 2009. By 2018, 21 percent of Morogoro sample farmers and 17 percent in the Mbeya region had adopted transplanting in rows.

Turning to the use of agricultural machinery, about 42 percent of the surveyed farmers in Morogoro region already used four-wheeled tractors (TR) in 2009, but the use of power tillers (PT) and draft animals (DA) was not common. Since then, the use of TR has continued to increase, reaching about 54 percent of the total sample households in 2018. In the same year, PT and DA's use has also reached about 8 and 18 percent, respectively. The increase of DA use in the Morogoro region is mainly attributed to nomadic herders' inflow into this region in the mid-2000s. In Mbeya region, 83% of farmers used DA in 2009, but the ratio has declined by 16 percentage points between 2009 and 2018. During the same period, TR remained relatively unchanged at about 7 percent, while PT's use has increased by 16 percentage points. Our descriptive results are in line with the findings of [Kirui and Braun \(2018\)](#) who show a high growth rate of farm mechanization in some SSA countries, including Tanzania.

In general, farmers in Shinyanga region appear to lag behind in the use of rice farming technologies, which affects their production rate. Their farming methods seem to have not changed much in about nine years. This contrasts with other areas, where statistics show that farmers have been increasingly using new rice farming technologies.

Table 3.2 shows the *t*-test comparison of changes over time in terms of rice cultivation technologies. We present our results into two categories: rainfed plots and irrigated plots. The results show that for irrigated sample plots, yield levels have not changed much in the past nine years. But the use of MV, chemical fertilizer and transplantation in rows appears to be significantly

increasing. The use of PT has also increased by 17%, while the use of DA has decreased by 30%.

Turning to rainfed plots, the results show that there has been a significant increase in paddy yield. In 2018, the average yield in rain-fed plots was approximately 2.4t/ha, which is roughly equal to the national average of 2.5t/ha. The adoption of some agricultural technologies such as MVs, chemical fertilizer, bund construction, and transplanting has also increased. However, the adoption rates are still low compared to those in irrigated plots. In terms of agricultural machinery, TR's use has not increased, but PT's use had increased from about 0.4 percent in 2009 to 5.8 percent in 2018. Unlike in irrigated areas, DA's use remains relatively high on rainfed with about 70 percent in 2018.

3.5 Conclusion

This chapter discussed various efforts to improve rice production, including introducing various rice technologies such as MV, chemical fertilizer, and improved agronomic practices. We applied the household-level data to descriptively show how the adoption of these technologies has changed over time. The descriptive results show that adoption rates for these technologies have gradually increased from 2009 to 2018. But the adoption pattern varies across agro-ecological zones. Irrigated areas appear to have high adoption rates and relatively higher yields, indicating the possibility of rice Green Revolution in irrigated lowlands. However, only a small proportion of the total rice area is irrigated, undermining the potential influence of such yield on country-level productivity. Our descriptive results show similar patterns to previous studies that empirically examined factors associated with the adoption of rice technologies in Tanzania ([Nakano et al., 2013, 2016, 2018b](#)). Our descriptive results suggest that to achieve the rice Green Revolution in Tanzania, policies that aim to increase irrigation infrastructures and those aiming to improve productivity in rainfed remains important.

Table 3.1: The use of rice technologies by regions (2009, 2012 and 2018)

	Morogoro			Mbeya			Shinyanga		
	2009	2012	2018	2009	2012	2018	2009	2012	2018
	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)
Irrigated plot (dummy)	0.20	0.22	0.30	0.48	0.42	0.11	0.04	0.01	0.03
Paddy yield in sample plot (tons/ha)	2.44	2.16	2.92	2.52	2.35	3.03	1.84	1.36	2.18
Adoption rate of MVs (%)	36.21	38.74	43.40	1.96	7.18	25.24	3.50	3.21	4.19
Amount of chemical fertilizer used (kg/ha)	20.88	24.61	34.05	25.18	38.62	82.28	0.85	2.80	4.51
Share of bunded plot (%)	24.14	36.04	41.70	51.47	45.93	55.24	95.72	72.86	91.94
Adoption rate of transplanting (%)	32.33	31.98	34.04	52.94	51.20	44.29	46.30	64.29	66.13
Adoption rate of transplanting in rows (%)	13.79	14.86	21.70	13.24	6.70	17.14	6.23	3.93	3.87
Share of leveled plot (%)	31.90	48.20	40.00	57.35	57.89	57.14	87.94	82.14	53.87
Use of TR (%)	42.67	50.45	54.47	7.35	6.70	7.62	0.00	0.00	0.97
Use of PT (%)	1.72	4.50	7.66	1.96	6.22	18.57	0.00	1.43	0.65
Use of DA (%)	4.31	12.16	18.30	82.84	81.34	67.14	98.05	94.64	95.16
Use of of handheld tools (%)	51.29	32.88	19.57	7.84	5.74	6.67	1.95	3.93	3.23
Observation (households)	232	222	235	204	209	210	257	280	310

Source: Author (2020). *** denotes significant at 1%, ** significant at 5%, and * significant at 10% in *t*-test comparison

Table 3.2: The use of rice technologies by irrigation status of the sample plot (2009, 2012 and 2018)

	Irrigated plots					Rainfed plots				
	2009	2012	2018	Difference		2009	2012	2018	Difference	
	(i)	(ii)	(iii)	(ii) - (i)	(iii) - (i)	(iv)	(v)	(vi)	(v) - (iv)	(vi) - (iv)
Paddy yield in sample plot (tons/ha)	3.72	3.42	4.06	-0.30	0.34	1.82	1.54	2.43	-0.28***	0.60***
Adoption rate of MVs (%)	31.82	40.88	68.63	9.06	36.81***	8.91	9.41	15.01	0.50	6.10***
Amount of chemical fertilizer used (kg/ha)	35.44	54.26	83.19	18.81**	47.75***	8.80	12.00	27.86	3.20	19.06***
Share of bunded plot (%)	88.96	85.40	92.16	-3.56	3.20	50.09	45.82	62.02	-4.27	11.93***
Adoption rate of transplanting (%)	92.86	90.51	83.33	-2.35	-9.52**	29.50	40.77	44.87	11.27***	15.37***
Adoption rate of transplanting in rows (%)	29.22	26.28	47.06	-2.94	17.84***	5.57	3.83	7.81	-1.73	2.24
Share of leveled plot (%)	76.62	65.69	78.43	-10.93**	1.81	55.47	64.11	46.09	8.64***	-9.38***
Use of TR (%)	9.09	13.14	14.71	4.05	5.61	18.55	18.82	20.21	0.26	1.66
Use of PT (%)	3.90	10.22	20.59	6.32**	16.69***	0.37	2.26	5.82	1.89***	5.45***
Use of DA (%)	52.60	44.53	23.53	-8.07	-29.07***	64.94	69.86	69.68	4.93*	4.74*
Use of handheld tools (%)	34.42	32.12	41.18	-2.30	6.76	16.14	9.06	4.29	-7.08***	-11.85***
Observation (households)	154	137	102			539	574	653		

Source: Author (2020). *** denotes significant at 1%, ** significant at 5%, and * significant at 10% in *t*-test comparison

Chapter 4.

Impact of microcredit on rice production

4.1 Introduction

In this chapter, we apply data from the randomized control trial to examine the impact of microcredit on the technology adoption and productivity of rice cultivation in Tanzania. Unlike previous microcredit studies, this study is unique in two ways. First, we examine the impact of microcredit on modern inputs such as chemical fertilizer and improved modern varieties and improved agronomic practices. Second, this randomized experiment's intervention was specifically designed for agricultural households, as we will explain later in this chapter. The rest of the chapter is organized as follows. Section 4.2 describes the study site while Section 4.3 presents data collection methods, and implementation of the BRAC program. Section 4.4 discusses methodology for our analysis. In section 4.5, we discuss the estimation results on the impact of microcredit. Section 4.6 presents the conclusion and policy implications.

4.2 Study site

This chapter is based on data obtained from the BRAC-IRRI agricultural credit program (referred to as the BRAC program hereafter). The program involved the household-level randomized experiment of microcredit service implemented as a collaborative research project between the International Rice Research Institute (IRRI) and BRAC, one of the world's largest microfinance institutions. The BRAC program was implemented in Ilonga and Chanzuru villages in Kilosa District, Morogoro Region, Tanzania.

4.2.1 Kilosa District

Kilosa District is located in the western part of Morogoro Region, bordering with Dodoma Region and Gairo District in the north, Iringa Region on the south-west, Kilombero District on the south, and Morogoro Rural and Mvomero Districts in the east (Figure 4.1). The district covers a total area of 14,918km², and by 2012, it has a population of 438,175 people (the United Republic of Tanzania, 2012). The average household size is about 4.3, which is slightly below the regional average of 4.5. The population density ranges from 35 to 45 people per square kilometer. The district falls in the moderately productive agricultural zone, with an annual rainfall of about 600mm to 1200mm and annual temperature ranging between 18°C and 31°C.

As shown in Figure 4.1, Kilosa District has sufficient infrastructures, compared to other districts of Morogoro Region. The trunk roads from Dar-es-salaam to Dodoma and from Dar-es-salaam to Zambia passes near the district. Kilosa district can also be accessed by railway linking Dar es Salaam and Mwanza (in Lake Victoria's shores). The presence of good infrastructure makes Kilosa to be more economically active, and therefore, a variety of services can be easily accessed. By the time this study was conducted, access to financial services was gradually increasing. Several commercial banks and MFIs are operating in the district, including NGO-type microfinance institutions (e.g., BRAC and FINCA) and SACCOs (savings and credit cooperative organizations). However, smallholder farmers are not clients targeted by these institutions, and it is not easy to find loan products in the credit market that are specifically designed for agriculture. Farm inputs such as improved varieties of seed, chemical fertilizer, insecticides, and herbicides could be purchased in Kilosa town and even in some of the villages in the district.

4.2.2 Ilonga and Chanzuru irrigation schemes

The villages of Ilonga and Chanzuru are located approximately 15 kilometers from Kilosa town. Each of the villages has its own irrigation scheme. By 2013, the total developed area of Ilonga

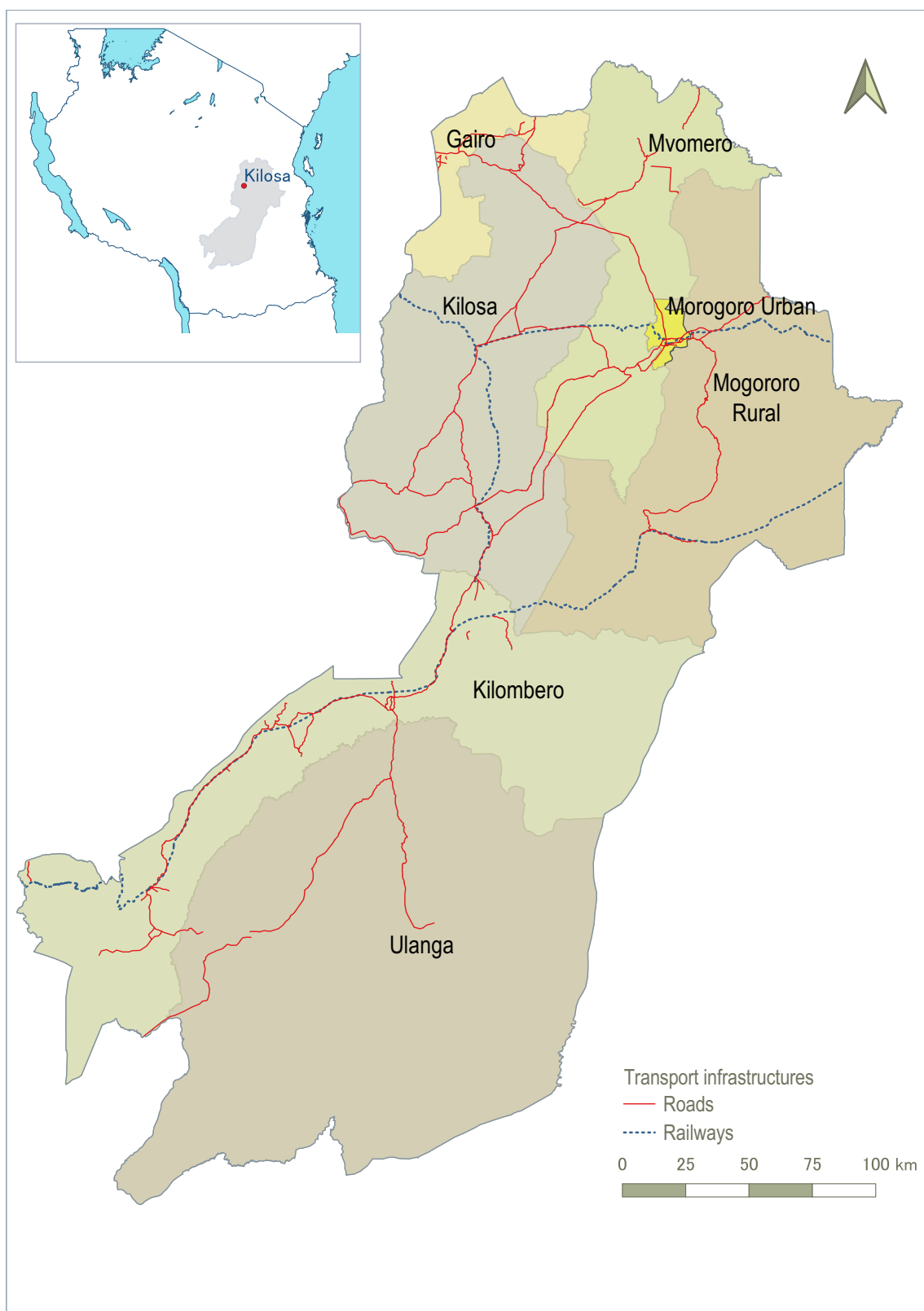


Figure 4.1: A map of Morogoro Region showing a location of Kilosa District
Source: Author (2020)

irrigation scheme was 120 hectares, supporting about 600 households. During the same year, Chanzuru, had 400 hectares of developed area with 725 households. Even though the two irrigation schemes are nearby, Ilonga is by far ahead of Chanzuru regarding technology adoption and rice production environment.

First, Ilonga irrigation scheme has better irrigation infrastructures than does Chanzuru irrigation scheme. It is also located in the upper stream, which gives it better access to water than Chanzuru, especially during a water shortage. Second, Ilonga is in proximity to agricultural research centers, such as the Agricultural Research Institute (ARI) and the Ministry of Agriculture Training Institute (MATI). Therefore farmers in Ilonga have an advantage since they can even learn about new agricultural technologies by visiting the experimental plots at those research centers. Third, before microcredit intervention, JICA had already conducted rice training in Ilonga during the 2009 cultivation season. The contents of TANRICE training include the use of modern varieties, chemical fertilizer, improved bund construction, plot leveling, and transplanting in rows. Therefore, all these factors indicate that many farmers in Ilonga farmers have a better understanding of rice cultivation technologies.

In two irrigation schemes, the annual cropping calendar starts from October to September of the succeeding year and has two cropping seasons: (i) the main season starting from October to June and (ii) the short season starting from July to September. During the main season, farmers grow rice in irrigated plots, and other crops such as maize, beans, sunflower, and sesame are grown in upland plots. In the irrigation scheme, the land preparation for rice cultivation starts between November, and planting usually starts around January. From January through May, the labor demand for agricultural activities such as transplanting, weeding, and bird scaring is high. The paddy is harvested starts between June and July. Soon after harvesting, the irrigated plots are prepared to cultivate dry season crops, such as vegetables and legumes.

In general, farmers in our study sites have limited access to credit and input markets. In

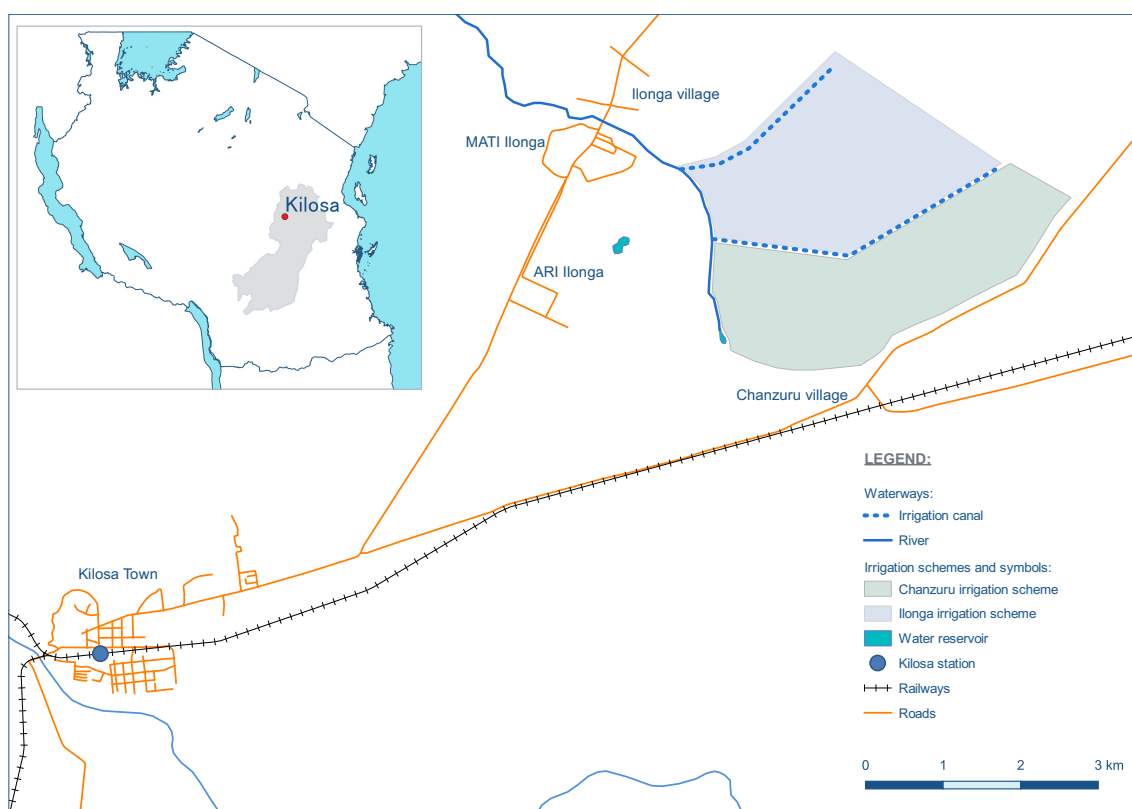


Figure 4.2: A map of Ilonga and Chanzuru irrigation schemes
Source: Author (2020)

2012, only about 8% of the farmers borrowed money from credit sources other than the BRAC program. Chemical fertilizer can be purchased at the agrovet stores (retailers of agricultural and veterinary products) in the villages. It is common among the farmers in our study sites to hire labor and rent machinery and animals for rice cultivation. In 2012, 63% of the farmers hired machinery and animals, while 90% of the farmers use hired labor for cultivating rice. This suggests that there is little constraint on the agricultural laborers, machinery, and animal rental markets.

4.3 Data and Description of BRAC Program

4.3.1 Data

The data collection was conducted in three rounds of surveys, from 2010 to 2012. The baseline survey was conducted from September to November 2010, where 412 households were randomly

selected from a roster of farmers growing rice in Ilonga and Chanzuru irrigation schemes. The second survey was conducted from August to September 2011, followed by the intervention of the BRAC program from November 2011 to May 2012.¹ During the intervention, the 412 households interviewed in the first survey were randomly assigned to one of two groups. One group consisted of 208 households who were eligible to obtain credit from the BRAC program; the other group consisted of 204 non-eligible households.

In 2012, all sample households were revisited in a survey designed to collect data for assessing the impact of the BRAC program. Out of the original sample of 412 households, 17 could not be interviewed, 7 were dropped for violating the program's conditions by obtaining credit without being eligible, and one household was dropped due to its extreme value. Therefore, our 2012 sample consisted of 387 households. In our analysis, data sets collected in the 2010 and 2012 surveys are used; the former survey (2010) is referred to as the baseline survey, and the latter survey (2012) is referred to as the endline survey.

During the baseline survey, we asked farmers to identify their most important plot. We collected detailed information about rice cultivation on the identified plot, together with other household-level variables, including basic household characteristics and income-related variables. During the endline survey in 2012, we asked farmers in the BRAC program questions similar to those in the previous survey on the plot where they applied most of the fertilizer obtained through BRAC. For those who did not join the program, we asked about the same plots as in the baseline survey (we call them sample plots). Thus, our data is not plot-level but household-level panel data, and for crop income, we use data from sample rice plots and other plots used by the household to grow rice and other crops.

¹Due to budget constraints, the 2011 survey covered only 358 households out of 412. Since our evaluation is based on cross-sectional variation created by the RCT in 2012 and the baseline characteristics from the baseline survey, we do not use the data from the 2011 survey for the main analysis in order to avoid sample size reduction. Instead, we use them to estimate the yield response presented in the appendix.

4.3.2 Details of the BRAC program

The BRAC program intended to support rice cultivation for farmers in the two irrigation schemes; however, there was no restriction placed on farmers' use of the credit they obtained from BRAC. That means farmers had the freedom to choose how to allocate the credit they obtained through the BRAC program.

After randomization in 2011, a community organizer from the Kilosa branch of BRAC Tanzania visited the eligible households and explained the conditions for borrowing from the BRAC program. Farmers who agreed to the program's terms were asked to form groups of jointly liable credit borrowers. However, each group had about 15 to 20 farmers, larger than the usual group size of about five borrowers in standard microfinance operations. Therefore, we cannot say that the standard procedures for group liability were followed or taken seriously by farmers. Nonetheless, the repayment rate was as high as 73% (by a record of BRAC before the completion of harvesting season) to 92.5% (as the self-report of the farmers during the survey).

Only eligible households who agreed with conditions for participation could obtain credit from the program. Each borrower received a loan with a value of 80,000 Tanzanian Shillings (TShs), or approximately 50 USD at the 2012 exchange rate. Half of the credit (TShs. 40,000) was received as cash, while the remaining TShs 40,000 was in the form of a voucher that could be used to pay for fertilizer based on the village-level market price. The voucher could be redeemed at the selected fertilizer dealer's store in the village and could be exchanged to obtain about 26kg of UREA. The loan duration was one cultivating season; an annual interest rate of 25 percent was charged; thus, the total repayment including interest was TShs 100,000.

Knowing that farmers receive most of their income after harvesting and selling paddy and other crops grown in the wet season, borrowers from the BRAC program were required to repay 20 percent of the total payment weekly during the cultivation period, to maintain the standards of MFIs operations. The remaining 80 percent was to be repaid in one installment after the harvesting

season. Since the program targeted rice-growing households, BRAC offered a one-day training session on basic rice cultivation techniques and fertilizer use. Only credit borrowers were allowed to participate in the training. BRAC conducted follow-up and monitoring activities to ensure borrowers were using their microcredit for productive purposes.

There were some other criteria considered in the implementation of the BRAC program, including the intervention's size. The decisions regarding the amount of cash credit and fertilizer were reached after consulting officials at BRAC Tanzania, agronomists from JICA, and local government officials. According to experts, if farmers were given large amounts of chemical fertilizer, it could have caused water lodging and damaged rice crops. If they were given a small amount of fertilizer, it would impact plots growing traditional varieties rather than those growing MVs. Similarly, if the program offered a large amount of credit, farmers would probably attempt to spend it on other non-agricultural activities. With this in mind, we decided to provide a medium-term loan rate, of which half was provided as fertilizer, and half as cash, expecting that if the borrowers needed additional chemical fertilizer, they could use part of the cash to increase the amount of fertilizer.

4.4 Empirical Strategies and Key Variables

4.4.1 Empirical Strategies

Although eligibility for the program could be randomly assigned, we could not force farmers to take the credit. Thus, being an actual borrower is endogenously determined by the farmers themselves, and the selection bias remains in our study design. To circumvent this problem, we utilize our data obtained from RCT to estimate the impact of microcredit. We first estimate the intention-to-treat (ITT) effect by using randomly assigned eligibility to the program. The ITT can be expressed as

$$ITT = E(Y_{1iE} | Z_i = 1) - E(Y_{0iE} | Z_i = 0) \quad (4.1)$$

where Y_{1iE} is the endline outcome of household i if they are eligible to participate in the BRAC program, and Y_{0iE} is the endline outcome of the same household if they are not eligible to participate. Z_i is a dummy variable that takes 1 if a household is invited to the program and 0 otherwise. In reality, we cannot observe Y_{1iE} and Y_{0iE} for the same household i . However, since the households are randomly assigned into an eligible and non-eligible group, then the non-eligible group is the counterfactual of the eligible group, and ITT can be estimated as the coefficient β in Ordinary Least Square (OLS) regression.

It should be noted that ITT estimates give the partial treatment effect based on eligibility to the program regardless of whether the household actually took advantage of the credit offered. In order to examine the impact of being a borrower, we estimate the local average treatment effect (LATE), which is defined by

$$LATE = E(Y_{1iE} | D_{1i} \neq D_{0i}) \quad (4.2)$$

where, D_i is a dummy variable that takes a value of 1 if a household is a borrower and 0 if it is not. As [Angrist and Imbens \(1995\)](#) show, if Y_{1iE} , Y_{0iE} , D_{1i} , and D_{0i} are independent of Z_i , and if $D_{1i} \geq D_{0i}$ for all i (i.e., monotonicity), then LATE can be estimated as coefficient β in a regression model, $Y_{iE} = \alpha + \beta D_i + \varepsilon_i$ by Two Stage Least Square(2SLS) model, using the Z_i as an instrumental variable (IV) for D_i .

To increase estimation power, we follow the lead of [McKenzie \(2012\)](#) and estimate the analysis of covariance (ANCOVA) by including the outcome variable at the baseline. Therefore, we specify the ITT-ANCOVA as

$$Y_{iE} = \alpha + \beta_1 Z_i + \beta_2 Y_{iB} + \beta_k \mathbf{X}_{iK} + \varepsilon_i \quad (4.3)$$

where Y_{iE} is the outcome variable of household i observed in the endline survey, Z_i is the dummy variable representing eligibility for the BRAC program, Y_{iB} denotes the pre-intervention outcome variable observed in baseline survey, and \mathbf{X}_{iK} is the vector of household characteristics. The LATE-ANCOVA is specified as

$$Y_{iE} = \alpha + \beta_1 D_i + \beta_2 Y_{iB} + \beta_k \mathbf{X}_{iK} + \varepsilon_i \quad (4.4)$$

where D_i is a dummy variable having value 1 if the household borrowed from the BRAC program and 0 otherwise.

4.4.2 Key variables

Our main dependent variables are divided into three categories: (i) technology adoption variables; (ii) land productivity and production costs variables; and (iii) household income variables. Technology adoption variables include the use of modern inputs (i.e., MVs and chemical fertilizer), adoption of improved agronomic practices including improved bunds, leveling, transplanting in row and the use of insecticides and herbicides. Land productivity and production costs variables include paddy yield, revenue, total input costs, paid-out costs of hired labor use, paid-out costs of machinery and animal use, imputed costs of using family labor, imputed costs of using own machinery and animals, income and profit.

Household level income variables include, total household income, income from selling livestock and livestock products, business and wage labor income, total crop income and its components: which are total crop revenue, income from rice cultivation, income crops other than rice, total costs for using hired labor, machinery and animal and use current input use. In addition, we also examine the impact on school and medical expenditure, household income after paying the loan from BRAC Program, the use of credit other than that offered by BRAC. These additional

variables aim to examine the possibility that credit was used for purposes other than agricultural production. We present how key variables were calculated in the Appendix.

4.5 Results

4.5.1 Descriptive Results

Table 4.1 and 4.2 show a descriptive analysis of the technology adoption, land productivity and production costs variables. Among eligible households, some farmers took a loan from the program and those who did not. We call those who took a loan “borrower” to distinguish them from eligible households. As shown in the number of observations, 80 households out of 205 eligible households borrowed credit from the BRAC program, indicating that the credit uptake was about 39 percent.² The number of credit borrowers in each village was 40 households, out of 101 eligible households in Ilonga and 104 eligible households in Chanzuru. We conduct the *t*-test comparisons between eligible and non-eligible households and between borrowers and non-eligible households. We also conduct a sub-sample analysis for the Ilonga and Chanzuru irrigation schemes. The reason for this is that, as we discussed earlier, farmers in Ilonga enjoy more favorable conditions in terms of availability of irrigation water as compared to farmers in Chanzuru, and thus the impact of credit may differ between the farmers in the two schemes.

Descriptive results for the total sample (columns 1 to 3) show that credit borrowers increased the application of chemical fertilizer and adoption rates of improved bunds in their sample rice plots. The average amount of chemical fertilizer application by borrowers is 78 kilograms per hectare, and the adoption rates of improved bunds are about 13 percent. As we explained in Chapter 3, improved bunds are efficient in preventing nutrients from spilling out of the rice plots. It is possible that farmers adopted bunds after deciding that they would use chemical fertilizer.

²This is relatively high compared to other microcredit related studies such as [Angelucci et al. \(2015\)](#); [Banerjee et al. \(2015b,a\)](#); [Crépon et al. \(2015\)](#); [Hossain et al. \(2019\)](#) and [Tarozzi et al. \(2015\)](#) which report the uptake rates ranging from about 10% to 30%.

However, the increase in chemical fertilizer application and improved bunds by credit borrowers did not increase paddy yield, revenue, income, and profit. Borrowers have a paddy yield of about 3.17 tons per hectare, while non-eligible farmers have 3.12 tons per hectare, and there is no significant difference between the two groups. Borrowers also increased their total input costs as they applied more chemical fertilizer than non-eligible farmers. Furthermore, their imputed costs for using family labor appears to be 337.9 USD per hectare, which is lower than 493.4 USD per hectare of non-eligible farmers, suggesting that credit borrowers reduced their use of family labor in the sample plot and possibly invested it in other economic activities or leisure.

Turning to sub-sample analysis (columns 4 to 6 for Ilonga, and columns 7 to 9 for Chanzuru), results show that only credit borrowers in Chanzuru significantly increased the amount of chemical fertilizer application and adoption rates of improved bunds. In contrast, borrowers in Ilonga increased the adoption rates of MVs. The average amount of chemical fertilizer application by borrowers in Chanzuru is 61.7 kilograms per hectare, and the adoption rate of improved bunds is about 15 percent. The total input costs are significantly higher for borrowers in Chanzuru than eligible farmers in the same village. Borrowers in Chanzuru also significantly reduced their total imputed costs to an average of 327.3 USD per hectare compared to 544.7 USD per hectare of non-eligible households. The decline in imputed costs can be associated with a significantly high profit among borrowers.

The results of sub-sample analysis suggest that most of differences observed in total sample mainly occurred in Chanzuru, and only few significant changes occurred in Ilonga. As we discussed earlier, farmers in Ilonga are technologically ahead of their neighbors in Chanzuru, and their irrigation infrastructures are relatively in good conditions. Panel A shows that even non-eligible farmers in Ilonga applied more about 84 kg per hectare of chemical fertilizer and their adoption rates of MVs is 39.5 percent.³ The figures are higher than that of their counterparts in

³Farmers in Ilonga are applying chemical fertilizer close to the recommended amount of 120kg/ha (i.e., 40kg/ha of Phosphate and 80kg/ha of nitrogen-based fertilizer such as UREA). In fact, since nitrogen-based fertilizers are

Chanzuru who apply 20 kg per hectare of chemical fertilizer and their adoption rates of MVs is 9.3 percent. This suggest that farmers in Ilonga have favorable conditions such as better access to irrigation water and exposure to new rice technologies, which enables them to attain higher paddy yield even in the absence of microcredit intervention.

Table 4.3 . shows a descriptive analysis of the household income variables. The table uses the same structure as Table 4.1 and 4.2. We present results using four panels. Panel A consists of total household income from different sources, Panel B shows the total cost of crop cultivation, Panel C shows the sub-components of total crop income, and Panel D shows school and medical expenditure.

The descriptive results for the total sample (columns 1 to 3) show that eligible households and borrowers increased total income from crops other than rice (mainly maize). The average income from crops other than rice for eligible households is 60.6 USD, while for borrowers it is 60.68 USD; non-eligible households, it is 21.3 USD. The increase in income from these crops, however, was not large enough to result in an increase in total income from crop cultivation or in total household income.

We expected that increased fertilizer use would result to an increase in total income from rice. However, contrary to our expectation, we do not observe a significant difference in income from rice either between eligible and non-eligible farmers or between borrowers and non-eligible farmers. There is no significant difference for the variables such as total household income, crop revenue and crop production costs.

Looking at the sub-sample analysis (columns 4 to 6 for Ilonga, and columns 7 to 9 for Chanzuru), results show that for Ilonga there are no significant differences among the three groups except that medical expenditure for borrower households is higher than for non-eligible households. In Chanzuru, eligible households have significantly higher income from business and wage

commonly used than the Phosphate ones, it is possible that they are already applying the recommended amount nitrogen fertilizers.

activities as well as income from crops other than rice. Furthermore, borrower households in Chanzuru have significantly higher total crop income and income from crops other than rice. They also have higher crop revenue and expenditure in current input use, which includes the costs of seeds, chemical fertilizers, insecticides and herbicides.

Table 4.1: Technology adoption by household's status in BRAC Program

VARIABLES	Total Sample			Ilonga			Chanzuru		
	Eligible	Borrower	Non-eligible	Eligible	Borrower	Non-eligible	Eligible	Borrower	Non-eligible
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Use of chemical fertilizer (kg/ha): 2012	61.34	78.00***	53.19	87.98	94.33	84.16	35.47**	61.67***	20.83
Modern variety: 2012	23.33	32.72	24.71	37.41	54.36*	39.48	9.65	11.08	9.27
Adoption of improved bund (%): 2012	7.80	12.50*	6.04	6.93	10.00	7.53	8.65	15.00**	4.49
Adoption of leveling (%): 2012	39.02	40.00	38.46	33.66	32.50	33.33	44.23	47.50	43.82
Adoption of transplanting in row (%): 2012	13.17	15.00	13.19	23.76	25.00	24.73	2.88	5.00	1.12
Use of insecticide and herbicide (liter/ha): 2012	5.60	8.07	5.10	9.47	14.45	5.83	1.85	1.69	4.33
Observation (Households)	205	80	182	101	40	93	104	40	89

Source: Author (2020). *** denotes significant at 1%, ** significant at 5%, and * significant at 10% in *t*-test comparison between eligible and non-eligible households or between borrower and non-eligible households.

Table 4.2: Land productivity and production costs by household's status in BRAC Program

VARIABLES	Total Sample			Ilonga			Chanzuru		
	Eligible	Borrower	Non-eligible	Eligible	Borrower	Non-eligible	Eligible	Borrower	Non-eligible
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Yield (t/ha): 2012	2.99	3.17	3.12	3.53	3.52	3.81	2.46	2.83	2.40
Revenue (USD/ha): 2012	1,267.57	1,330.83	1,326.70	1,469.15	1,430.07	1,596.90	1,071.79	1,231.58	1,044.35
Total input costs (USD/ha): 2012	97.26	118.95**	89.00	138.32	156.15	126.82	57.38	81.75***	49.49
Paid-out cost of labor use (USD/ha): 2012	276.70	284.16	281.78	302.11	280.46	318.81	252.02	287.87	243.10
Imputed costs of family labor (USD/ha): 2012	428.68*	337.86***	493.37	388.89	348.46	444.28	467.33	327.26***	544.66
Paid-out cost of machinery and animal use (USD/ha): 2012	60.47	72.55	59.37	71.75	82.36	79.71	49.51	62.74*	38.11
Imputed cost of machinery and animal use for (USD/ha): 2012	0.69*	0.80	1.63	0.51	0.00	1.78	0.87	1.60	1.46
Income (USD/ha): 2012	833.14	855.16	896.55	956.98	911.11	1,071.57	712.88	799.22	713.66
Profit (USD/ha): 2012	403.77	516.51	401.55	567.58	562.65	625.50	244.69	470.37**	167.54
Observation (Households)	205	80	182	101	40	93	104	40	89

Source: Author (2020). *** denotes significant at 1%, ** significant at 5%, and * significant at 10% in *t*-test comparison between eligible and non-eligible households or between borrower and non-eligible households.

Table 4.3: Household income, expenditure, and credit use by household's status in BRAC Program

VARIABLES	Total Sample			Ilonga			Chanzuru		
	Eligible	Borrower	Non-eligible	Eligible	Borrower	Non-eligible	Eligible	Borrower	Non-eligible
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
<i>Panel A: Total household income</i>									
Total household income (USD): 2012	837.31	888.22	888.72	965.46	783.08	790.90	712.85	993.35	990.93
Livestock income(USD): 2012	24.24	29.54	34.79	16.78	18.07	37.68	31.49	41.02	31.77
Business and wage labor income (USD): 2012	263.21	217.03	306.99	357.74	160.67	146.58	171.41*	273.40	474.61
Total crop income (USD): 2012	549.85	641.64	546.94	590.94	604.35	606.64	509.95	678.94*	484.56
<i>Panel B: Total crop revenues and total costs of crop cultivation</i>									
Crop revenues (USD): 2012	815.37	948.25	822.70	865.84	901.71	938.41	766.35	994.80**	701.79
Paid out costs for machinery and animal use (USD): 2012	47.80	62.12	46.54	43.17	53.84	54.65	52.29	70.40**	38.07
Paid out costs for hired labor (USD): 2012	175.37	192.34	187.90	175.47	182.73	218.73	175.27	201.95	155.67
Costs for current input use (USD): 2012	50.01	62.28*	48.54	70.52	74.23	73.21	30.10	50.33***	22.77
<i>Panel C: Sub-components of crop income</i>									
Total rice income (USD): 2012	489.25	580.96	525.64	565.59	593.86	593.79	415.11	568.07	454.44
Income from crops other than rice (USD): 2012	60.60***	60.68***	21.30	25.34	10.48	12.86	94.84***	110.87***	30.12
<i>Panel D: Credit access, school expenditure and medical expenditure</i>									
Use of credit other than BRAC Program (USD): 2012	18.29	12.17	15.73	25.83	18.17	27.49	10.96	6.17	3.45
School Expenditure (USD): 2012	139.29	167.52	137.27	125.12	161.07	116.48	153.05	173.98	158.99
Medical Expenditure (USD): 2012	61.94	113.07	72.49	86.05	156.50*	63.79	38.53	69.63	81.58
Observation (Households)	205	80	182	101	40	93	104	40	89

Source: Author (2020). *** denotes significant at 1%, ** significant at 5%, and * significant at 10% in *t*-test comparison between eligible and non-eligible households or between borrower and non-eligible households.

4.5.2 Estimation Results

Before estimating the impact of microcredit, we examine the balance of baseline outcome and control variables between eligible and non-eligible households. As shown in Table B2, there is no statistically significant difference between eligible and non-eligible households, except for adopting leveling and imputed costs of machinery and animal use, which are significant at 10 percent. This indicates that randomization was generally successful. Nevertheless, we include the baseline household characteristics as control variables in our estimations of the ITT-ANCOVA and LATE-ANCOVA, to eliminate the influence due to initial differences on the post-intervention outcome.

From Table 4.4 to Table 4.7 we present the ITT-ANCOVA and LATE-ANCOVA estimation results regarding the impact of microcredit on technology adoption. Each table has six columns, where columns 1 and 2 presents the estimates for the total sample, while the rest presents the sub-sample analysis for Ilonga (columns 3 and 4) and Chanzuru (columns 5 and 6). Although not reported in the main text, the coefficient of eligibility for the program on being a borrower is highly statistically significant in the first stage estimation of LATE-ANCOVA, suggesting that being eligible for the BRAC program is a suitable IV for being a borrower in our LATE-ANCOVA estimation.⁴ In both ITT-ANCOVA and LATE-ANCOVA, we control for the baseline dependent variable and baseline household characteristics, which are total land holdings (ha), the value of household assets (USD), number of adult household members, years of schooling of household head, female household head dummy, and age of household head. Since the number of villages in our sample is only two, and we use a randomly assigned variable as IV we report the non-clustered robust standard error. As we mention earlier, the ITT-ANCOVA estimates give the partial treatment effect based on eligibility to the program regardless of whether the household borrowed credit from the program not. For this reason, our discussion will mainly focus on LATE-ANCOVA, and the

⁴The first stage results are presented in the appendix.

results for ITT-ANCOVA are presented for reference purposes only.

Furthermore, it should be noted that we are examining the impact of microcredit intervention on a wide range of dependent variables by testing one hypothesis after another. This approach increases the probability of concluding falsely that the program had an impact of one or more variables because they are evaluated without considering other related dependent variables. To reduce the probability of these false conclusions, we conduct multiple hypotheses testing using the [Romano and Wolf \(2005\)](#) and [Clarke et al. \(2019\)](#) approach. The results of variables that remain significant even after conducting multiple hypothesis testing are marked by ++ signs next to parentheses enclosing standard errors for the corresponding coefficient.

Impact on technology adoption and land productivity

The results on the impact of microcredit on the adoption of rice technology and land productivity are respectively presented in Table [4.4](#) and Table [4.5](#). The LATE-ANCOVA estimates show that borrowing from the BRAC program significantly increased chemical fertilizer application by about 22 kg per hectare, although the effect appears to be not significant when we conduct multiple hypotheses testing. We find no significant impact on the adoption of other rice technologies, including modern varieties, improved bunds, leveling, transplanting in rows, and the use of insecticides and herbicides. Furthermore, the results in Table [4.4](#), columns 1 and 2, show that participation in the microcredit program did not significantly increase the yield, revenue, income, and profit. However, it significantly reduces the imputed costs of family labor by 183 USD per hectare, although this effect is not significant after testing multiple hypotheses.

Turning to sub-sample analysis, estimation results in columns 3 to 6 of Table [4.4](#) show that credit borrowers in Chanzuru increased fertilizer application by 42 kg per hectare, while those in Ilonga did not significantly change their levels of fertilizer application. The effect of microcredit in Chanzuru is significant even after conducting the multiple hypothesis testing. Like

overall results, we do not find a significant impact on remaining variables related to rice technology adoption, land productivity or production costs, except for imputed costs of using family labor, which is significantly lower among credit borrowers in Chanzuru village. However, this effect is not significant after we conduct multiple hypothesis testing.

The results from the sample plot indicate that farmers with good irrigation infrastructures better access to extension services use chemical fertilizer in large quantities, even without credit intervention. As a result, when they are given a small amount of credit, they do not increase the use of fertilizer beyond the amount they normally use. Since they do not increase the adoption rates of rice technology, then their levels of paddy yield also remain unchanged. On the other hand, farmers who grow rice in non-conducive environments or without good extension services increase chemical fertilizer application after receiving credit, even if it is amount. However, due to limited knowledge of using chemical fertilizer and other complementary technologies such as MVs and transplanting in rows, they fail to increase yield and other land productivity indicators.

To further examine why fertilizer application in Chanzuru did not translate into high yield, we examine the returns to chemical fertilizer application, using the Correlated Random Effect (CRE) model and present the results in the appendix. The CRE estimates show that yield response to chemical fertilizer application is statistically significant and positive in total sample analysis and Ilonga, but it is not significant in Chanzuru. The application of one 1kg of chemical fertilizer increases paddy by 6 kg in general and 8 kg in Ilonga. These levels of paddy yield response are considered moderate in comparison to other parts of SSA.

Impact on household income variables

Table 4.6 and Table 4.7 show the estimation results regarding the impact of microcredit on household income and other dependent variables, following a similar structure as that in Table 4.4. Columns (1) and (2) show the ITT-ANCOVA and LATE-ANCOVA estimates for the total sam-

ple, while columns (3) to (6) show those for the Ilonga and Chanzuru sub-sample, respectively. The overall results presented in columns (1) and (2) show that microcredit did not have any significant impact on total income from rice cultivation, including rice grown in non-sample plots. However, it had a significant impact on income from crops other than rice. The estimations using total sample show that the use of microcredit led to an increase in income from other crops of approximately by 61 USD, although the effect does not appear to be not significant after we run the multiple hypotheses test. Furthermore, we do not find any impact of microcredit on total crop income or household income. The results suggesting that increase in income from non-rice crops was too small to have a significant influence on total income from crop cultivation or on total household income.

In the sub-sample analysis, we also observe that this increase in income from other crops arises mainly in Chanzuru. Since farmers in Chanzuru work under less favorable conditions for rice cultivation compared to farmers in Ilonga, it is possible that they used part of the credit for maize production, where they would expect higher returns. However, this effect should be interpreted with caution as it is not significant when we conduct multiple hypothesis testing. Other sub-components of household income, crop revenue, and production costs appear to be unaffected by either credit eligibility or credit use. Therefore, even though there is a possibility that the loan was used for different activities, it was not effective in increasing income from such sources. It is also notable that there are no significant differences in total household incomes even after subtracting the loan repayments.

Supplementary analysis

Although not presented in this thesis, the published article by [Nakano and Magezi \(2020\)](#) presents additional analyses on the impact of BRAC program. In that publication, we first attempt to examine the impact of the program using ITT and LATE without ANCOVA. This is due to the

concern that between baseline and endline surveys, some farmers might have changed their sample plots and that would affect the endline results if we control for baseline dependent variables. Interestingly, the findings are consistent and robust to those presented here.

Second, there was a concern that farmers (especially in Ilonga where we don't observe significant changes in chemical fertilizer application) might have applied some of the chemical fertilizer in some other plots. Therefore, we analyzed the impact of using all rice-growing plots. However, we only have data on only few variables, including chemical fertilizer use, paddy yield, revenue, and paid-out costs of fertilizer, machinery, animals, and hired labor. We find almost consistent results to our main analysis, where farmers in Chanzuru increased the use of chemical fertilizer in other plots.

Third, we conducted the sub-sample analysis based on whether the household had received training before 2012 (by 2011 cultivation season). The purpose of this approach was to examine whether the training cut-off would offer a better comparison than the village-wise sub-sample. However, since most of the trained farmers are in Ilonga village, the results that are largely consistent to the village-wise sub-sample analysis presented in this chapter. We find that borrowers in the non-trained group increase the chemical fertilizer application, but they do not achieve higher yield or revenue. Therefore, our results remain robust even after we considering different empirical approaches in evaluating the impact of the BRAC program.

Table 4.4: ANCOVA estimates of the impact of the BRAC program on technology adoption: 2012

	Total Sample ITT	Total Sample LATE	Ilonga ITT	Ilonga LATE	Chanzuru ITT	Chanzuru LATE
	(1)	(2)	(3)	(4)	(5)	(6)
Use of chemical fertilizer (kg/ha): 2012	8.77* (4.881)	22.47* (12.163)	3.86 (8.096)	9.65 (19.797)	16.56*** (5.626)++	42.20*** (13.158)++
Modern variety: 2012	-0.78 (3.651)	-2.01 (9.266)	-4.01 (6.252)	-10.06 (15.615)	1.25 (4.004)	3.18 (9.957)
Adoption of improved bund (%): 2012	2.94 (2.555)	7.51 (6.424)	1.20 (3.499)	2.97 (8.412)	3.90 (3.558)	9.79 (8.616)
Adoption of leveling (%): 2012	-1.09 (4.990)	-2.80 (12.664)	0.31 (6.933)	0.79 (17.000)	0.32 (7.250)	0.82 (18.251)
Adoption of transplanting in row (%): 2012	0.94 (3.236)	2.41 (8.182)	-2.02 (6.291)	-5.09 (15.487)	2.38 (1.810)	6.11 (4.513)
Use of insecticide and herbicide (kg/ha): 2012	0.27 (2.889)	0.69 (7.266)	2.79 (4.746)	7.06 (11.706)	-2.49 (2.747)	-6.25 (6.768)
Cragg-Donald Wald F statistic		112.62		57.47		54.66
Observations (Household)	387	387	194	194	193	193

Source: Author (2020). *** denotes significant at 1%, ** significant at 5%, and * significant at 10% . +++ denotes significant at 1%, ++ significant at 5%, and + significant at 10% in multiple hypotheses testing. Robust standard errors in parentheses. In each estimation model, we control for household characteristics at baseline (i.e., total land holdings (ha), value of household assets (USD), number of adult household members, years of schooling of household head, female household head dummy, and age of household head) and the baseline dependent variable.

Table 4.5: ANCOVA estimates of the impact of the BRAC program on land productivity and production costs: 2012

	Total Sample ITT	Total Sample LATE	Ilonga ITT	Ilonga LATE	Chanzuru ITT	Chanzuru LATE
	(1)	(2)	(3)	(4)	(5)	(6)
Yield (t/ha): 2012	-0.15 (0.168)	-0.40 (0.428)	-0.41 (0.274)	-1.04 (0.677)	0.06 (0.188)	0.15 (0.466)
Revenue (USD/ha): 2012	-67.34 (70.468)	-172.54 (179.406)	-178.79 (113.446)	-447.33 (279.252)	28.09 (81.261)	71.57 (201.018)
Total input costs (USD/ha): 2012	6.59 (8.997)	16.87 (22.588)	8.96 (16.512)	22.51 (40.355)	8.50 (7.704)	21.50 (18.608)
Paid-out cost of labor use (USD/ha): 2012	-8.17 (22.045)	-20.82 (55.586)	-15.45 (32.945)	-38.85 (80.956)	5.64 (29.662)	14.30 (73.306)
Imputed costs of family labor (USD/ha): 2012	-71.80* (37.729)	-183.75* (95.049)	-43.83 (49.664)	-111.37 (123.513)	-95.43 (58.993)	-243.47* (145.462)
Paid-out cost of machinery and animal use (USD/ha): 2012	3.63 (6.977)	9.26 (17.515)	-4.65 (10.281)	-11.31 (24.479)	9.36 (9.581)	23.81 (23.811)
Imputed cost of machinery and animal use for (USD/ha): 2012	-0.77 (0.538)	-1.99 (1.372)	-1.11 (0.768)	-2.79 (1.893)	-0.66 (0.789)	-1.69 (1.987)
Income (USD/ha): 2012	-71.04 (66.906)	-181.67 (169.668)	-174.34 (109.718)	-440.51 (272.478)	5.22 (76.995)	13.27 (191.133)
Profit (USD/ha): 2012	0.91 (71.588)	2.32 (180.263)	-126.60 (112.748)	-325.75 (285.305)	109.86 (88.887)	278.37 (215.390)
Cragg-Donald Wald F statistic		112.62		57.47		54.66
Observations (Household)	387	387	194	194	193	193

Source: Author (2020). *** denotes significant at 1%, ** significant at 5%, and * significant at 10% . + + + denotes significant at 1%, ++ significant at 5%, and + significant at 10% in multiple hypotheses testing. Robust standard errors in parentheses. In each estimation model, we control for household characteristics at baseline (i.e., total land holdings (ha), value of household assets (USD), number of adult household members, years of schooling of household head, female household head dummy, and age of household head) and the baseline dependent variable.

Table 4.6: ANCOVA estimates of the impact of the BRAC program on household income variables and crops production costs: 2012

	Total Sample ITT	Total Sample LATE	Ilonga ITT	Ilonga LATE	Chanzuru ITT	Chanzuru LATE
	(1)	(2)	(3)	(4)	(5)	(6)
<i>Household income variables</i>						
Total household income (USD): 2012	-5.93 (132.345)	-15.10 (332.638)	134.85 (179.120)	335.27 (438.747)	-200.86 (187.592)	-513.20 (478.769)
Livestock income(USD): 2012	-8.10 (8.606)	-20.70 (21.838)	-19.23 (14.898)	-48.14 (36.792)	-0.70 (11.573)	-1.78 (28.756)
Business and wage labor income (USD): 2012	23.78 (114.493)	60.96 (289.833)	197.61 (156.678)	496.24 (391.789)	-185.04 (164.166)	-471.60 (414.842)
Total crop income (USD): 2012	-21.58 (52.029)	-54.94 (131.317)	-50.54 (79.404)	-125.65 (193.450)	-35.98 (61.203)	-92.81 (156.734)
Total crop revenue (USD): 2012	-41.69 (64.098)	-106.17 (162.402)	-115.61 (98.966)	-287.48 (243.200)	-34.36 (70.673)	-88.59 (180.653)
<i>Crops production costs</i>						
Total paid out costs for machinery and animal use (USD): 2012	0.54 (5.716)	1.38 (14.420)	-6.97 (7.795)	-16.91 (18.575)	5.74 (8.070)	14.83 (20.278)
Total paid out costs for hired labor (USD): 2012	-15.70 (16.736)	-40.22 (42.691)	-30.91 (25.225)	-77.90 (62.646)	2.33 (22.285)	5.94 (55.341)
Total costs for current input use (USD): 2012	2.42 (5.336)	6.20 (13.444)	2.32 (9.345)	5.78 (22.829)	4.25 (4.799)	10.88 (11.754)
Cragg-Donald Wald F statistic		112.62		57.47		54.66
Observations (Household)	387	387	194	194	193	193

Source: Author (2020). *** denotes significant at 1%, ** significant at 5%, and * significant at 10% . + + + denotes significant at 1%, ++ significant at 5%, and + significant at 10% in multiple hypotheses testing. Robust standard errors in parentheses. In each estimation model, we control for household characteristics at baseline (i.e., total land holdings (ha), value of household assets (USD), number of adult household members, years of schooling of household head, female household head dummy, and age of household head) and the baseline dependent variable.

Table 4.7: ANCOVA estimates of the impact of BRAC program on components of crop income and other household-level variables: 2012

	Total Sample ITT	Total Sample LATE	Ilonga ITT	Ilonga LATE	Chanzuru ITT	Chanzuru LATE
	(1)	(2)	(3)	(4)	(5)	(6)
<i>Components of crop income</i>						
Total rice income (USD): 2012	-52.24 (48.866)	-134.68 (125.536)	-54.63 (74.880)	-138.70 (185.576)	-71.29 (61.418)	-182.63 (158.939)
Income from crops other than rice (USD): 2012	23.93** (10.381)	60.94** (26.433)	-0.58 (8.240)	-1.43 (20.006)	39.43** (18.560)	102.01** (47.140)
<i>Other household-level variables</i>						
School Expenditure (USD): 2012	21.25 (27.800)	54.45 (70.406)	28.17 (31.317)	70.78 (76.721)	6.32 (43.932)	16.11 (109.554)
Medical Expenditure (USD): 2012	-9.16 (24.153)	-23.47 (61.453)	36.59 (34.120)	91.95 (82.087)	-33.49 (36.224)	-85.32 (92.291)
Use of credit other than BRAC Program (USD): 2012	2.15 (7.120)	5.51 (18.001)	-0.18 (12.525)	-0.45 (30.708)	7.85 (5.534)	19.95 (14.126)
Cragg-Donald Wald F statistic		112.62		57.47		54.66
Observations (Household)	387	387	194	194	193	193

Source: Author (2020). *** denotes significant at 1%, ** significant at 5%, and * significant at 10% . + + + denotes significant at 1%, ++ significant at 5%, and + significant at 10% in multiple hypotheses testing. Robust standard errors in parentheses. In each estimation model, we control for household characteristics at baseline (i.e., total land holdings (ha), value of household assets (USD), number of adult household members, years of schooling of household head, female household head dummy, and age of household head) and the baseline dependent variable.

4.6 Conclusion

This Chapter 4 analyzed the impact of microcredit on technology adoption and land productivity. We use data from the randomized control trial (RCT) of the microcredit intervention conducted in Tanzania. In the intervention, we offered microcredit to randomly selected farmers and investigated its impact on adopting technologies such as high-yielding modern varieties, chemical fertilizer, other agronomic practices, and land productivity. We first estimated the intention-to-treat (ITT) effect of farmers eligible to borrow credit from the program. In addition to ITT, we estimate the local average treatment effects (LATE) of the program, using eligibility status as an IV. We also apply the ANCOVA approach to increase estimation power. Overall, we do not observe any significant impact on technology adoption or increased paddy yield, profit, or household income. Lack of significant effect of credit on fertilizer use or paddy yield is consistent with [Njeru et al. \(2016\)](#), who found that credit use did not increase chemical fertilizer or paddy yield in Kenya.

We explored further by conducting sub-sample analyses comparing borrowers and non-borrowers in the irrigation scheme with better access to irrigation water and extension services against those without better access to irrigation water and extension services. Our results show that farmers in the irrigation scheme with good access to water and extension services apply a relatively high amount of chemical fertilizer near the recommended level, even without credit use. Therefore, even after some of them borrowed credit, they did not increase chemical fertilizer use. On the other hand, farmers without better access to irrigation water and extension services usually do not apply a high chemical fertilizer quantity. When they borrowed credit from the program, they significantly increased chemical fertilizer use. However, the increased use of fertilizer did not increase yield or profit for these farmers. Although this is not conclusive, low rates of yield response to an application of chemical fertilizer can be one of the possible reasons. If this is the case, our results support the argument that emphasizes the importance of the extension services

before the input and credit market development [Otsuka and Kijima \(2010\)](#).

Our results show that even though microcredit did not impact total household income, it significantly increased income from crops other than rice in the village without better access to irrigation water and extension system. However, the effect is not significant after multiple hypothesis testing. Our findings are consistent with previous studies, which report little or no impact of microcredit on the household income of small and medium-scale enterprises in urban and rural settings in developing countries ([Angelucci et al., 2015](#); [Attanasio et al., 2015](#); [Augsburg et al., 2015](#); [Crépon et al., 2015](#); [Hossain et al., 2019](#); [Tarozzi et al., 2015](#)). Our results suggest that it is crucial to understand clients' characteristics and their socioeconomic environment when MFIs design their loan products targeting clients in agricultural communities. Additionally, our findings suggest that credit access may not be the only constraint on rural households.

Chapter 5.

Impact of Mechanization of Rice Production

5.1 Introduction

In this chapter, we use three-year panel data from smallholder farmers in Tanzania to examine the impact of mechanization on rice cultivation. We apply the multinomial endogenous treatment model to account for multiple farm implements used for land preparation, including machinery, draft animals, and hand hoes. The rest of this chapter is organized as follows. Section 5.2 presents the status of mechanization in Tanzania and compares it to SSA using the macro statistical data. Section 5.3 describes the study area, data collection and hypothesis, while Section 5.4 presents the descriptive analysis. Section 5.5 discusses the empirical strategy followed by Section 5.6, which presents the estimation results of the effect of mechanization. The chapter conclusion is presented in Section 5.7.

5.2 Mechanization trend in Tanzania and SSA

5.2.1 Mechanization in SSA

To present the mechanization trend in SSA, we use statistical data from the Food and Agriculture Organization (FAO, 2020). The data contains information on the number of tractors, including TR and PT, from 1961 to 2002. We provide an overview using two figures: the first one showing the trend of agricultural mechanization in SSA in comparison with South East Asia (SEA) and South Asia (SA); the second one showing the mechanization trend in Tanzania.

Figure 5.1 shows the number of tractors in use in SA and SEA starts to increase rapidly in the early 1970s and in the 1990s respectively, while SSA does not exhibit such an increasing trend. The number of tractors in use increased steadily from 170,980 in 1961 to the peak at

246,320 in 1981, then decreased to 136,550 in 2002.¹ According to [Pingali et al. \(1987\)](#), tractors were introduced in SSA in three phases. The first phase was under the colonial rule between 1945 and 1955, when Zimbabwe, Kenya, Zambia, and Malawi started to introduce tractors. The second phase was from the late 1950s to the 1970s, when countries such as Tanzania, Ethiopia, Ghana, and Côte d'Ivoire started to promote state-sponsored mechanization schemes after their independence. The third phase was between the 1970s and the 1980s, when countries rich in oil and other exportable natural resources such as Nigeria, Cameroon, and the Democratic Republic of Congo (D.R.C) started to make efforts of increasing tractors use. However, most state-sponsored tractor rental schemes were discarded under the structural adjustment programs, resulting in the decline in the use of machinery in the 1990s [Pingali \(2007\)](#).

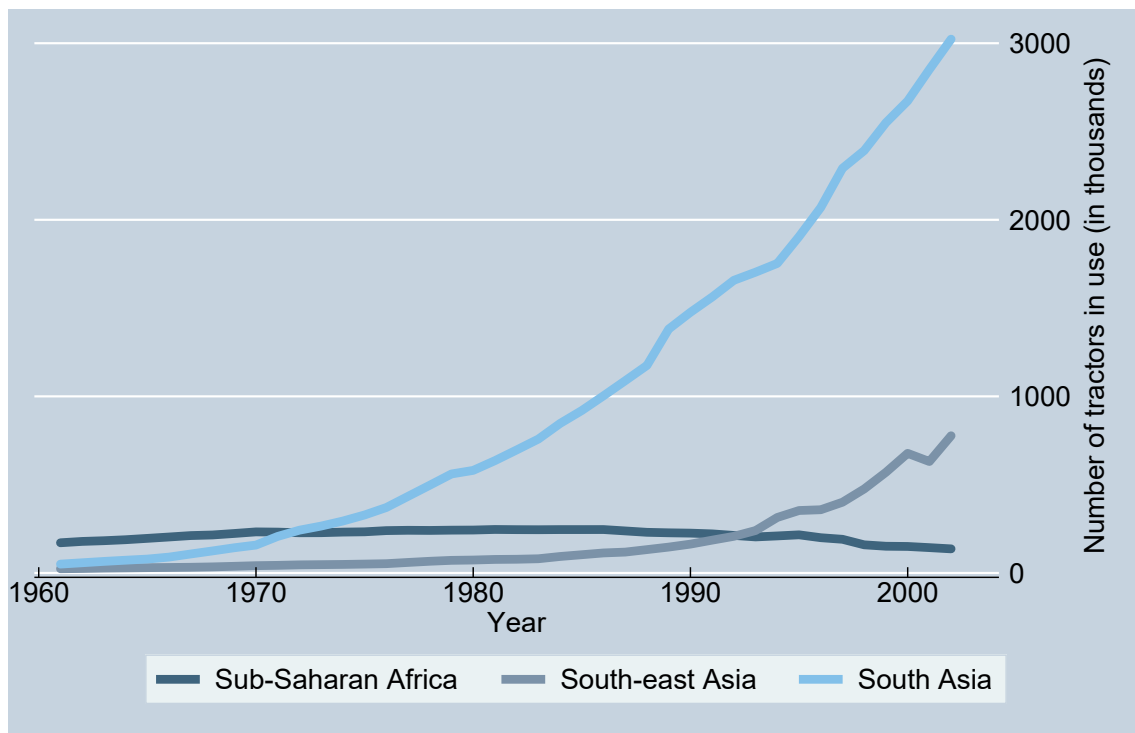


Figure 5.1: Number of tractors in use in SSA, SA, SEA

Source: Author using data from [FAO \(2020\)](#)

Although the macro statistical data after 2002 is not available, [Kirui and Braun \(2018\)](#) shows

¹ Please note that the FAO data is available only up to 2002.

that the tractor use has been increasing in several countries in SSA in the 2000s and 2010s. Their assessment categorizes Tanzania as one of the countries in SSA that had the highest mechanization and agricultural growth rates between 2005 and 2014. Other countries in the same categories are Angola, Botswana, Ethiopia, Malawi, Mali, Morocco, Niger, Rwanda, Togo, Zambia. The mechanization growth rate was also high in Burkina Faso, Burundi, Gambia, Senegal, South Africa, and Sudan (the former), but these countries were reported to have low agricultural growth rates.

Therefore, as farm machinery continues to be more common in SSA, it is important to understand their role, particularly on small-scale farms, to promote effective agricultural mechanization in the region.

5.2.2 Mechanization in Tanzania

In this subsection, we discuss the overall trend of agricultural mechanization in Tanzania based on macro statistics from the World Bank ([The World Bank, 2020](#)) and other previous literature. Figure 5.2 presents the total number of tractors and tractors per 100 square kilometers from 1961 to 2002. As the figure shows, agricultural mechanization in Tanzania can be divided into five main phases. The first phase was between the 1940s to 1961, before independence, when the colonial authorities introduced tractors as a part of economic recovery programs after World War Two ([Pingali et al., 1987](#)). Most tractor users were foreign settlers conducting large-scale cultivation of exportable crops, including coffee, sisal, and groundnuts. The rest of the farming system primarily relied on handheld tools and draft animal power for land preparation. Statistics show that by the time Tanzania gained independence in 1961, the total number of tractors was 16,550, and the number of tractors per 100 square kilometers was 31.8.

The second phase was between 1961 to 1967, where the number of tractors increased gradually across the country for two reasons. First, after the independence, some foreign settlers left the country, and their farms and equipment were placed under the management of local authori-

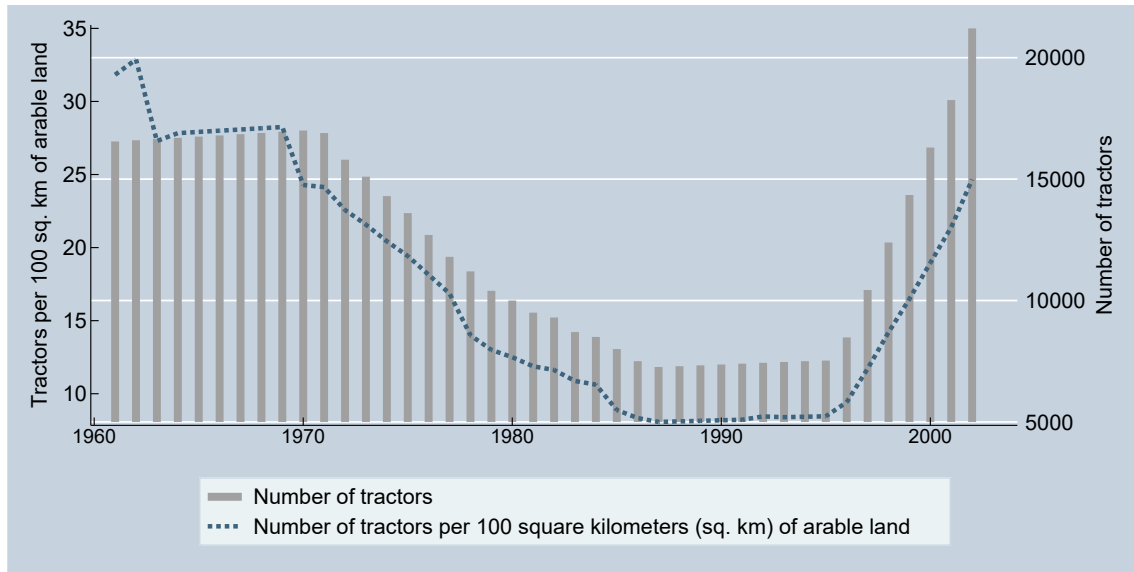


Figure 5.2: Number of tractors in use in Tanzania

Source: Author using data from [The World Bank \(2020\)](#)

ties and farmers cooperatives. Second, between 1962 and 1965, the government implemented the village settlement schemes ([Bryceson, 1982](#); [Meertens, 2000](#)). The project aimed to introduce a modern farming system, relying heavily on mechanization, fertilizers, and insecticides. Although the project contributed to an increase in the number of tractors, the demand for mechanization was still low and, tractors were operating below their utilization rates. Many village settlement schemes could not be productive enough without financial support, and the project was discontinued in 1966 ([Bryceson, 1982](#)).

The third phase was from 1967 to 1985, when the government implemented the socialist policy, called *Ujamaa* (translated as familyhood). The policy led to the nationalization of private banks, commercial farms, and other privately owned businesses. Between 1967 and 1973, the rural residents were relocated to the new or existing villages under the villagization campaign. Village residents were required to work collectively on the village farms, and each household was given a private farm of only about one acre ([Meertens, 2000](#)). Farmers were compelled to use tools suitable for their private farms, while tractors were primarily used on large communal

farms ([Mrema et al., 2020](#)). Farmers' incentive to increase productivity was low, partly due to centralized price control and the ineffectiveness of the input distribution system. By the early 1980s, the government was facing a budget deficit and gradually losing the ability to support state-sponsored programs, including mechanization. During that period, the number of tractors dropped from its peak of around 17,000 in 1970 to about 8,000 in 1985.

The fourth phase began in 1986, when the country entered the structural adjustment programs (SAP). Economic reforms that occurred in the first five years of SAP (1986 to 1991) include the elimination of the government's support on agricultural mechanization and phasing out subsidies for agricultural inputs. Even though the reforms eased the burden on the government's budget, it significantly resulted in high prices of tractors and spare parts, and other agricultural inputs ([Meertens, 2000](#)). Furthermore, donors' interests shifted towards draft animal power (DA), as they were considered more appropriate, given the low demand for mechanized tillage and the economic condition of that time. The number of tractors remained around 7,500 units. Tanzania's mechanization trend between 1961 to the late 1990s is in line with that of the SSA in general ([Magezi et al., 2021](#)).

During the fifth phase that began from the late 1990s, the country observed a significant increase of tractors, including TRs and PTs. From 1991, reforms for liberalization of financial sectors under SAP were implemented in phases, allowing the establishment of private banks and the deregulation of the interest rate structure. This enabled large-scale farmers and private entrepreneurs to access credit more efficiently and invest in economic activities. In 1995, the land policy was enacted, allowing investment in agriculture by the private sector and foreign investors and provided incentives for local communities to invest in land development. These changes in land tenure and financial policies gradually brought results and contributed to the increase in tractors from the late 1990s.

The trend of machine use in Tanzania after the late 1990s differs from that of other African

countries, and one reason is the rapid increase of PTs. In the early 2000s, PTs were introduced in Tanzania, and they have continued to increase ever since (Agyei-Holmes, 2016). According to Mrema et al. (2018), roughly 70% of all PTs in the SSA are located in Tanzania, Madagascar, and South Africa. Usually, PTs are imported directly by private entrepreneurs and farmers from India, China, and Japan, but the process is considered to be costly. The government had intervened from time to time by importing agricultural implements in bulk and then selling them to private owners at subsidized prices. Mrema et al. (2020) show that the number of PTs increased significantly in 2009 after the government imported more than 2000 PTs and distributed them to private buyers in various districts. Between 2005 to 2015, the number of PTs in the country increased from roughly 300 to about 9,000. Around the same period, the number of operational TRs rose from 7,200 in 2005 to nearly 13,000 in 2014 (Mrema et al., 2020). As we mention earlier, Kirui and Braun (2018) shows that Tanzania is one of the countries in SSA with the highest mechanization and agricultural growth rates between 2005 and 2014.

Despite the increase, the distribution of TRs and PTs is not even across the country. The northwestern regions of Tanzania, including Shinyanga, Tabora, and Mwanza, are still dependent on draft animals. There are also differences in the number of TRs and PTs across regions, mainly due to the type of crops grown, soil characteristics, and the availability of spares and machinery repair services. In general, about 62 percent of farms are still being plowed with hand plows, while 14 percent are being prepared for TRs and PTs, and 24 percent are dependent on DA (Mrema et al., 2020).

5.3 Study Site, Data and Hypotheses

5.3.1 Study site

In the following sections, we investigate the role of machinery used on rice cultivation by using a part of the Extensive Survey (ES) data set used in Chapter 3, Section 3.4. We initially intended

to examine the role of mechanization using the complete ES data set. However, as shown in Table 3.1 (Chapter 3), we found that tractors are not widely adopted in Lake Zone. One possible reason is that most of the farmers in this zone are also pastoralists, and they mainly use their own draft animals for land preparation activities.² Furthermore, during our field visit, we found that Kyela district in Mbeya also has low rates of machinery use and draft animals are commonly used. Therefore, our analysis excludes observations from these areas.



Figure 5.3: Villages used in evaluating the impact of mechanization
Source: Author (2020)

²The number of livestock is shown in Chapter 2, Figure 2.3

Instead, we use data collected from two districts of Morogoro region (Kilombero and Mvomero districts), the Mbarali district in the Mbeya region (Figure 5.3). In our study area, there are two cropping seasons. During the main season, farmers grow rice in rainfed or irrigated lowlands and other crops such as maize and legumes in the upland plots. In the short season, most lowland plots are left to fallow, except in irrigated lowlands where farmers grow vegetables and seasonal crops. Since most crops, including rice, are grown in the main season, usually there is a surge of demand for hired labor and farm machinery, especially at the beginning of the season. For rice plots preparation, farmers use TR, PT, DA, and handheld tools, depending on their accessibility and rice plots condition. Farmers can access machinery through rental services offered by private operators. In most cases, TR and PT operators are stationed in nearby urban centers and move to rice-growing areas to offer the service after the season starts. The fees for machinery rental services are not regulated and depend on service providers and farmers' agreement.

5.3.2 Data

The data set we are using in this Chapter covers 34 villages in three districts. In each village, ten households were randomly selected, generating a total sample of 340 at the baseline. We replaced households if the original household at the baseline is missing in the following surveys. We dropped outliers and some observations that had missing values in key variables. As a result, we obtained unbalanced panel data with the number of observations of 985 households in three years.

Our sample includes farmers who grow rice in both rain-fed and irrigated areas. During the survey, we asked farmers to identify the most important plot (hereafter called sample plot) and asked in detail about the machinery use and other information related to rice cultivation. Therefore our data is not plot-level but household-level panel data. In addition to rice cultivation in the sample plot, other household-level information, including basic household characteristics,

crop cultivation in dry season and rain season, livestock keeping, household assets, and access to credit were collected. In addition to household-level surveys, we also conducted interviews with village leaders in each round of the survey. During the interview, information such as access to machinery rental services and other village-level data were collected.

In addition, we gathered the data on village-level population density from the database compiled by NASA Socioeconomic Data and Applications Center (SEDAC) and Center for International Earth Science Information Network ([SEDAC, 2020](#)). The datasets cover the global population density estimates for 2000, 2005, 2010, 2015, and 2020. Since the available data do not cover survey years (i.e., 2009, 2012, and 2018). We use data from the closest years prior to our survey.³ The data sets are available in the form of a GIS raster, with the resolution of one square kilometer per pixel. We merge the raster data set with the GPS coordinates of our sample villages, then extract the population density values.

5.3.3 Hypotheses

To postulate our hypotheses, we rely on the existing mechanization literature and our observations during field visits. Regarding the association between mechanization and cultivated area, [Pingali \(2007\)](#) suggests that tractors can be more effective for expanding the household's cultivated area in scenarios where either the household can easily extend their farm into fallow land or can reclaim the land that is outside the frontier. However, this tends to differ depending on the cropping system and agro-ecological environment. In the context of rice farming, cultivated areas can be expanded more easily in rainfed lowlands than in irrigated lowlands. This is because, in irrigated lowlands, it is considered difficult to expand the land area due to permanent farm infrastructures such as bunds and water canals.

Furthermore, there is a growing viewpoint that in rainfed ecosystems, mechanization can

³We use the 2005 population data for the 2009 survey, 2010 data for the 2012 survey, and 2015 data for the 2018 survey.

also facilitate the expansion of cultivated areas within a farm unit by helping to speed up the land preparation process, allowing timely crop establishment. According to personal interviews with extension officers, farmers in rainfed lowlands cannot prepare their plots before the rain season because the land is too dry, particularly if the soil composition has a high content of clay. Tractors are considered to help farmers prepare a large portion of the plots within a short time. If this viewpoint holds, we expect that tractors' use will have a positive relationship with the area cultivated within a rice plot.

Mechanization is also expected to play a role in labor productivity and land productivity, but the association is not straightforward. This is because the mechanized tillage only reduces the labor required for land preparation activities, and does not directly improve land productivity, since there is no evidence of the significant difference in yields based on whether the tillage was performed with hand hoes, animal traction tractors (Pingali et al., 1987). Therefore, we expect that the effects on productivity will depend on where the freed workforce is reallocated. If it is reallocated to carry out yield-enhancing labor-intensive agronomic practices such as transplanting and weeding, it may positively affect the amount of crop harvested per unit land area (land productivity) (Diao et al., 2016; Nin-Pratt and McBride, 2014). On the other hand, it should be noted that the adoption of such agronomic practices will also increase labor demand, hence negatively affecting the amount of crop produced per unit labor use (labor productivity). Therefore, we hypothesize that:

Therefore, we hypothesize that:

- H I: Mechanization facilitates the expansion of the cultivated area, particularly in rainfed lowlands, measured by the positive association between PT or TR use of the cultivated area within the rice plot.*
- H II: Mechanization will enhance the adoption and performance of modern rice technologies, which will induce the increase in land productivity, which is measured by the positive relationship between TR or PT and paddy yield, income, and profit.*
- H III: Mechanization will increase the efficient use of labor and result in high labor productivity,*

which is measured by the positive association between TR or PT use and the amount of paddy produced per unit labor use.

5.4 Descriptive analysis

Table 5.1 shows the changes in farm appliances for land preparation from 2009 to 2018 among our sample farmers (Panel A). We also present other key village-level variables such as the availability of machinery and draft animal in the village, wage rates of hired labor for land preparation activities, machinery rental rates, and village-level population density (Panel B).

The descriptive results show that over time, the proportion of farmers using four-wheeled tractors (TRs) and power-tillers (PTs) has increased, while the use of handheld tools (HT) declines, and the draft animals (DA) remain nearly unchanged. By 2009, about 33 percent of the farmers in our sample already used TRs. The percentage continued to rise, reaching about 42 in 2018. During the same period, the use of PTs increased from less than 3 percent in 2009 to about 16 in 2018. As we mentioned in Section 2, PTs were less common in years before our surveys, and they were imported in large numbers in 2009. Since then, the proportion of farmers using PTs and their rental market size has increased. They are also consistent with [Kirui and Braun \(2018\)](#) and [Mrema et al. \(2018\)](#), who show a high growth rate of farm mechanization in some SSA countries, including Tanzania.

Unlike TRs and PTs, the use of DA remains nearly unchanged, while handheld tools declined from about 39 percent in 2009 to 17 percent in 2018. We investigate further what tools were used in 2009 by the farmers who used TRs and PTs in 2018 (Table C2, in the appendix). We find that out of all of the sample farmers who used TRs in 2018, about 67 percent had used TRs in 2009, and 27 percent transitioned from using HT use, and 6 percent from DAs use. Regarding PTs, only 3 percent of PT users in 2018 had used PTs in 2009, while 50 percent transitioned from DA and 29 percent from HTs. This suggests that transitions from HTs to TRs and that from HTs

and DAs to PTs were active, whereas such transition is rarely observed from DA to TRs.

In Panel B, we also observe a significant increase in the number of machinery in the village, particularly PTs. In 2009, each village had an average of 2.3 TRs and 0.7 PTs. In 2018, the average number of TRs per village slightly increase to 3.4 while the number of PTs increased to 8.2. The growing number of TRs and PTs indicates that there is an evolving machinery rental service that might have contributed to the increased use of machinery among farmers. During this period, the wage rate for hired labor increased from 4.3 to 6.3 thousand Tanzanian Shillings per day, which also might have induced agricultural mechanization. The population density also increased over time from 65 to 81 people per square kilometer from 2009 to 2018, suggesting an increased demand for food in rural areas.

In Table 5.2, we compare rice cultivation-related variables based on farm implements used for land preparation. We categorize our sample into irrigated and rain-fed and further divide into TRs, PTs, DA, and HTs users for land preparation. We conduct a *t*-test comparison of TRs, PTs, and DA against HTs users.

Panel A shows the size of the cultivated area and technology adoption in sample plots. Farmers sometimes grow rice in a part of their plots and leave the remaining part fallow. Therefore, we distinguish the area under cultivation in the sample plot from the size of the plot. As important technologies for rice cultivation, we show the adoption rate of modern varieties (MVs), chemical fertilizer use, and the adoption rate of bunding, plot leveling and transplanting in rows. Bunds are constructed by piling soil around the paddy plot for water and soil nutrients management. Although bunds are common in irrigated lowlands, they are applied less frequently in rainfed lowlands. Leveling is the process of moving soil from a raised part to a lower part of the paddy field while making sure that the topsoil is evenly distributed. Leveling facilitates uniform distribution of water and soil nutrients in rice basins and allows even paddy growth. Transplanting in rows is important for controlling the plant density and easing the weeding. All these technologies are

labor- and care-intensive but essential to achieve high paddy yield (Nakano et al., 2018b; Otsuka and Larson, 2013, 2016).

The descriptive results in Panel A show that farmers who use TRs, in both irrigated and rainfed plots cultivate more area than handheld tools users within a plot. This is in line with the literature indicating that mechanized tillage can play a role in expanding the area under crop cultivation (Pingali, 2007; Takeshima et al., 2013). In terms of technology adoption, TR users in both irrigated and rain-fed areas have low adoption rates of bunds, possibly because TRs are large and likely to destroy bunds when they are being transported to plots. TR users are also less likely to adopt transplanting in rows and MVs than HTs users. This is possibly because TR users do not want to adopt these labor- and care-intensive technologies after they expand cultivating areas.

PT users in both irrigated and rain-fed areas cultivate larger area than HTs users, similar to TRs users. Their technology adoption pattern, however, differs from that of TRs users. In irrigated lowlands, PT users apply more chemical fertilizers, insecticides, and herbicides but have low adoption rates of MVs. Contrary to TRs, farmers who use PTs in rainfed lowlands achieve higher adoption rates of bunds and transplanting in rows, chemical fertilizers, and insecticides, and herbicides. The results suggest that PTs are positively associated with intensive use of yield-enhancing technologies. It is also notable that most farmers do not use their own TRs, while 9 to 17 percent of farmers use their own PTs. This implies the importance of access to the rental machinery market.

Turning to land and labor productivity in Panel B, the results show that the use of TRs is not associated with high paddy yield or any other land productivity variable. In rainfed lowlands, TR users achieve even lower paddy yield than HT users, possibly due to low adoption rates of yield-enhancing technologies. On the other hand, farmers who use PTs achieve paddy yields of about 5.3 tons per hectare in irrigated areas and 4.1 tons per hectare in rainfed areas, which are significantly higher than PT users. Their revenues and profit per hectare are also high. PT and

TR users successfully reduce labor use per hectare and achieve high labor productivity.⁴ This suggests that, even though PTs and TRs might have different roles in enhancing land productivity, their contribution to reducing labor use and improving labor productivity is the same.

In Table 5.3 , we present the area under rice cultivation at the household level, total household income, and its components. Note that since some farmers grow rice in more than one plot, the area under cultivation within a plot in Panel A and at the household level shown here should be distinguished. Both TR and PT users grow rice in the larger area, suggesting that mechanization allows area expansion at the household level. Generally, the results show that rice farming accounts for a large part of household income across all groups, indicating the importance of rice production on farmers' income. In irrigated lowlands, farmers who use TRs obtain more income from rice cultivated in sample plots, suggesting that even though TR use is not associated with higher income per hectare, they may result in higher total income by facilitating the expansion of the cultivated area than HT users.

In irrigated lowlands, TR users obtain high income from business and wage activities. PT users in both irrigated and rain-fed obtain significantly higher income from total rice produced in non-sample rice plots and income from crops other than rice than HT users. As a result, they achieve a higher total household income.

Note, however, that machinery use here is measured only in the sample plot and we do not have detailed data on machinery and labor use in other plots. Since farmers on average cultivate 1.5 rice plots, we need to admit that our mechanization variable is pronoun to measurement error when the outcome variable is at the household level. Nonetheless, our results suggest that mechanization in the sample plot contributes to the expansion of rice cultivating areas for households. Furthermore, the labor freed from rice cultivation in the sample plot seems to be reallocated to

⁴Although the mechanized plots have low labor use, such labor reductions are primarily associated with land preparation activities. For other activities such as transplanting, bird scaring, and harvesting, the labor use, particularly hired labor is significantly high, as shown in Table C4 in the Appendix.

other income-generating activities, which makes farmers achieve high household income.

Table 5.1: Accessibility and use of machinery rental service and related variables at village level

	(1)	(2)	(3)
VARIABLES	2009	2012	2018
<i>Panel A: Farm appliances used by the household to prepare rice plots:</i>			
Use of PTs or TRs (%)	35.76	46.11	59.28
Use of TRs (%)	33.33	38.94	42.51
Use of PTs (%)	2.42	7.17	16.77
Use of DA (%)	24.55	28.04	23.65
Use of handheld tools (%)	39.7	25.86	17.07
<i>Panel B: Machinery rental market and wage rates and population density at the village-level:</i>			
Number of TR in the village	2.27	4.8	3.36
Number of PT in the village	0.74	2.05	8.24
TR rental fee ('000 TShs/acre)	40.73	40.04	25.22
PT rental fee ('000 TShs/acre)	43.16	40.73	32.11
DA rental fee ('000 TShs/acre)	38.12	33.99	22.73
Wage rate of using hired labor for land preparation ('000 TShs/day)	4.34	6.33	6.26
Population density ('00 people/km ²)	0.65	0.73	0.81

Source: Authors, (2020).

Notes: (i) TRs, PTs, and DA stand for four-wheeled tractors, power tillers, and draft animals, respectively. (ii) All the monetary values are adjusted for inflation using the 2009 value of Tanzanian Shillings (TShs). (iii) Since not all villages have machinery rental markets, TRs and PT's rental rates are based on villages where their market exists.

Table 5.2: Cultivated area, technology adoption, and productivity by farm implements used for land preparation

VARIABLES	Irrigated				Rainfed			
	TR	PT	DA	HT	TR	PT	DA	HT
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
<i>Panel A: Cultivated area and technology adoption</i>								
Area cultivated in sample plot (ha)	1.14***	1.00***	1.17***	0.53	1.20***	1.37***	1.45***	0.78
Adoption rate of plot leveling (%)	67.39	70.73	74.62	70.59	27.19	36.96	44.17*	34.07
Adoption rate of bunds (%)	73.91***	90.24	90.77	92.65	15.71**	86.96***	50.00***	24.44
Adoption rate of transplanting in rows (%)	15.22***	60.98	20.77***	48.53	2.42***	26.09**	15.83	11.11
Adoption rate of MVs (%)	39.13***	65.85*	13.08***	78.68	20.85***	45.65	21.67***	37.78
Amount of chemical fertilizer used (kg/ha)	62.45	131.23***	36.16**	57.33	20.79	80.27***	33.97**	18.11
Amount of insecticide and herbicide used (liter/ha)	1.81	2.40*	0.74***	1.74	2.19***	2.24***	2.87***	1.22
<i>Panel B: Land and labor productivity</i>								
Paddy yield (tons/ha)	3.78	5.27***	3.43	3.72	2.09***	4.12***	2.72	2.54
Revenue per hectare ('000 TShs/ha)	1694.89	2,209.82***	1596	1547.25	822.86**	1,479.40***	1028.67	999.81
Income per hectare ('000 TShs/ha)	1016.51	1,355.29**	1092.2	1017.44	444.88***	913.66	659.11	704.16
Profit per hectare ('000 TShs/ha)	806.02	1,171.64***	732.49	613.12	274.41	731.83***	392.31	301.07
Labor use per hectare (person-days/ha)	162.64***	202.45***	173.53***	273.08	113.27***	114.03***	111.32***	205.97
Labor productivity (kg/person-days)	32.95***	34.50***	30.59**	20.26	28.13**	61.94***	39.31***	21.02
Observations (Households)	46	41	130	136	331	46	120	135

Source: Author (2020).

Notes: (i) TR, PT, DA, HT respectively denote the use of Four-wheeled tractors, Power tillers, draft animals, and Handheld tools for land preparation activities in sample rice plot. (ii) *** denotes significant at 1%, ** significant at 5%, and * significant at 10% in *t*-test comparison. (iii) All the monetary values are adjusted for inflation using the 2009 value of Tanzanian Shilling (TShs).

Table 5.3: Household income and its components by farm implements used for land preparation

VARIABLES	Irrigated				Rainfed			
	TR	PT	DA	HT	TR	PT	DA	HT
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Area under rice cultivation at HH level (ha)	1.45***	1.80***	1.55***	0.86	1.51***	2.10***	1.77***	1.07
Total household income ('00,000 TShs)	22.08	30.04***	26.50***	15.02	14.26	30.06***	18.87***	11.15
Income from rice grown in sample plot ('00,000 TShs)	10.80***	11.90***	11.65***	4.68	4.60	9.71***	9.84***	4.71
Income from rice grown in non-sample plots ('00,000 TShs)	2.77	6.90**	4.94*	2.58	2.16	7.52***	2.67	1.91
Income from crops other than rice ('00,000 TShs)	3.39	8.39***	7.60***	3.33	2.58	6.87***	2.96	2.42
Income from livestock production ('00,000 TShs)	2.01	1.92	1.57	0.88	1.03	3.10***	0.65	0.4
Income from business and wage activities ('00,000 TShs)	3.11	0.92	0.74*	3.54	3.89*	2.85	2.74	1.7
Farmers who used their own TR or PT (%)	0.00	17.07	N/A	N/A	0.6	8.70	N/A	N/A
Observations (Households)	46	41	130	136	331	46	120	135

Source: Author (2020). TR, PT, DA, HT respectively denote the use of Four-wheeled tractors, Power tillers, draft animals, and Handheld tools for land preparation activities in sample rice plot. *** denotes significant at 1%, ** significant at 5%, and * significant at 10% in *t*-test comparison.

5.5 Empirical strategy and key variables

5.5.1 Empirical strategy

To examine the effects of mechanization, we consider that farmers make their own decisions on whether to adopt a certain agricultural technology or not, which may cause the problem of endogeneity. Particularly in this study, the endogeneity problem may arise if unobserved factors that affects household's decision to use a certain implement for land preparation are also correlated with outcome variables such as paddy yield and revenue. For example, if some rice farmers have high motivation, such a trait can lead them to seek knowledge about tractor use as well as how to improve paddy yield. Therefore, such unobserved factors must be controlled to establish the causal relationship between mechanization and rice cultivation.

To address this challenge, we apply the multinomial endogenous treatment effect (METE) model ([Deb and Trivedi, 2006a,b](#)). The model allows us to evaluate the alternative choices of farm implements used for land preparation (i.e., TR, PT, DA, and handheld tools). It also allows us to correct for endogeneity and the potential interdependence in adoption decisions. We also follow the lead of [Kim et al. \(2019\)](#) and combine the METE model with the Mundlak-Chamberlain approach (we refer this model as, CRE-METE). This allows further control for time-invariant unobserved household-level heterogeneity that may correlate with observed variables. In Mundlak-Chamberlain approach, the mean values of time-variant household-level explanatory variables are included in the estimation model as additional aggressors.

The estimation of METE model involves two stages. In the first stage, farmer's choice to use one of the four farm implements for land preparation is determined. Our dependent variable for this stage is a categorical variable which takes one if the household used TR for preparation of sample plot, two if PT was used (but no TR was used), three if DA was used (but no TR or

PT was used), and zero if only handheld tools were used.⁵ This categorization is similar to the one used in descriptive analyses. There were few cases where farmers used both TP and DA for land preparation. After close examination of the original data and questionnaire, we classify these household under DA category. We denote this categorical variable as j , where is $j = 0, 1, 2, 3$ for handheld tools, TR, PT, and DA respectively.

Following [Deb and Trivedi \(2006a\)](#) and [Deb and Trivedi \(2006b\)](#), let EV_{ij}^* denote the utility obtained by household i from using j^{th} implement for land preparation activities in their sample rice plot as:

$$EV_{ij}^* = z_i' \alpha_j + \delta_j l_{ij} + \eta_{ij}. \quad (5.1)$$

Without loss of generality, let $j = 0$ denote the base category (i.e., handheld tools) and $EV_{ij}^* = 0$. z_i is a vector of exogenous covariates and α_j are parameters associated with z_i . l_{ij} is unobserved characteristics affecting household i 's decision on using j^{th} for land preparation as well as the outcome variables such as paddy yield and revenue. η_{ij} are independently and identically distributed error terms.

It should be noted that, EV_{ij}^* is not directly observed. Instead we observe a vector of binary variables, d_i , indicating whether the household used TR, PT, or DA to prepare their rice plots (i.e., $d_i = d_{i1}, d_{i2}, d_{i3}$). The probability of using either choice of j is expressed as:

$$\Pr(d_{ij} = 1 \mid z_i, l_{ij}) = g(z_i' \alpha_j + \delta_j l_{ij}), j = 0, 1, 2, 3 \quad (5.2)$$

Following [Khonje et al. \(2018\)](#) and [Kim et al. \(2019\)](#) we assume that g has a mixed multinomial logit structure, presented as:

$$\Pr(d_{ij} = 1 \mid z_i, l_{ij}) = \frac{\exp(z_i' \alpha_j + \delta_j l_{ij})}{1 + \sum_{k=1}^3 \exp(z_i' \alpha_k + \delta_k l_{ik})} \quad (5.3)$$

⁵This categorization is similar to the one use in descriptive analysis.

Therefore, we estimate the first stage by applying the pooled multinomial logit (MNL) model, which is commonly used for categorical dependent variables with outcomes that have no natural ordering. We combine the MNL model with Mundlak-Chamberlain approach, where the over-time averages of household-level explanatory variables (Mundlak-Chamberlain device) are included as additional regressors (we refer the first stage estimation model as CRE-MNL). Although not presented in the manuscript, we conducted Hausman test and confirmed that our specification does not violate the independence of irrelevant alternatives (IIA) assumption of multinomial logit.

To control for endogeneity, we use a set of potential IVs, including the distance from home to sample plot, the number of four-wheeled tractors (TRs), and two-wheeled tractors (PTs) in the village, population density, and the number of bulls owned by the household.⁶ All these variables enhances the use of machinery and draft animals, but are less likely to correlate with the outcome variables of rice cultivation. For example, regarding distance from home, preparing a plot using handheld tools takes longer than TR, PT, and DA. If a remotely located plot is prepared with handheld tools, it would cost the farmer time and money to make several trips to and from the plot. Therefore, we expect the farmer with plots located far from home to use TR, PT, or DA for land preparation rather than using manual tools.

The second stage is estimated by using the Ordinary Least Square (OLS) with the selectivity correction term obtained from the first stage, and Mundlak-Chamberlain approach.⁷ The second stage equation is denoted as:

$$E(y_{i,r} | d_i, x_i, l_i) = x_i' \beta + \sum_{j=1}^3 \gamma_j d_{ij} + \sum_{j=1}^3 \lambda_j l_{ij} \quad (5.4)$$

where $y_{i,r}$ is the outcome variable of interest, such as rice technologies, land productivity and

⁶To avoid the reverse causality problem, the number of bulls was not included as an IV for total household income, income from business and wage activities, and income from livestock production.

⁷Although the estimation of METE-CRE is a two stage process, it is implemented using a single STATA command called *mtreatreg*.

labor productivity. x_i is the vector of exogenous covariates and β is the associated parameter. Parameters γ_j (for $j = 1, 2, 3$) denote the effects of using TR, PT, DA, relative to base category (i.e., handheld tools). The model is estimated using a maximum simulated likelihood approach and 300 Halton sequence-based quasi-random draws. We assume the outcome variables follows the normal distribution.⁸

Although there is no direct way to test if our IV satisfies exclusion restrictions, we conduct falsification tests to examine the validity of our IVs, following [Di Falco et al. \(2011\)](#). The basic idea is that if the IVs for mechanization satisfy the exclusion restriction, they should not have any significant effect on outcome variables of the sample households that used only handheld tools (i.e., $j = 0$). We test this by including the candidate IVs as additional explanatory variables along with z_i in a regression involving only households that used handheld tools. The tests are conducted for each dependent variable of interest (i.e., cultivated area, yield, etc.) using pooled OLS regression with Mundlak–Chamberlain device (CRE-POLS). If the potential IV is significantly associated with outcome variables in the falsification tests (regardless of the coefficient sign), they are not used in the second stage.⁹ Therefore, we use a different set of IVs for each dependent variable. We also examine whether the estimation model would still satisfy the exclusion restriction even after dropping some IVs that did not pass the falsification tests. For this purpose, we conduct the Wald Test for joint significance of the exclusion restriction for different specifications of the multinomial model. The results presented in Table C8 in the appendix show that including any set of IVs leads to a statistically significant improvement in the fit of the first stage multinomial models.

⁸We use the STATA command *mtreatreg* to implement the METE-CRE model.

⁹Results for falsification tests are presented in the Table C5 to C7 in the appendix.

5.5.2 Key variables

Our empirical analysis focuses on three groups of dependent variables, selected based on their relevance in testing our hypotheses. The first group covers variables related to cultivated area and technology adoption in the sample plot. Variables in this group are: (i) Area cultivated in sample plot (ha), (ii) Adoption rate of plot leveling (%), (iii) Adoption rate of bunds (%), (iv) Adoption rate of transplanting in rows (%), (v) Adoption rate of MVs (%), (vi) Amount of chemical fertilizer used (kg/ha), and (vii) Amount of insecticide and herbicide used (liter/ha).

The second group presents key variables related to land productivity and labor productivity, which are: (i) Paddy yield in sample plot (tons/ha), (ii) Revenue from rice cultivated in sample plot ('000 TShs/ha), (iii) Income from rice cultivated in sample plot ('000 TShs/ha), (iv) Profit from rice cultivated in sample plot ('000 TShs/ha), (v) Labor use in sample plot (person-days/ha), and (vi) Productivity of labor use sample plot (kg/person-days).

The third group is not directly related to our hypotheses but aims to examine the broader implication of mechanization beyond land productivity and labor productivity. We consider that on farmers' perspective, what is important for them may be the total revenues they obtain after investing in crop production, rather than the benefits they obtain per unit of land or per unit of labor use. Furthermore, we expect that if there will be labor-saving due to mechanization use in the sample plot, the freed labor force will be allocated in other economic activities. Since the labor-saving occurs during the busy months of crop cultivation, we focus on incomes from crops cultivation rather than overall household income. Therefore, we examine the effect of mechanization on the total rice production and its derivatives and their potential effect on income obtained from cultivation of other crops. These variables are: (i) Area under rice cultivation at HH level (ha), (ii) Total household income ('00,000 TShs), (iii) Income from rice grown in sample plot ('00,000 TShs), (iv) Income from rice grown in non-sample plots ('00,000 TShs), (v) Income from crops other than rice ('00,000 TShs), (vi) Income from livestock production ('00,000 TShs), and (vii) Income

from business and wage activities ('00,000 TShs).

5.6 Estimation Results

The estimation results for the determinants and impact of mechanization are presented from Table 3 to Table 6. In each estimation, we report robust standard errors clustered at the household level in parentheses. As basic household and plot-level characteristics, we also control for the number of working-age adults, years of schooling of household head, female-headed household, age of household head, landholdings in the lowlands, and upland area, the value of non-farm household assets, amount of credit received by the household, whether the irrigated plot, total rainfall amount during the land preparation season, size of the plot, and district and year interaction dummies.

Table 5.4 presents the first stage results for the determinants of the TRs, PTs, and DA for land preparation. Results are shown in three columns. Column 1 shows the results for the use of TRs, while columns 2 and 3 show the results for PTs and DA, respectively. The base category is the use of handheld tools. We found a positive relationship between population density and the use of TRs and DA. This result is consistent with [Pingali et al. \(1987\)](#), who suggested that as the population grows and the food demand increases, mechanized tillage either by TRs or DA becomes necessary to expand the cultivated area.

We also found that the existence of TRs and PTs in the village increases the probability of farmers using them. Since few farmers use their own machinery, the result may suggest that access to the rental machinery market seems to be an important determinant of machinery used, as [Binswanger and Rosenzweig \(1986\)](#) argue. Furthermore, our estimates show that the distance from the farmer's home to the sample plot is associated with a high probability of using farm machinery and DA. We also find that that TRs are less likely to be used in irrigated plots. It is difficult for heavy and large TRs to be moved to the farm and maneuvered within a plot without destroying bunds and irrigation channels because there are no special roads for machinery to pass in paddy

fields in Tanzania. Our estimations show that farmers with large plots are likely to use TRs, PTs, and DA. We also find that the amount of non-farm household assets increases the probability of using TRs, PTs, and DA, suggesting that wealthy farmers are more likely to use machinery.

Table 5.5 shows the impact of mechanization on the area cultivated within the sample plot and technology adoption. On average, the use of TRs is associated with an increase of cultivated area within the sample plot by 0.34 hectares compared to HTs use. On the other hand, TRs are negatively associated with the adoption of bunds and MVs. One of the possible reasons is that labor- and care-intensive technologies are less likely to be adopted in large plots because they require high monitoring costs for hired labor (Hayami and Otsuka, 1993). Contrary to TRs, the use of PTs does not increase the cultivated area within sample plots. We also find that the use of PT is positively associated with the adoption of yield-enhancing technologies, including bunds, transplanting in rows, chemical fertilizer application, and insecticides and herbicides application. The use of PTs significantly increases adoption rates of bunds by about 18.9 percent and transplanting in rows by 14.0 percent. PTs are also associated with high chemical fertilizer application of about 45.3 kilograms per hectare and insecticides and herbicides of 0.7 liters per hectare.

The estimation results of the impact of mechanization on land productivity and labor productivity are presented in Table 5.6. The results show that the paddy yield of TR users is not statistically higher than that of HT users. On the other hand, the use of PTs is positively associated with an increase in paddy yield of about 1.2 tons per hectare. The yield gain results in high revenues of about 355,000 TShs per hectare and a profit of about 446,000 TShs per hectare. However, the income per hectare of PT users is not statistically higher than that of HT users, perhaps because of increased production costs, including machinery rental costs. We find that TRs are associated with a significant reduction in labor use, which positively affects land productivity. Compared to handheld tools, TRs increase labor productivity by 14.3 kilograms of paddy per person-days of labor use. PTs are also associated with a significant reduction in labor use, increasing labor pro-

ductivity by 11.9 kilograms of paddy per person-days of labor use. In sum, these findings suggest that large-size machinery (TRs) can contribute to the extensification, while it does not affect paddy yield. On the other hand, small-size machines significantly contribute to the intensification of rice cultivation, whereas it does not affect the area under cultivation within a plot.

Regarding draft animals (DA), we find that their impact follows a similar pattern to that of TRs, with few exceptions. draft animals have a significant positive effect on extensification but do not result in high paddy yield or revenues per hectare. Contrary to TRs, however, they are associated with high income and profit per hectare, suggesting that DA users produce rice at low paid-out and imputed costs per hectare.

Table 5.7 present the results on the impact of mechanization on the area under rice cultivation at household level, household income, and its components income. As we discussed earlier, we should note that machinery use here is measured in the sample plot since we do not have detailed data on machinery use in other plots. This would cause measurement errors in the machinery use at the household level as, on average, farmers cultivate 1.5 plots. Thus, the results should be interpreted with caution. We find that both TR and PT use in sample plots increases the area under rice cultivation at the household level by 0.25 to 0.38 hectares. We find that PTs are associated with high income from non-sample rice plots and from crops other than rice, while TRs are associated with high income from business and wage activities. As a result, both TR and PT users earn higher household income than HT users. This suggests that the labor freed from rice cultivation in sample plots might have been reallocated to the cultivation of other crops or non-farm economic activities, resulting in higher household income.

5.7 Conclusion

This Chapter examined the impact of mechanization in rice production using three-year panel data collected in Tanzania, one of the major rice-producing countries in SSA. Specifically, we exam-

ined the effects of mechanization on the expansion of the area under rice cultivation, technology adoption, land productivity, and labor productivity. We also examine under what conditions agricultural mechanization occurs. We focused on the use of four-wheeled tractors (TRs) and power tillers (PTs) for land preparation of rice cultivation.

We began by examining how the agricultural mechanization in rice cultivation evolves in Tanzania. Descriptive results show that the use of TRs and PTs has gradually increased and changed how farmers prepare their rice plots in recent years. We further investigate the determinants of household use of machinery and draft animal. We found a positive relationship between population density and TR and DA use, which is consistent with Pingali, Bigot, and Binswanger (1987)s' prediction that mechanized tillage emerges to expand the cultivated area, following the rise in population density and increased food demand. In fact, TR use is associated with the larger cultivated area, which supports their argument. We also found that the number of TR and PT in the village has a positive relationship with TR and PT use. Since few farmers use their own machinery, the access to rental machinery market seems to be an important factor that affects the machinery use by small-scale farmers.

In evaluating the impact of mechanization on rice cultivation, we applied the multinomial endogenous treatment effect to control for possible endogeneity problem which arises from farmer's endogenous selection of cultivation methods. In sum, our results show that large-size TR contributes to the expansion of area under rice cultivation both within a plot and household level but does not increase paddy yield.

On the other hand, PT users adopt yield-enhancing agronomic practices more often and apply a more chemical fertilizer, insecticides, and herbicides, resulting in high paddy yield, revenues, and profit per hectare. By examining types of land preparation activities carried out using TR and PT, we found that many PT users utilized them in puddling, while most of the TR users utilized them in plowing and hallowing. PTs are considered to be efficient for puddling, thus creating ideal

conditions for paddy seedbeds during crop establishment. Other benefits of puddling include enhancing nutrient and water uptake by the plant, water conservation, evenly distributing nutrients, and reducing weed intensity (Sharma and De Datta, 1985). While the evidence on this matter remains scant, the effect of PT on yield may be due to its effectiveness in performing puddling. Our results are partially consistent with previous empirical studies by Mano, Takahashi, and Otsuka (2020) and Houssou and Chapoto (2015), who report the positive relationship between agricultural mechanization and intensification, although we do not observe such a tendency for large-scale mechanization. Despite these differences, we find that both PTs and TRs significantly reduce labor use, resulting in increased labor productivity. We also find evidence suggesting that the labor force freed from rice cultivation was reallocated to the cultivation of other crops, resulting in high household income among PT users.

Table 5.4: First stage regression: Determinants of mechanization (MNL-CRE)

VARIABLES	TR	PT	DA
Distance from home to sample plot (km)	0.263*** (0.078)	0.202* (0.110)	0.215** (0.086)
Number of four-wheeled tractors in this village	0.077** (0.039)	0.166*** (0.041)	0.066* (0.037)
Number of two-wheeled tractors in this village	0.093** (0.037)	0.122*** (0.045)	0.044 (0.043)
Population density ('00 people/km ²)	0.480*** (0.179)	0.259 (0.230)	0.349** (0.157)
Number of bulls owned	0.067 (0.174)	0.163 (0.186)	0.195 (0.172)
Number of working age adults	0.014 (0.106)	0.351* (0.188)	-0.001 (0.126)
Years of schooling of household head	0.021 (0.058)	-0.007 (0.116)	0.040 (0.076)
Female headed household (dummy)	-0.257 (0.565)	1.235 (1.364)	-1.157 (1.379)
Age of household head	-0.022 (0.022)	-0.011 (0.031)	0.027 (0.029)
Landholdings in lowland area (ha)	0.070 (0.075)	-0.029 (0.129)	0.088 (0.081)
Landholdings in upland area (ha)	-0.014 (0.101)	0.156 (0.121)	-0.124 (0.082)
Value of non-farm household assets (mil. TSh)	0.371* (0.206)	0.448** (0.218)	0.531** (0.261)
Amount of credit received by the household ('00,000 Tsh)	0.235 (0.146)	0.356** (0.155)	0.177 (0.154)
Irrigated plot (dummy)	-2.043*** (0.434)	-0.115 (0.545)	-0.103 (0.466)
Size of the plot (ha)	0.918*** (0.296)	0.870** (0.358)	0.906*** (0.302)
Kilombero district x Year=2018 (dummy)	0.732** (0.338)	0.093 (0.703)	1.005*** (0.378)
Mvomero district x Year=2012 (dummy)	0.598* (0.326)	-0.513 (0.821)	-2.063*** (0.683)
Mvomero district x Year=2018 (dummy)	1.613*** (0.367)	1.322** (0.529)	-2.145*** (0.671)
Mbarali district x Year=2012 (dummy)	0.168 (0.514)	0.807 (0.604)	1.383*** (0.400)
Mbarali district x Year=2018 (dummy)	-2.320*** (0.746)	1.455 (0.907)	0.004 (0.811)
Constant	-0.699 (0.717)	-3.597*** (1.012)	-1.082 (0.759)
Mundlak–Chamberlain (MC) device	Yes	Yes	Yes
Observations (households): 985			

Source: Author (2020).

Notes: (i) TRs, PTs, DA, HT respectively denote the use of Four-wheeled tractors, Power tillers, draft animals, and Handheld tools for land preparation activities in sample rice plots. (ii) *** denotes significant at 1%, ** significant at 5%, and * significant at 10% in t-test comparison. (iii) All the monetary values are adjusted for inflation using the 2009 value of Tanzanian Shilling (TShs).

Table 5.5: Impact of mechanization on cultivated area and technology adoption (CRE-METE estimates)

VARIABLES	(1) Area cultivated in sample plot (ha)	(2) Adoption rate of plot leveling (%)	(3) Adoption rate of bunds (%)	(4) Adoption rate of transplanting in rows (%)	(5) Adoption rate of MVs (%)	(6) Amount of chemical fertilizer used (kg/ha)	(7) Amount of insecticide and herbicide used (liter/ha)
Four-wheeled tractors (TR)	0.335*** (0.072)	-9.087 (18.260)	-24.752*** (5.974)	4.973 (3.990)	-38.721*** (5.737)	-24.812*** (8.675)	-0.417 (0.271)
Power tillers (PT)	-0.009 (0.110)	1.566 (18.189)	18.946*** (5.923)	13.966* (7.779)	-18.396* (10.631)	45.330*** (15.055)	0.719* (0.430)
Draft animals (DA)	0.317*** (0.096)	32.946*** (8.997)	24.291*** (5.686)	-9.586* (5.552)	-56.796*** (5.235)	4.673 (31.374)	-0.448* (0.265)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mundlak–Chamberlain device	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-0.106 (0.166)	40.365*** (13.968)	41.664*** (9.602)	10.972 (9.097)	49.183*** (10.348)	52.947*** (18.781)	0.627 (0.387)
Observations	985	985	985	985	985	985	985

Source: Author (2020).

Notes: (i) Robust standard errors clustered at the household level in parentheses. (ii) The value for handheld tools users (i.e., $j=0$) is used as the base category. (iii) *** denotes significant at 1%, ** significant at 5%, and * significant at 10%. (iv) We control for a number of working-age adults, years of schooling of household head, female-headed household (dummy), age of household head, landholdings in lowland area (ha), landholdings in the upland area (ha), the value of non-farm household assets (million TShs), amount of credit received by the household ('00,000 TShs), irrigated plot (dummy), size of the plot (ha) and district and year interaction dummies.

Table 5.6: Impact of mechanization on land productivity and labor productivity (CRE-METE estimates: Full sample)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Paddy yield in sample plot (t/ha)	Revenue from rice in sample plot (‘000 TShs/ha)	Income from rice in sample plot (‘000 TShs/ha)	Profit in sample plot (‘000 TShs/ha)	Total labor use (person-days/ha)	Labor productivity (kg/person-days)
Four-wheeled tractors (TR)	0.179 (0.563)	-86.796 (162.099)	-239.274 (413.303)	288.786 (218.351)	-148.968*** (14.327)	14.294*** (2.882)
Power tillers (PT)	1.153*** (0.383)	354.904** (152.943)	195.334 (192.325)	446.191** (209.200)	-55.075*** (18.885)	11.948* (6.483)
Draft animals (DA)	0.189 (0.353)	219.174 (139.641)	330.036** (160.879)	208.297* (119.330)	-79.799*** (29.634)	3.898 (3.442)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Mundlak–Chamberlain device	Yes	Yes	Yes	Yes	Yes	Yes
Constant	2.554*** (0.454)	1,154.793*** (186.559)	881.846*** (262.695)	388.498* (201.679)	238.135*** (23.657)	16.156*** (6.230)
Observations	985	985	985	985	985	985

Source: Author (2020).

Notes: (i) Robust standard errors clustered at the household level in parentheses. (ii) The value for handheld tools users (i.e., $j=0$) is used as the base category. (iii) *** denotes significant at 1%, ** significant at 5%, and * significant at 10%. (iv) We control for a number of working-age adults, years of schooling of household head, female-headed household (dummy), age of household head, landholdings in lowland area (ha), landholdings in the upland area (ha), the value of non-farm household assets (million TShs), amount of credit received by the household (‘00,000 TShs), irrigated plot (dummy), size of the plot (ha) and district and year interaction dummies.

Table 5.7: Impact of mechanization on household income and related variables (CRE-METE estimates)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Area under rice cultivation at HH level (ha)	Total household income (‘00,000 TShs)	Income from rice grown in sample plot (‘00,000 TShs)	Income from rice grown in non-sample plots (‘00,000 TShs)	Income from crops other than rice (‘00,000 TShs)	Income from livestock production (‘00,000 TShs)	Income from business and wage activities (‘00,000 TShs)
Four-wheeled tractors (TR)	0.247** (0.101)	-2.028 (2.848)	-1.732* (0.984)	-1.741* (0.993)	-0.285 (1.218)	-0.023 (0.400)	1.938* (1.047)
Power tillers (PT)	0.375* (0.218)	8.725** (4.059)	2.445 (1.713)	3.358* (1.981)	4.375** (1.754)	1.209 (0.930)	-1.612 (1.486)
Draft animals (DA)	0.368*** (0.120)	8.503*** (2.596)	3.390*** (1.069)	0.526 (1.031)	2.575** (1.224)	1.221*** (0.389)	-1.367 (1.171)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mundlak–Chamberlain device	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-0.232 (0.213)	1.075 (5.259)	1.433 (2.260)	0.389 (1.814)	-0.888 (2.018)	0.518 (1.085)	-0.146 (2.520)
Observations	985	985	985	985	985	985	985

Source: Author (2020).

Notes: (i) Robust standard errors clustered at the household level in parentheses. (ii) The value for handheld tools users (i.e., $j=0$) is used as the base category. (iii) *** denotes significant at 1%, ** significant at 5%, and * significant at 10%. (iv) We control for a number of working-age adults, years of schooling of household head, female-headed household (dummy), age of household head, landholdings in lowland area (ha), landholdings in the upland area (ha), the value of non-farm household assets (million TShs), amount of credit received by the household (‘00,000 TShs), irrigated plot (dummy), size of the plot (ha) and district and year interaction dummies.

Chapter 6.

Conclusions

6.1 Conclusions

Over the past two decades, Sub-Saharan Africa (SSA) economy has shown steady growth. Yet, there are several remaining challenges, including an increasing number of the poor and the large share of undernourished population. Therefore, to address the mentioned challenges, improving agricultural productivity through technological changes is a central development agenda in SSA. Among major staple cereal crops grown in SSA, rice has the potential of leading the Green Revolution in Africa. Several initiatives have been implemented to improve rice production and productivity. These include introducing the high-yielding modern varieties, promoting the use of agro-chemicals, and improved agronomic cultivation methods. However, these technologies are not widely adopted; thus, rice productivity remains low. Among the reasons for low adoption rates is that farmers in SSA are constrained by factors such as lack of access to credit, labor shortage, lack of knowledge on new technologies, and poor access to input and output markets.

To address some of these challenges, this study focused on two aspects, namely microcredit and mechanization. Microcredit has been widely discussed in the literature, but according to author's knowledge, there is a limited number of studies that rigorously examine impact of microcredit on agricultural production, particularly rice. Furthermore, studies on mechanization in SSA have remained scant, despite the recent increase in the use of four-wheeled tractors and power tillers among rice farmers.

The study explored the role of microcredits and mechanization on improving rice productivity using data collected in Tanzania, one of the major rice-producing countries in SSA. Specifically, the study aimed: (i) to assess rice technologies promoted in Tanzania and their recent adoption trend; (ii) to evaluate the impact of microcredit on the adoption of rice technologies, productivity,

and overall household income; and (iii) to examine the effects of mechanization on the expansion of area under rice cultivation, land productivity, and labor productivity.

To assess the adoption trend of rice technologies in Tanzania, we applied the nationally representative three-year panel data. We have descriptively shown that adoption rates for rice technologies such as MVs, transplanting in rows, and chemical fertilizers have gradually increased from 2009 to 2018. But the adoption pattern varies across agro-ecological zones. Irrigated areas appear to have high adoption rates and relatively higher yields, indicating the possibility of rice Green Revolution in irrigated lowlands. However, only a small proportion of total rice area is irrigated, which undermines the potential influence of such yield gain on country-level productivity. Our descriptive results presented a similar pattern to previous studies that empirically examined factors associated with the adoption of rice technologies in Tanzania. Therefore, we conclude that in order to improve rice production in Tanzania, policies that aim to increasing irrigation infrastructures and those aiming to enhance productivity in rainfed lowlands will be important.

Regarding the microcredit, we analyzed the impact of the microcredit program on technology adoption and rice cultivation productivity by conducting an RCT in Tanzania. In the intervention, we offered microcredit to randomly selected farmers and investigated its impact on adopting technologies such as high-yielding modern varieties, chemical fertilizer, other agronomic practices, and land productivity. We first estimate the intention-to-treat (ITT) effect of farmers eligible to borrow credit from the program. In addition to ITT, we estimate the local average treatment effects (LATE) of the program, using eligibility status as an IV. We also apply the ANCOVA approach to increase estimation power. Overall, we did not observe any significant impact on technology adoption or increased paddy yield, profit, or household income. Lack of significant effect of credit on fertilizer use or paddy yield is consistent with the previous studies, which found that credit use did not increase chemical fertilizer or paddy yield.

We explored further by conducting sub-sample analyses comparing borrowers and non-

borrowers in the irrigation scheme with better access to irrigation water and extension systems against those without better access to irrigation water and extension systems. Our results show that those farmers in the irrigation scheme with good access to water and extension systems have applied a relatively high amount of chemical fertilizer, which is near the recommended level, even without credit use. Therefore, even after some of them borrowed credit, they did not increase chemical fertilizer use.

On the other hand, farmers without better access to irrigation water and extension services usually do not apply a high chemical fertilizer quantity. Therefore, when they borrowed credit, they significantly increased chemical fertilizer. However, the increased use of fertilizer did not increase yield or profit for these farmers. Although this is not conclusive, low rates of yield response to an application of chemical fertilizer can be one of the possible reasons. If this is the case, our results support the argument that emphasizes the importance of the extension services before the input and credit market development. Our results suggest that it is crucial to understand clients' characteristics and their socioeconomic environment when MFIs design their loan products targeting clients in agricultural communities. Additionally, our findings suggest that credit access may not be the only constraint on rural households.

Turning to mechanization, we use a three-year panel data from two regions of Tanzania. We considered the fact that farmers make their own decisions on whether to use agricultural machinery or other implements, which causes endogeneity bias in estimating the impact of machinery on various outcome variables. To mitigate this problem, we applied multinomial endogenous treatment effect (METE) models. We found that the use of TRs increases the area under rice cultivation both within a plot and at the household level, but it is not associated with high yield. Contrary to TRs, PTs are associated with the high adoption rates of yield-enhancing technologies such as chemical fertilizer, pesticide, and other agronomic practices, resulting in high paddy yield. Despite these differences, both PTs and TRs significantly reduce labor use, resulting in increased labor produc-

tivity. We also observe that both PT and TR use increases the area under rice cultivation at the household level. Furthermore, we find evidence suggesting that the labor force freed from rice cultivation was reallocated to the cultivation of other crops or non-farm income-generating activities, resulting in high income from business and wage activities and total household income.

Our findings suggest that large-size machinery (TRs) can contribute to the extensification both within a plot and at the household level, while it does not affect paddy yield. On the other hand, small-size machines significantly contribute to the extensification at the household level and intensification of rice cultivation. The possible explanation is that TRs are likely to be used in the rain-fed area, where there is still space for area expansion compared to irrigated areas. On the other hand, PTs' ability to perform tasks such as puddling more timely and efficiently may enhance paddy yield. Our results are partially consistent with previous empirical studies who report the positive relationship between agricultural mechanization and intensification, although we do not observe such a tendency in large-size mechanization. Our results would contribute to recent policy debates that aim to promote small-scale agricultural mechanization.

6.2 Limitation of the study and external validity

There are several limitations to the findings of our study, as we discuss in the following subsections.

Microcredit research

There are three significant limitations in our research on microcredit. First, we do not have a clear explanation of how the farmers use the credit. In some cases, we do not observe any significant increase in the amount of chemical fertilizer used or other technology that requires cash. Other microcredit studies have pointed out that credit may be used for purposes other than what is intended, such as general consumption or spending on tempting goods ([Banerjee et al., 2015b](#);

[Attanasio et al., 2015](#)). We cannot examine this possibility because we do not have complete consumption data. Second, due to the relatively small sample size and modest take-up rate of the credit program, our analyses' statistical power is not high, which is similar to other microcredit impact evaluations. Thus, the results should be interpreted with care. Third, during the cultivation season of our credit intervention, rainfall was relatively scarce compared to previous years, although the paddy yield was not low. Rice production is sensitive to weather conditions, including rainfall, which might have affected our results, especially through the low yield response.

Regarding external validity, our survey was conducted in two irrigation schemes in one district. Since most rice is grown under rain-fed conditions in Tanzania, our study sites may not represent typical rice-growing villages in Tanzania. Given that our survey was conducted in selected villages and only in one year, we cannot ensure the external validity of our results. However, we believe that our research provides an important case study, which shows that credit may not be effective in increasing agricultural productivity even in irrigated areas if the yield response is not high. Despite these limitations, our study suggests that addressing credit constraint may not be enough to encourage the adoption of new technologies and improve the productivity of rice cultivation

Mechanization research

In examining the effects of mechanization, we faced the following caveat. First, although we intended to examine the effects of mechanization using the country representative data set, we failed to do so because the rates of machinery use were low in some regions.

Concerning the external validity, our data are from both irrigated and rainfed lowlands but are not country representative. On the other hand, the analysis takes into account different implements for land preparation including draft animals. However, we cannot confidently say that our findings are generalizable, because of diverse factors that we could not control in our anal-

ysis, such as quality of tillage, soil condition and how developed the machinery rental markets are. Nevertheless, our findings suggest that mechanization among smallholder farmers can be an effective means for the expansion of area under rice cultivation and improving productivity.

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Appendices

Appendix A: Supplementary information for Chapter 3

A1 Other improved agronomic practices and crop management techniques

A1.1 Rice seed separation using a brine solution

Seed preparation involves putting winnowed seeds in clean water in a brine solution and removing all floating seeds (poor quality seeds); then seeds that sunk (good quality seeds) are washed with clean water five times. The right brine solution is made by gradually adding 2kg of salt into 10liters of water. To determine the right concentration, immerse a fresh egg into the formed brine solution. The right concentration should allow an egg to float. The main purpose of this technology is to obtain a well-filled heavy grains that ensures high germination percentage and produce seedlings with high growth vigor.

A1.2 Raising seeds in wet nursery bed

In this practice, wet nursery (usually about 1.5m x 15m) beds are prepared in puddled soils, which is well leveled with water inlets and drainage outlets. Then farmers distribute evenly, 10g/m² of pre-soaked seeds and cover them with mud using hands. Other management practices such as fertilizer, water management, weed control, irrigation are done as required. Seedlings are ready for transplanting at 21 days. The technology is aimed at producing healthy and vigorous seedlings with good tillering ability hence maximization of yield.

A1.3 Puddling

Puddling is the process of thorough mixing of soil in flooded field, which involves soaking of harrowed plots with water, then using farm implements to break the remaining soil lumps to form a thick soil paste before transplanting seedling. Power-tillers (attached with a rotary tiller or a rotovator) is the effective tool for puddling, but other means such as draft animals and hand hoes are commonly used. Puddling creates the ideal conditions for paddy seedbed during crop establishment. Other benefits include enhancing nutrient and water uptake by the plant, water conservation, evenly distributing nutrients, and reducing weed intensity. Despite the benefits, puddling can mainly be practiced in irrigated lowlands and in rain-fed areas where water-harvesting is possible.

A1.4 Weed control by using cultural methods

Usually done early enough to avoid loss of yield, preferably 2 weeks after transplanting, then 3 weeks after the first weeding. Push weeders have been commonly used for this purpose. However, this method is labor-intensive and less efficient. Therefore, good land preparation methods and appropriate water management are also recommended. Effective weed control eliminates competition for nutrients and moisture between rice plants and weeds, thus increasing their uptake efficiency, hence increasing yields.

A1.5 Weed control by using herbicides

Herbicides are used as an alternative to traditional weeding method. Two common herbicides in Tanzania include (i) Roundup, which contain glyphosate active ingredient, and usually applied before plowing; and (ii) Over herbicides that kill broad-leaved weeds and sedges in the field (for example 2,4-D Amine). Herbicides are used since they can control weeds even at the age before they are able to exert considerable competition on crops critically.

A1.6 Water management

Water supply in the field should be: (i) 2-5cm in nursery bed; (ii) below 5cm after transplanting (to allow root development) and on the 3rd day should be increased and maintained at 5cm for 10 days; (iii) a field should be drained to 3-5cm, to allow for weeding and fertilizer application; (iv) increase water depth to 10cm after weeding and 15cm at productive stages; and (v) the field should be drained 2-3 weeks before harvesting. Aims to facilitate weed control and enhances nutrient availability and utilization by plants. d

Appendix B: Supplementary information for Chapter 4

Table B1: Summary statistics of key variables used in Chapter 4

VARIABLES	(1)	(2)	(3)
	Mean	Minimum	Maximum
Eligible for BRAC program (dummy): 2012	0.53	0.00	1.00
BRAC borrower (dummy): 2012	0.21	0.00	1.00
Number of adult HH members: 2010	2.76	1.00	11.00
Years of schooling of HH head: 2010	5.91	0.00	16.00
Female household head (dummy): 2010	0.21	0.00	1.00
Age of HH head: 2010	47.81	20.00	87.00
Total land holdings (ha): 2010	0.37	0.00	12.55
Value of production assets (USD): 2010	35.05	2.00	6,793.33
Value of non-production assets (USD): 2010	335.37	20.00	3,380.00
Ilonga village: 2010	0.50	0.00	1.00
Use of chemical fertilizer (kg/ha): 2012	57.51	0.00	247.52
Modern variety: 2012	23.98	0.00	100.00
Adoption of improved bund (%): 2012	6.98	0.00	100.00
Adoption of leveling (%): 2012	38.76	0.00	100.00
Adoption of transplanting in row (%): 2012	13.18	0.00	100.00
Use of insecticide and herbicide (kg/ha): 2012	5.36	0.00	247.52
Yield (t/ha): 2012	3.05	0.00	10.63
Revenue (USD/ha): 2012	1,295.38	0.00	4,723.14
Total input costs (USD/ha): 2012	93.38	0.00	777.23
Paid-out cost of labor use (USD/ha): 2012	279.09	0.00	1,227.72
Imputed costs of family labor (USD/ha): 2012	459.10	0.00	2,021.25
Paid-out cost of machinery and animal use (USD/ha): 2012	59.95	0.00	305.28
Imputed cost of machinery and animal use for (USD/ha): 2012	1.13	0.00	33.00
Income (USD/ha): 2012	862.96	-985.15	3,743.38
Profit (USD/ha): 2012	402.73	-1,441.97	3,615.49
Total household income (USD): 2012	861.48	-337.23	11,385.87
Total livestock income(USD): 2012	29.20	0.00	848.00
Business and wage labor income (USD): 2012	283.80	-84.00	10,533.33
Total crop income (USD): 2012	548.48	-337.23	3,414.46
Total crop revenue (USD):2012	818.82	0.00	4,929.52
Total paid out costs for machinery and animal use (USD):2012	47.21	0.00	530.00
Total paid out costs for hired labor (USD):2012	181.26	0.00	2,063.29
Total costs for current input use (USD):2012	49.32	0.00	665.00
Total rice income (USD): 2012	506.37	-337.23	2,974.46
Income from crops other than rice (USD):2012	42.12	-220.00	1,560.00
School Expenditure (USD): 2012	138.34	0.00	2,298.67
Medical Expenditure (USD): 2012	66.90	0.00	1,920.00
HH income after paying the loan from BRAC Program: 2012	847.70	-337.23	11,385.87
Use of credit other than BRAC Program (USD): 2012	17.09	0.00	666.67

Source: Author (2020). The number of observations is 387 households.

Table B2: Examining the balance between Eligible and Non-Eligible households at the baseline

VARIABLES	(1)	(2)	(1) - (2)
	Eligible	Non-Eligible	Difference
Number of adult HH members: 2010	2.70	2.83	-0.13
Years of schooling of HH head: 2010	5.86	5.96	-0.10
Female household head (dummy): 2010	0.20	0.21	-0.01
Age of HH head: 2010	47.01	48.70	-1.69
Total land holdings (ha): 2010	0.40	0.33	0.07
Value of production assets (USD): 2010	11.42	61.65	-50.23
Value of non-production assets (USD): 2010	303.77	370.97	-67.21
Ilonga village: 2010	0.49	0.51	-0.02
Use of chemical fertilizer (kg/ha): 2010	41.00	44.39	-3.39
Modern variety: 2010	18.67	18.16	0.50
Adoption of improved bund (%): 2010	5.85	8.24	-2.39
Adoption of leveling (%): 2010	72.68	64.84	7.85*
Adoption of transplanting in row (%): 2010	18.54	20.33	-1.79
Use of insecticide and herbicide (kg/ha): 2010	1.28	1.21	0.08
Yield (t/ha): 2010	2.20	2.21	-0.01
Revenue (USD/ha): 2010	630.44	637.91	-7.47
Total input costs (USD/ha): 2010	52.35	53.38	-1.03
Paid-out cost of labor use (USD/ha): 2010	158.90	154.96	3.94
Imputed costs of family labor (USD/ha): 2010	594.02	593.63	0.39
Paid-out cost of machinery and animal use (USD/ha): 2010	20.81	24.76	-3.95
Imputed cost of machinery and animal use for (USD/ha): 2010	0.00	0.96	-0.96*
Income (USD/ha): 2010	411.15	417.26	-6.11
Profit (USD/ha): 2010	-191.43	-180.49	-10.94
Total household income (USD): 2010	3,543.84	455.68	3,088.17
Livestock income(USD): 2010	35.09	40.73	-5.64
Business and wage labor income (USD): 2010	173.93	177.47	-3.54
Total crop income (USD): 2010	3,334.83	237.48	3,097.35
Total crop revenue (USD):2010	3,476.75	380.71	3,096.04
Total paid out costs for machinery and animal use (USD):2010	20.72	21.15	-0.43
Total paid out costs for hired labor (USD): 2010	100.48	98.57	1.91
Total costs for current input use (USD): 2010	19.22	20.87	-1.66
Total rice income (USD): 2010	219.27	205.79	13.48
Income from crops other than rice (USD):2010	3,115.56	31.69	3,083.87
Use of credit other than BRAC Program (USD): 2010	18.67	9.27	9.40
Observation (Households)	205	182	

Source: Author (2020). *** denotes significant at 1%, ** significant at 5%, and * significant at 10% in *t*-test comparison between eligible and non-eligible households.

Table B3: First stage estimates of LATE

VARIABLES	(1)	(2)	(3)
	Total Sample	Ilonga	Chanzuru
	BRAC borrower (dummy)	BRAC borrower (dummy)	BRAC borrower (dummy)
Eligible for BRAC program (dummy)	0.390*** (0.000)	0.398*** (0.000)	0.392*** (0.000)
Ilonga village (dummy)	0.002 (0.949)		
Total land holdings (ha): 2010	0.007 (0.785)	0.069* (0.085)	-0.018 (0.343)
Value of household assets (USD): 2010	0.000 (0.214)	0.000 (0.534)	0.000 (0.212)
Number of adult HH members: 2010	-0.007 (0.574)	0.004 (0.842)	-0.018 (0.287)
Years of schooling of HH head: 2010	-0.001 (0.867)	-0.004 (0.657)	-0.001 (0.933)
Female household head (dummy): 2010	-0.030 (0.514)	-0.009 (0.903)	-0.064 (0.289)
Age of HH head: 2010	-0.001 (0.508)	-0.001 (0.424)	-0.001 (0.692)
Constant	0.058 (0.509)	0.047 (0.672)	0.088 (0.541)
Cragg-Donald Wald F statistic	112.62	57.47	54.66
Observations	387	194	193

Source: Author (2020). Robust standard errors in parentheses.

Details on yield response estimations

To estimate rates of return to fertilizer, we use unbalanced three-year panel data collected in 2010, 2011, and 2012. The total number of observations for this analysis is 1,165 (i.e., 412 households in 2010, 365 households in 2011, and 387 households in 2012). We begin by considering the paddy yield Y on rice plot i from the household j at time t to be a function of several vectors denoted as

$$Y_{ijt} = f(X_{ijt}, Z_{ijt}, \mu_{ijt}) \quad (\text{B.1})$$

where the vector X_{ijt} is comprised of inputs chosen by the household (including fertilizer), the vector Z_{ijt} includes those characteristics of the household that likely influence yield, and the vector μ_{ijt} is the composite error term containing time-invariant and time-varying unobservable characteristics of the production system. In our estimations, we consider the heterogeneous nature of farmers' production environment in developing countries and choose the quadratic function form because it allows zeros in input and output variables, as well as its concavity, which accounts for diminishing returns. We estimate the model using correlated random effect (CRE) because it allows us to control for time-invariant unobserved household-level heterogeneity by including the Mundlak-Chamberlain device. According to [Wooldridge \(2010\)](#), the production function with the Mundlak-Chamberlain device is equivalent to the household fixed effects (FE) estimator in this context the model is linear. We confirm this by presenting both CRE and FE estimates in [Table B4](#) and [Table B5](#), respectively.

Table B4: Yield response: CRE estimates

VARIABLES	(1)	(2)	(3)
	Yield (Kg/ha)	Yield (Kg/ha)	Yield (Kg/ha)
	Overall (CRE)	Ilonga (CRE)	Chanzuru (CRE)
Use of chemical fertilizer (kg/ha)	6.02** (2.67)	8.08* (4.43)	3.13 (2.47)
Use of chemical fertilizer (kg/ha) squared	0.00 (0.01)	-0.00 (0.02)	-0.00 (0.01)
Seed rate (kg/ha)	2.44 (1.93)	1.79 (10.45)	0.47 (1.90)
Seed rate (kg/ha) squared	-0.00 (0.00)	0.01 (0.05)	-0.00 (0.00)
Size of experimental plot (ha)	-652.74* (371.35)	-642.56 (1,692.43)	-393.57 (345.42)
Size of experimental plot (ha) squared	43.39** (20.71)	-303.60 (819.94)	28.67 (19.39)
Total machinery and animal use (workdays/ha)	-2.39 (9.82)	-4.96 (7.57)	57.92** (25.36)
Total labor use (Person-days/ha)	0.80*** (0.24)	1.21*** (0.44)	0.66** (0.28)
Modern Variety (Dummy)	319.14** (153.44)	330.62 (201.17)	283.95 (219.10)
Insecticide/Herbicide (Dummy)	-10.07** (4.33)	-14.11*** (4.59)	-1.95 (2.10)
Size of owned plots in upland area (ha)	-652.02*** (205.05)	-140.70 (490.94)	-861.00*** (243.99)
Size of owned plots in lowland area except sample plot (ha)	52.59 (120.29)	-86.73 (223.44)	69.12 (128.98)
Village and year dummy variables	Included	Included	Included
Household-level control variables	Included	Included	Included
Mundlak and Chamberlain devices	Included	Included	Included
Constant	1,449.75*** (362.72)	1,759.68** (805.90)	2,077.33*** (431.03)
Observations	1,164	583	581
Number of households	412	208	204

Source: Author (2020). Robust standard errors clustered at household level in parentheses. In CRE estimations, we control for the following household characteristics: number of adult household members, years of schooling of household head, female headed household (dummy), and age of household head, and size of the household.

Table B5: Yield response: FE estimates

VARIABLES	(1)	(2)	(3)
	Yield (Kg/ha)	Yield (Kg/ha)	Yield (Kg/ha)
	Overall (FE)	Ilonga (FE)	Chanzuru (FE)
Use of chemical fertilizer (kg/ha)	6.09** (2.62)	7.54* (4.31)	3.37 (2.49)
Use of chemical fertilizer (kg/ha) squared	0.00 (0.01)	0.00 (0.02)	-0.00 (0.01)
Seed rate (kg/ha)	2.33 (1.91)	1.31 (10.57)	0.73 (1.91)
Seed rate (kg/ha) squared	-0.00 (0.00)	0.01 (0.05)	-0.00 (0.00)
Size of experimental plot (ha)	-638.05* (362.98)	-719.04 (1,643.95)	-389.10 (389.60)
Size of experimental plot (ha) squared	42.34** (20.26)	-301.86 (805.71)	27.47 (21.87)
Total machinery and animal use (workdays/ha)	-2.31 (9.69)	-5.27 (7.27)	51.30** (24.10)
Total labor use (Person-days/ha)	0.81*** (0.24)	1.12*** (0.42)	0.64** (0.28)
Modern Variety (Dummy)	338.07** (149.34)	364.24* (191.65)	260.35 (225.58)
Insecticide/Herbicide (Dummy)	-9.64** (4.12)	-13.44*** (4.23)	-1.96 (2.27)
Size of owned plots in upland area (ha)	-605.68*** (201.68)	-43.76 (501.55)	-716.69*** (223.05)
Size of owned plots in lowland area except sample plot (ha)	49.48 (118.76)	-111.53 (215.93)	75.37 (141.51)
Year = 2011 (dummy)	793.29*** (84.86)	956.08*** (143.72)	599.74*** (87.07)
Year = 2012 (dummy)	823.80*** (95.19)	1,011.85*** (164.78)	643.47*** (113.93)
Constant	1,790.61*** (253.59)	1,877.79** (750.45)	1,604.33*** (294.16)
Observations	1,164	583	581
Number of households	412	208	204

Source: Author (2020). Robust standard errors clustered at household-level in parentheses.

Appendix C: Supplementary information for Chapter 5

Table C1: Summary statistics for Chapter 5

Variable	Mean	Min	Max
Use of PT or TR (%)	47.11	0.00	100.00
Use of TR (%)	38.27	0.00	100.00
Use of PT (%)	8.83	0.00	100.00
Use of DA (%)	25.38	0.00	100.00
Use of of handheld tools (%)	27.51	0.00	100.00
Number of four-wheeled tractors in this village	3.46	0.00	23.00
Number of two-wheeled tractors in this village	3.71	0.00	34.00
Farmer used their own PT (dummy)	0.01	0.00	1.00
Farmer used their own TR (dummy)	0.00	0.00	1.00
TR rental fee ('000 TShs)	34.25	20.79	60.00
PT rental fee ('000 TShs)	38.06	10.40	62.37
DA rental fee ('000 TShs)	31.50	15.59	50.00
Wage rate of using hired labor for land prep ('000 TShs/day)	5.64	2.31	10.40
Population density ('00 people/km2)	0.73	0.02	5.96
Number of working age adults	3.17	0.00	13.00
Years of schooling of household head	6.33	0.00	14.00
Female headed household (dummy)	0.11	0.00	1.00
Age of household head	47.86	19.00	100.00
Landholdings in lowland area (ha)	2.92	0.00	52.02
Landholdings in upland area (ha)	0.77	0.00	50.90
Value of non-farm household assets (mil. TShs)	0.76	0.00	14.75
Amount of credit received by the household ('00,000 TShs)	0.53	0.00	30.00
Number of bulls owned	0.64	0.00	55.00
Area under rice cultivation at HH level (ha)	1.43	0.10	12.12
Area cultivated in sample plot (ha)	1.07	0.10	8.48
Size of the plot (ha)	1.42	0.20	16.16
Irrigated plot (dummy)	0.36	0.00	1.00
Leveled plot (dummy)	0.47	0.00	1.00
Adoption rate of transplanting in rows (%)	18.17	0.00	100.00
Adoption rate of MVs (%)	34.11	0.00	100.00
Amount of chemical fertilizer used (kg/ha)	38.42	0.00	371.29
The amount of insecticide and herbicide used (liter/ha)	1.88	0.00	9.90
Paddy yield in sample plot (tons/ha)	2.94	0.00	9.36
Revenue from rice cultivated in sample plot ('000 TShs/ha)	1,203.36	0.00	4,271.71
Income from rice cultivated in sample plot ('000 TShs/ha)	757.48	-1,352.71	3,689.79
Profit from rice cultivated in sample plot ('000 TShs/ha)	483.18	-2,258.03	3,436.66
Total labor use (person-days/ha)	161.81	14.85	569.38
Productivity of total labor use (kg/person-days)	29.82	0.00	342.86
Total household income ('00,000 TShs)	17.87	-26.51	253.81
Income from sample plot ('00,000 TShs)	7.03	-32.92	134.39
Rice income from other plots ('00,000 TShs)	3.09	-3.48	119.86
Crop income from other plots ('00,000 TShs)	3.85	-8.03	119.86
Income from livestock production('00,000 TShs)	1.13	-7.49	65.37
Income from business and wage activities ('00,000 TShs)	2.78	-10.81	164.23

Sample size: 985 households

Table C2: Power substitutions over time

	Implement used by farmers in 2018			
	TR	PT	DA	HT
<i>Panel A: Implements they used in 2009 (%)</i>				
TR	67.33	17.65	11.86	11.36
PT	0.00	2.94	5.08	0.00
DA	5.94	50.00	47.46	13.64
HT	26.73	29.41	35.59	75.00
<i>Panel B: Implements they used in 2012 (%)</i>				
TR	72.28	30.30	12.31	25.00
PT	2.97	21.21	6.15	6.82
DA	8.91	33.33	55.38	13.64
HT	15.84	15.15	26.15	54.55

Table C3: IVs and household and plot-level control variables by farm implements used for land preparation

VARIABLES	Irrigated				Rainfed			
	TR	PT	DA	HT	TR	PT	DA	HT
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Distance from home to sample plot (km)	4.14***	2.63	3.50***	2.13	3.47***	2.89**	3.44***	2.04
Population density ('00 people/km2)	0.63**	0.77	1.1	0.98	0.6	0.63	0.74**	0.52
Number of four-wheeled tractors in the village	8.41***	8.34***	6.47***	3.02	2.06***	4.09***	3.72***	0.85
Number of two-wheeled tractors in the village	5.30***	8.68***	1.73	1.49	2.52	16.11***	6.48***	2.01
Number of bulls owned	0.24	0.24	2.35***	0.17	0.18	1.09***	1.28***	0.12
Number of working age adults	3.15	3.1	3.31**	2.88	3.22	3.17	3.29	3.1
Years of schooling of household head	6.35	6.37	5.46***	6.38	6.54	6.41	6.62	6.32
Female headed household (dummy)	0.17	0.17	0.06**	0.15	0.14**	0.09	0.09	0.07
Age of household head	42.63**	50.8	47.55	47.21	48.63	46.24	48.44	47.87
Landholdings in lowland area (ha)	2.86***	3.15***	4.45***	1.81	2.72	3.32*	3.41**	2.44
Landholdings in upland area (ha)	0.32	0.48	0.77	0.48	0.82	1.33	1.01	0.74
Value of non-farm household assets (million TShs)	1.05***	1.22***	0.95***	0.56	0.77***	0.99***	0.73***	0.46
Amount of credit received by the household ('00,000 TShs)	1.01***	1.43***	0.64	0.26	0.62***	0.89***	0.39**	0.07
Size of the plot (ha)	1.38***	1.10***	1.79***	0.62	1.47***	1.97***	2.19***	1.03
Observations (Households)	46	41	130	136	331	46	120	135

Source: Author (2020). TR, PT, DA, HT respectively denote the use of Four-wheeled tractors, Power tillers, draft animals, and Handheld tools for land preparation activities in sample rice plot. *** denotes significant at 1%, ** significant at 5%, and * significant at 10% in *t*-test comparison.

Table C4: Labor use for rice cultivation activities in sample plots

VARIABLES	Irrigated				Rainfed			
	TR	PT	DA	HT	TR	PT	DA	HT
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Total hired labor use (person-days/ha)	106.18	159.76	88.13***	130.7	57.97***	76.44	46.76***	81.49
Hired labor use for preparing rice plot (person-day/ha)	7.04***	19.89***	10.83***	42.6	3.17***	5.27***	3.01***	24.28
Hired labor use for transplanting (person-day/ha)	23.06	28.94**	22.86	19.48	1.77***	11.35**	6.01	6.09
Hired labor use for direct seeding (person-day/ha)	1.13	0.54	0.31	0.68	1.93***	0.17***	1.45***	3.81
Hired labor use for weeding (person-day/ha)	13.62	20.12	15.47	15.63	19.13	10.32**	14.10*	20.29
Hired labor use for bird scaring (person-day/ha)	23.13	53.86***	16.83	25.7	14.17	23.83**	3.85	8.97
Hired labor use for harvesting (person-day/ha)	38.20**	36.41**	21.82	26.6	17.8	25.50*	18.34	18.05
Total family labor use (person-days/ha)	56.46***	42.68***	85.40***	144.15	55.27***	37.59***	64.51***	127.93
Family labor use for preparing rice plot (person-day/ha)	7.89***	4.63***	12.61***	23.11	2.89***	6.41***	7.11***	28.77
Family labor use for transplanting (person-day/ha)	8.95	2.78**	8.77	10.37	0.41***	2.98	4.47	5.45
Family labor use for direct seeding (person-day/ha)	1.24	0.98	2.1	1.59	3.29***	1.02***	2.05***	5.65
Family labor use for weeding (person-day/ha)	10.08***	7.06***	16.27**	23.58	14.89***	8.71***	14.59***	26.73
Family labor use for bird scaring (person-day/ha)	18.59***	18.23***	24.26***	61.72	22.80***	9.05***	17.99***	39.08
Family labor use for harvesting (person-day/ha)	9.70***	8.99**	21.39	25.08	11.36***	9.42***	18.29	25.04
Observations (Households)	46	41	130	136	331	46	120	135

Source: Author (2020). TR, PT, DA, HT respectively denote the use of Four-wheeled tractors, Power tillers, draft animals, and Handheld tools for land preparation activities in sample rice plot. *** denotes significant at 1%, ** significant at 5%, and * significant at 10% in *t*-test comparison.

Table C5: Falsification test for the cultivated area and technology adoption (Pooled OLS with MC device)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Area cultivated in sample plot (ha)	Adoption rate of plot leveling (%)	Adoption rate of bunds (%)	Adoption rate of transplanting in rows (%)	Adoption rate of MVs (%)	Amount of chemical fertilizer used (kg/ha)	Amount of insecticide and herbicide used (liter/ha)
Distance from home to sample plot (km)	0.015 (0.019)	-2.328 (3.089)	-0.702 (3.148)	1.093 (2.481)	-0.767 (3.323)	6.838 (5.255)	0.027 (0.105)
Number of four-wheeled tractors in this village	-0.010* (0.005)	0.258 (1.408)	1.412 (0.967)	4.313*** (1.056)	-1.426 (0.962)	7.890*** (1.675)	0.046 (0.040)
Number of two-wheeled tractors in this village	0.001 (0.007)	-1.467 (1.164)	0.151 (0.704)	0.605 (0.930)	-1.003 (1.278)	1.169 (1.674)	0.018 (0.046)
Population density ('00 people/km2)	-0.048 (0.030)	-8.823** (3.705)	1.620 (3.879)	-1.333 (4.126)	-2.873 (5.892)	17.931* (10.364)	-0.109 (0.143)
Number of bulls owned	-0.005 (0.013)	-3.106* (1.792)	1.749 (1.546)	-2.298 (1.719)	-1.035 (2.546)	-1.674 (2.667)	0.055 (0.054)
Constant	-0.014 (0.157)	38.816* (21.692)	45.596*** (16.191)	21.878 (22.516)	40.994* (21.505)	11.094 (31.882)	-0.270 (0.773)
Observations	271	271	271	271	271	271	271
Adjusted R-squared	0.559	0.161	0.516	0.255	0.292	0.227	0.123

Source: Author (2020).

Notes: (i) Robust standard errors clustered at the household level in parentheses. (ii) In this test, candidate IVs are included as additional explanatory variables in a pooled OLS regression with Mundlak–Chamberlain (MC) device (hence CRE-POLS) for each dependent variable. Observations used in these tests are households that used handheld tools for land preparation (i.e., $j=0$). (iii) *** denotes significant at 1%, ** significant at 5%, and * significant at 10%. (iv) We control for the number of working-age adults, years of schooling of household head, female-headed household (dummy), age of household head, landholdings in lowland area (ha), landholdings in lowland area (ha), the value of non-farm household assets (million TShs), amount of credit received by the household ('00,000 TShs), irrigated plot (dummy) size of the plot (ha) and district and year interaction dummies.

Table C6: Falsification test for variables related to land and labor productivity (Pooled OLS with MC device)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Paddy yield in sample plot (t/ha)	Revenue from rice in sample plot (‘000 TShs/ha)	Income from rice in sample plot (‘000 TShs/ha)	Profit in sample plot (‘000 TShs/ha)	Total labor use (person-days/ha)	Labor productivity (kg/person-days)
Distance from home to sample plot (km)	0.178 (0.125)	52.039 (47.514)	40.810 (49.918)	35.973 (47.870)	-8.439 (10.252)	4.136* (2.493)
Number of four-wheeled tractors in this village	0.065 (0.043)	64.044*** (22.812)	60.491*** (19.187)	50.719** (21.979)	3.041 (2.329)	-0.357 (0.471)
Number of two-wheeled tractors in this village	0.008 (0.057)	-13.505 (25.780)	-12.547 (24.092)	1.730 (26.214)	-1.258 (2.418)	-0.508 (0.961)
Population density (‘00 people/km2)	-0.108 (0.160)	26.867 (62.999)	45.634 (54.475)	-36.265 (55.335)	40.409*** (10.769)	-3.826 (2.599)
Number of bulls owned	-0.036 (0.129)	42.647 (42.357)	85.298** (36.655)	31.480 (45.617)	8.635* (4.976)	-0.083 (2.147)
Constant	2.518*** (0.878)	896.668*** (342.276)	688.596** (300.711)	674.834** (341.739)	88.564 (55.036)	15.044 (9.761)
Observations	271	271	271	271	271	271
Adjusted R-squared	0.234	0.232	0.163	0.155	0.270	0.491

Source: Author (2020).

Notes: (i) Robust standard errors clustered at the household level in parentheses. (ii) In this test, candidate IVs are included as additional explanatory variables in a pooled OLS regression with Mundlak–Chamberlain (MC) device (hence CRE-POLS) for each dependent variable. Observations used in these tests are households that used handheld tools for land preparation (i.e., $j=0$). (iii) *** denotes significant at 1%, ** significant at 5%, and * significant at 10%. (iv) We control for the number of working-age adults, years of schooling of household head, female-headed household (dummy), age of household head, landholdings in lowland area (ha), landholdings in lowland area (ha), the value of non-farm household assets (million TShs), amount of credit received by the household (‘00,000 TShs), irrigated plot (dummy) size of the plot (ha) and district and year interaction dummies.

Table C7: Falsification test for household income and related variables (Pooled OLS with MC device)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Area under rice cultivation at HH level (ha)	Total household income (‘00,000 TShs)	Income from rice grown in sample plot (‘00,000 TShs)	Income from rice grown in non-sample plots (‘00,000 TShs)	Income from crops other than rice (‘00,000 TShs)	Income from livestock production (‘00,000 TShs)	Income from business and wage activities (‘00,000 TShs)
Distance from home to sample plot (km)	-0.025 (0.038)	0.325 (1.370)	0.526 (0.397)	0.034 (0.305)	0.131 (0.389)	0.040 (0.124)	-0.406 (0.703)
Number of four-wheeled tractors in this village	-0.026** (0.013)	0.557 (0.540)	0.208* (0.121)	-0.086 (0.132)	-0.100 (0.138)	0.170 (0.120)	0.365 (0.405)
Number of two-wheeled tractors in this village	-0.007 (0.019)	-0.608 (0.595)	-0.094 (0.181)	-0.251 (0.234)	-0.319 (0.229)	0.018 (0.044)	0.038 (0.217)
Population density (‘00 people/km2)	-0.117* (0.062)	-1.909 (1.672)	-0.096 (0.460)	-1.378* (0.721)	-1.033 (0.770)	0.222 (0.181)	0.375 (0.519)
Number of bulls owned	0.021 (0.075)	2.153 (2.495)	0.570 (0.478)	0.682 (0.891)	0.632 (0.881)	0.839 (0.862)	-0.569 (0.393)
Constant	-0.131 (0.294)	-1.472 (7.474)	0.436 (2.425)	0.121 (2.367)	-0.797 (2.497)	-0.647 (0.960)	-0.586 (3.446)
Observations	271	271	271	271	271	271	271
Adjusted R-squared	0.514	0.242	0.271	0.196	0.209	0.179	0.046

Source: Author (2020).

Notes: (i) Robust standard errors clustered at the household level in parentheses. (ii) In this test, candidate IVs are included as additional explanatory variables in a pooled OLS regression with Mundlak–Chamberlain (MC) device (hence CRE-POLS) for each dependent variable. Observations used in these tests are households that used handheld tools for land preparation (i.e., $j=0$). (iii) *** denotes significant at 1%, ** significant at 5%, and * significant at 10%. (iv) We control for the number of working-age adults, years of schooling of household head, female-headed household (dummy), age of household head, landholdings in lowland area (ha), landholdings in lowland area (ha), the value of non-farm household assets (million TShs), amount of credit received by the household (‘00,000 TShs), irrigated plot (dummy) size of the plot (ha) and district and year interaction dummies. (v) To avoid the reverse causality problem, the number of bulls was not included as an IV for total household income, income from business and wage activities, and income from livestock production

Table C8: Wald tests for various sets of instruments in the first stage estimation models

VARIABLES	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
Distance from home to sample plot (km)	✓		✓	✓				✓
Number of four-wheeled tractors in this village	✓	✓		✓	✓			
Number of two-wheeled tractors in this village	✓	✓	✓	✓	✓	✓		
Population density ('00 people/km2)	✓	✓	✓		✓	✓	✓	✓
Number of bulls owned	✓	✓	✓		✓	✓	✓	✓
Wald test χ^2	107.23	70.7	90.8	73.47	70.7	50.13	30.34	75.92
p-value χ^2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004	0.0000
Observations	985	985	985	985	985	985	985	985

Appendix D: Definition and Computation of Key Variables

D1 Rice Cultivation Variables

D1.1 Cultivated Area and External Inputs

To begin with cultivated area, there are four land-related variables. The first is total land holdings, lowland plot, upland plot, the most important plot and cultivated area. The cultivated area is the portion of the most important plot which was planted with rice in the particular cropping season. All variables were recorded in acres during interviews because it the commonly used unit in the study area. The variables were later converted to hectares by multiplying values with 0.404.

D1.2 Chemical Fertilizers and Insecticides and herbicides

Throughout all rounds of the survey, the amount of chemical fertilizer and herbicides applied were asked in several unit of measurements which familiar to farmers, then converted to standard units (kilogram or liters) during data processing. For example, each round of fertilizer application in the rice plot was converted into kilograms by multiplying the quantity applied with a respective conversion factor. The obtained products were summed up and divided by a cultivated area to give values into kilograms per hectare:

$$\text{The use of chemical fertilizer (kg/ha)} = \frac{\sum(\text{quantity applied} \times \text{conversion factor to kg})}{\text{cultivated area (ha)}}$$

The cost paid by a farmer to acquire fertilizer was calculated as:

$$\text{Chemical fertilizer cost (USD/ha)} = \frac{\sum(\text{quantity applied} \times \text{cost per unit (in Tsh)})}{\text{cultivated area (ha)} \times \text{conversion factor to USD}}$$

The calculation of seeds costs, and insecticides and herbicides costs follows the same methods as above. However, since most of households are using recycled seeds, then a variable for imputed seed cost is also generated. The calculation of imputed seed cost follows the same method except for the cost per unit value, which was substituted by the median cost of evaluated at the seeds' market price.

D1.3 Paid Out Labor Costs and Imputed Costs of Family Labor

This section includes calculating paid out cost for using hired labor, and imputed costs of using family labor for rice cultivation activities in the most important plots. The activities included are: (i) land preparation (that is, land clearing, plowing, leveling, puddling); (ii) transplanting; (iii) manual weeding (thinning and gaping); (iv) bird scaring; and (v) harvesting. Paid out costs variables were computed based on two types of contracts for hired labor in the study area, which are daily wage rate and piece rate. Among the two, is piece-rate contract, in which laborers are paid according to the unit of land they operate, is the most common. The piece-rate contract tends to be advantageous to both laborers and the plot owners because in most cases, it allows laborers to work jointly and to complete the work in a given time period.

Furthermore, even one individual makes a contract but found it difficult to meet the agreed target, that person can ask help from his peers to complete then assigned work. The plot owners also benefit by having their job done, less workers to be responsible for, and less contracts to keep tracking. The problem however, might rise when the peers fails to meet the quality of work, or time target demanded by the plot owner. In such circumstances, the daily wage contracts would be preferred. However, some farm activities were carried out by household members. There are some cases when a non-household member (for example visiting relatives, or exchange laborers) works without receiving any payment form. For such cases and other similar situations, the imputed cost of that activity were computed and accommodated in imputed cost variable. Therefore, imputed costs, do not only represent the evaluation of family labor but also few cases when an individual accomplished a task without involving any form of payments.

During data processing, the paid out costs for using hired labor was calculated based on the type of contract used. For piece rate contract, the paid out cost for were calculated as: *(number unit operated × cost per unit) / total area operated*, while for daily wage contract, the calculation was: *(number of person worked × number unit operated × daily wage rate person) / total area operated*. For imputed costs calculations, several stages were involved. First, the total labor use for each activity done by a man (*m*), a woman (*w*) and a children (*ch*) was calculated and converted into person days equivalent as:

$$\text{Total family labor use (in person days)} = \frac{N_m D_m t_m + N_w D_w t_w + N_{ch} D_{ch} t_{ch}}{8}$$

where N is a number of persons, D is number of days and t is number of hours a particular person worked respectively. Second, the imputed wage rates for each activity was calculated by dividing the total paid cost for hired labor (in TShs/acres) to total family labor use (in person days), then calculating the median value of imputed wage. The median value is used here, instead of mean because the labor market is not regulated and wage rates are not fixed. To obtain the imputed costs for family labor, the median value for each respective variable was multiplied with total family labor use, then divided by operated area and converted to USD/ha or adjusted for inflation to TShs/ha.

D1.4 Paid Out and Imputed Costs for Using Machinery or Animal

As we explained earlier, machinery and animals are usually used in the study areas for a land preparation and in harvesting. In most cases, machinery and animal used are not owned by rice farmers themselves but were can rented from better-off households, or individuals who are deliberately doing machinery and rental as their sources of income. The paid out costs for rented machinery or animal follows two types of contracts are for hired labor. Variables for paid out costs machinery and animal use for land preparation and harvesting were calculated as product of rental cost per unit operated and a number of unit operated. There were few cases where some households used their own machinery and animals. Therefore, imputed costs variables for using own machinery and animal were calculated by multiplying the median market rental rates with a number of unit operated.

D1.5 Yield, Revenue, Income and Profit

In the most important plot, some households plants more than one variety (thus the study presents the adoption of MV as the area share, rather than a dummy variable). Therefore, the total harvest from each variety planted was identified and then paddy yield was calculated and aggregated in tons per hectare. To compute for revenue (gross output value) from rice cultivation, the total harvest was multiplied by variety based average paddy prices (for MV and traditional varieties). The average paddy prices were calculated from the first sale of paddy for households who sold their paddy. For, household who did not sell their paddy, the median variety based median prices were used. After obtaining revenue, income from paddy cultivated in the most important plot was computed by subtracting the paid costs from the gross output value. The total paid costs is

an aggregate variable expressed in (USD/ha), it consists a sum of: (i) paid out costs for using hired labor in land preparation (i.e. land cleaning, ploughing, leveling, puddling), transplanting, weeding, bird scaring, harvesting; (ii) paid out cost for rented machinery and animal; and (iii) paid out costs for purchasing seeds, fertilizer and herbicides.

Lastly, the profit was computed by taking the subtracting total imputed costs from income. Total imputed costs (USD/ha) is a sum of: (i) Imputed costs for using family labor in land preparation, transplanting, weeding, bird scaring, harvesting; (ii) imputed costs for using own machinery and animal; and (iii) imputed costs for using self produced seeds. As explained earlier, imputed costs of family labor, use of owned machinery, and self-produced seeds were evaluated at village market wage rate, rental, and price, respectively. These computations are summarized below as follows:

$$\text{Total harvest (kg)} = \sum (\text{amount harvested} \times \text{conversion factor to kg})$$

$$\text{Yield (t/ha)} = \frac{\text{Total harvest (kg)}}{\text{cultivated area (ha)} \times 1000}$$

$$\text{Revenue (USD/ha)} = \frac{\text{Total harvest (kg)} \times \text{variety-based unit price (Tsh/kg)}}{\text{cultivated area (ha)} \times \text{conversion factor to USD}}$$

$$\text{Income (USD/ha)} = \text{Revenue (USD/ha)} - \text{Total paid costs (USD/ha)}$$

$$\begin{aligned} \text{Profit (USD/ha)} &= \text{Income (USD/ha)} - \text{Total impued costs (USD/ha)} \quad \dots \text{alternaltively,} \\ &= \text{Revenue (USD/ha)} - \text{Sum of total paid and impued costs (USD/ha)} \end{aligned}$$