博士論文

Empirical essays on rice technology adoption behavior in developing countries: A case study of the central highland zone of Madagascar

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Abstract

The high poverty ratio at present in rural areas of sub-Saharan Africa necessitates the improvement of agricultural productivity. In developing countries, a rural household directly and indirectly benefits from an increase of crop productivity. Therefore, agricultural productivity growth is considered to lead the inclusive, pro-poor growth of a developing economy. Due to the rapid population growth, land expansion will no longer be a promising measure for African farmers to increase crop production and the need for promotion of adoption of intensification technology is certain to be more and more important.

Madagascar is one of the poorest countries in the world. It has the world's 5th highest poverty head count ratio. The situation appears gloomy because the number of people in poverty is increasing. Since 80% of the population live in rural areas and depend on subsistence agriculture, crop productivity growth has been at the center of the national strategies of economic growth, poverty reduction, and food security. Rice production plays a crucial role in a rural economy as a source of a household's income and employment for unskilled laborers as well as being the staple food. Domestic rice production does not meet the domestic demands, and imported rice has been increasing in volume, necessitating policy efforts for rice productivity enhancement.

The main objective of this dissertation is to provide empirical evidence to help with understanding of technology adoption behavior and resource allocation within rice plots of rural households. The mainstream of adoption literature has seen the low rates of adoptions of promising technologies such as chemical fertilizer and improved seeds in developing countries as results of market failure, physical inaccessibility, or lack of information. This viewpoint is based on implicit assumption that adoptions of these technologies lead to better outcomes for

adopters. However, recent studies show that this assumption may not always hold for the real environment surrounding rural farmers in SSA.

This dissertation consists of 4 chapters excluding the introduction and the conclusion. Two datasets are used. Chapters 1 to 3 use a unique panel dataset with rich information collected from 600 households who were interviewed 8 times during a 4-year period from 2018 to 2021. The other dataset that consists of information from 70 farmers was specially prepared for the experiment in Chapter 4.

After confirming the strong association between rice cultivation and households' consumption levels in Chapter 1, profitability, and marginal productivity of chemical fertilizer in rice cultivation will be explored in Chapter 2. Two things were revealed. First, profitability of chemical fertilizer application in lowland rice cultivation is generally low and marginal productivity is heterogeneous across communes. Second, difference in the use of chemical fertilizer between lowland rice and upland rice was explained by the difference in the marginal productivity. Although profitability is not high in both types of plots, farmers' practice of using fertilizer more in uplands than in lowlands is rational. The analysis showed that upland rice plots have higher marginal productivity on average than lowland rice plots. These findings have importance because they suggest that cost reduction or subsidies alone will not increase the use of chemical fertilizer in lowlands. Development of new varieties of rice or practices to improve crop yield response to chemical fertilizer is required. These findings are also academically important because it provides evidence that poor farmers efficiently allocate the limited resources within their farm. Low profitability has been pointed out in existing literature to explain low rates of the adoption at farm level, but a situation in which a household uses it in some plots but not in others has been rarely studied. To my knowledge, this study is one of the first works to show that the within-farm allocation is driven by difference in marginal product.

In chapter 3, factors affecting adoption of upland rice and its impact on household welfare are examined. Madagascar is different from other SSA countries where upland rice has been promoted because it has a long tradition of rice cultivation in lowlands. Why upland rice is rapidly diffusing in the study area was not clear, especially when the following were taken into consideration: the lower of upland rice is lower than lowland rice, it's more vulnerable to biotic and abiotic events that adversely affect productivity such as drought and insect attacks, and the demand of labor is higher. Using propensity-score-matching (PSM) method, this study found that upland rice contributes to households' welfare by increasing rice consumption per capita and consumption level. This chapter contributes to the growing literature on upland rice diffusion in SSA. The adoption behavior regarding upland rice has been studied as a new promising crop in countries where rice is not the staple food or rice cultivation in lowlands is not environmentally or practically feasible. The conclusion of this chapter emphasizes the substantial role that upland rice plays in supplemental rice production for lowland rice growers.

In chapter 4, the impact of information provision on chemical fertilizer adoption and allocation was examined. Heterogeneity of marginal productivity that was presented in Chapter 2 suggests the importance of site-specific information regarding effectiveness of fertilizer application. The experiment was designed based on the latest agronomic knowledge that effectiveness of nitrogen fertilizer depends on the amount of phosphorus in the soil. Most literature on the role of plot-specific advice uses information that encourages farmers to increase the use of fertilizer to appropriate levels of fertilizer requirements. The experiment in this chapter distributed simple binary information which either encouraged or discouraged the fertilizer use based on soil characteristics. Key findings from this experiment include that soil characteristics and consequential expected effectiveness largely vary across plots even within a given village, which emphasizes the need for plot-specific information. Also, the results show that farmers utilized the information to use the given fertilizer efficiently, instead of being caught by the “traditional” agriculture. The information that the soil is responsive to nitrogen fertilizer increased the rates of application of nitrogen fertilizer and the information that nitrogen fertilizer may not be effective decreased its adoption rate.

Throughout the chapters, this dissertation depicts the farmers’ characteristics as profit maximizers. It was shown that farmers choose profitable ways of resource allocation and that they respond to new information that updates their knowledge. Policy implications derived from these findings are clear-cut. Rice varieties and agricultural practices to enhance yield response of lowland rice to fertilizer will play a critical role in promotion of intensification. Also, precision agriculture will have high potential to benefit farmers in SSA as this study shows that soil characteristics vary from plots to plots even within a small community in a village. Investment in connecting the cutting-edge digital technology and African farmers will be a powerful engine for poverty reduction in SSA.

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Ryosuke Ozaki

INTRODUCTION

0.1 Background

There is an increasing social demand to improve agricultural productivity in the developing countries, particularly sub-Saharan Africa (SSA) where poverty persists with an increasing trend in numbers in some countries. The global initiative of Sustainable Development Goals listed "Eradicating Poverty" as the first among the total 17 targets to be achieved by 2030. According to the recent world bank report, 18 out of 20 countries with the largest poverty rates are in SSA (World Bank, 2020). This geographically uneven distribution of poverty necessitates the international community to substantially increase efforts for the poverty reduction in SSA. The purpose of this dissertation is to contribute to a better understanding about rural farm households' decision-making about agricultural technology adoption, which is the key to the agricultural productivity growth and consequentially rural poverty reduction.

Technology adoption for productivity growth is not a new topic in the field of agricultural economics, but still worth being studied. While there is the consensus about the need for a substantial development of agricultural sector in SSA (Staatz and Dembele; 2008; Ravallio 2008; Dercon, 2009; Dercon, 2014), we have not reached conclusion about how to make it happen. The need for growth in agricultural sector is justified with the theoretical and empirical evidence. Growth in agricultural sector has larger impact on poverty than other sectors in developing countries where a large share of the populations are in rural areas and access to international markets is relatively limited (Gollin, 2010; Dethier and Effenberger, 2012; Irz et al, 2001; Ivanic and Martin, 2018).

Theoretically, the growth of crop productivity benefit farm households directly and indirectly. The main channel of the direct effect is from increased crop income. It will also contribute through creation of more labor demand with relatively high wages for unskilled labor in agricultural sector. The higher income of rural households result in increase of local tax revenue which can be in turn spent for investment in improvement of local infrastructure that may generate a consequential virtuous cycle. At national level, enhancement of agricultural productivity reduces food prices and promotes structural change by letting relatively high-skilled workers in the agricultural sector find job in non-agricultural sectors. Thus, the agricultural development will have spill-over effects to other sectors and lead to the inclusive, pro-poor economic growth.

These direct and indirect effects of agricultural development on poverty reduction have been empirically supported (de Janvry and Sadoulet, 2002; Minten and Barret, 2008; Irz et al., 2001). According to Ravallion and Datt (1996), which is one of the pioneering works in this field, primary sector growth was found to be associated with poverty reduction both in urban and rural sectors while such association was not find from the secondary sector growth. Ivanic and Martin (2018) showed that one-percentage increase in total factor productivity in the agriculture results in 0.89 percentage-point reduction of the poverty rate at $1.25 per day whereas the same degree of increase in industry and service sectors reduces 0.37 and 0.27 percentage points, respectively.

Basically, a nation may experience production growth by two different means, intensification of cultivation and expansion of agricultural land. According to the FAO report, crop productivity increased mainly via intensification in Asia and Latin America while the land expansion was the main driver of the production increase in SSA (FAO). In future, due to the rapid population growth, intensification will be the only way for SSA countries to increase productivity and ensure food security because possibility of further land expansion to increase agricultural output will be exhausted soon (Dethier and Effenberger, 2012; Otsuka and Muraoka, 2017).

Technological progress contributes to crop productivity improvement (Mundlak, 2012; Fuglie and Wang, 2012), but the use of promising technologies remains low and process of intensification appears to have been weak (Binswanger-Mkhize and Savastano, 2016). However, economists still have not found the appropriate approach to realize it. There is long-continued discussion about why the agricultural technologies such as chemical fertilizer and improved seeds, which contributed to increasing crop productivity in Asia since 1960s, have not been well adopted in SSA (Otsuka and Muraoka, 2017). Therefore, the challenge is to find an effective way to promote the technology adoption for intensification in SSA.

0.2 Literature review on technology adoption in developing countries

Based on the microeconomic view of a rural farm household as an utility maximizing entity, the simplest explanation of the adoption decisions is that farmers adopt a new technology when they perceive benefit from doing so. The benefit is the net benefit. Not only technologies with just positive impact on productivity but also those to reduce production costs are beneficial. Therefore, the conventional Expected Utility Maximization model is the primary candidate to describe the adoption behavior. A considerable characteristics of farm households in developing countries is non-separability of producer and consumer. Unlike business-oriented farms in developing countries, farmers in developing countries consume their products, which implies that their decisions as consumers and producers are connected and difficult to be distinguished (Kurosaki, 2009). There are three more concerns that make the issue difficult to be entangled. They are constraints, uncertainty, and risk.

First, rural farmers in developing countries have to make their decisions under various constraints that include financial liquidity constraints and physical constraints largely due to poor infrastructure. Limited access to credit markets is one the major problems in areas where farmers have seasonal liquidity constraints. If farmers can borrow the upfront cost, the adoption of new technology simply depends on net returns and not on the timing of costs and benefits (Foster and Rosenzweig, 2010). Transportation and transaction costs significantly reduces profitability of technology such as chemical fertilizer (Minten et al., 2013). These constraints impede farmers' adoption even if they know about the technologies and the potential benefit that they will gain by the adoption. Empirically, there is a technical need to distinguish between farmers who do not want to use the new technology and those who wants but are too constrained to adopt them[1] (Coady, 1995; Croppenstedt et al., 2003; Asfaw et al., 2012; Shiferaw, et al., 2008)

Second, the perceived benefits of technologies depend on information available to potential adopters. The benefits of new technologies are not clearly observed before adoption especially when farmers first get exposed to it. Farmers have to make a decision of adoption without fully knowing about the suitability of the technology to the real condition of their own fields (Duflo et al., 2008; Chavas and Nauges, 2020). Learning model has been developed to study the effects of this uncertainty, assuming that farmers are Bayesian learners who learn from their own experience and others. Many empirical studies have examined the roles of social network with neighbors, farmer's group, and extension services as factors to reduce the uncertainty.

The empirical studies have grown in volume by extending the scope to factors that potentially generate uncertainty in technology adoption. Ashour et al. (2016), for example, dealt with the "lemon" problem in input markets and its association with low rate of adoption with particular focus on farmers' belief. Bold et al. (2015) also revealed that considerably low quality of fertilizer and improved seeds sold in local markets in Uganda led to negative average returns. Recently, much attention is paid to heterogeneity of soil quality to which heterogeneous effects of fertilizer in farmers' fields are potentially attributed (Marenya and Barret, 2009).

Third, even if farmers have good access to a suitable technology to the local farms' environment, the benefits from technology adoption may not be realized as adopters expect due to weather-related risk and

[1] Double Hurdle model is used in literature to meet this demand (Asfaw, 2012).

other adverse shock to production. Considering the risk aversion as typical characteristics of rural farmers, the downside risk that farmers may face during cultivation should have something to do with their adoption decisions. Prospect theory has been applied to literature on agricultural technology adoption (Chavas and Nauges, 2020). Also, some empirical studies have shown that these risks actually adversely affected technology adoption among cotton farmers in China (Liu,2013) and that risk-averse farmers in Malawi were more likely to adopt drought tolerant variety of maize (Holden and Quiggin, 2017).

Another strand of studies in adoption literature includes studies that uses theories of behavioral economics (Streletskaya et al., 2020). This type of literature focuses on imperfect rationality of humans and examines whether or not it explains the low adoption rate of some technologies. One of the few examples of the application to the agricultural technology adoption behavior in a developing country is the experiment conducted in Kenya by Duflo et al (2011). This study showed that farmers evaluation of the e value of fertilizer depended on the timing of sales, which is consistent with hyperbolic time discount ratio in the behavioral economic theory.

Recent studies that conducted meta-analysis of empirical studies about determinants of technology adoption emphasize the importance of the context specific approach for promotion of adoption of these technologies. What the increasing number of case studies have shown is that determinants, constraints, profitability of adoption largely vary by geography, cultural context, and technology to be promoted (Suri, 2017 Ruzzante et al., 2021). While education, household size, land size, and access to credit, land tenure, access to extension services, and organization membership, are likely to have positive effects on adoption behavior (Ruzzante, et al., 2021), influence of these factors are not consistent across case studies (Munguia and Llewellyn, 2020). Existence and magnitudes of their influence on the adoption behavior highly depends on country and type of technology and thereby vary across studies (Sheahan and Barret, 2017).

Therefore, the analysis of profitability and the impact of new technology under a specific context still have potential to provide new insights to the literature. Analysis of decision of within-farm, plot-level allocation seems especially important since rigorous evidence has not been accumulated in the literature. The reason why it has not been well studied is partly because of data availability. The publicly available datasets regarding agricultural production in developing countries often do not have plot-level input-output data or even if they do, it is often cross-section which makes estimation results prone to be biased. (Doss, 2006). In this dissertation, we utilize a unique panel dataset constructed under the FyVary[2] project that is led by researchers of Japan International Research Center for Agricultural Sciences (JIRCAS). The dataset includes latest situation of Malagasy farmers and allows us to conduct plot-level analysis, which is one of the previous advantages of this dissertation.

0.3 Dataset construction

This dissertation aims to contribute to the growing literature related to agricultural technology adoption in developing countries through a set of new evidence using panel data collected from the central highland zone of Madagascar. Two datasets are mainly used in the analysis. First, from chapters 1 to 3, a unique panel dataset which is constructed by interviewing 600 households for 8 times[3] during July of 2018 and August 2021. To capture seasonality of livelihood of rural households, three rounds of survey were carried out in different times of a year; soon after harvesting months, 3 to 4 months after harvesting months, and before the harvesting months (see Table 0.1). Geographically, data collections were carried out from 3 out of 6 rural districts in the Vakinankaratra region. In total, 13 communes are selected across the 3 districts. Then, 60 villages that cover approximately the half of the total number of villages in the selected communes were chosen so that our dataset geographically represent as large part of the targeted communes as possible. The sample households were restricted to those who had grown rice in lowlands in the rainy season of 2017. From each village, 10 rice-growing farmers were randomly selected.

The questionnaire used in the interview has two advantages. First, we collected information about the use of inputs and outputs at all plots where a household had cultivated. Especially detailed information was collected regarding rice cultivation. Second, households' consumption and expenditure were recoded intensively at every round of survey. This enabled us to show seasonality of consumption levels and their relationship with rice cultivation. Finally, and most importantly, the same households were interviewed for 4 years, which is critically important in econometric analysis to obtain rigorous results by controlling household unobservable characteristics. Data collection was done by well-trained enumerators[4].

[2] FyVary is one of the projects of SATREPS, standing for FertilitY sensing and Variety Amelioration for Rice Yield and meaning "good rice" in local language (FyVary Project website: https://www.jircas.go.jp/ja/satreps).
[3] In the initial plan, 9 times of surveys would have been conducted during the same period of time, but due to the pandemic of Covid-19, a survey in July of 2020 was canceled. The data which would have been collected in the canceled survey was collected in the following survey in Oct of 2020.
[4] We usually hold a three-day training prior to each round of survey.

The other dataset was used for the experimental analysis in Chapter 4. This dataset had been constructed by data from farmers in two out of the same three districts as the panel dataset targeted. However, 5 villages were purposely selected from those not in the panel dataset so that the implementation of this experiment would not affect farmers in the panel survey. The procedure of the sample selection of this dataset will be described in the Chapter 4.

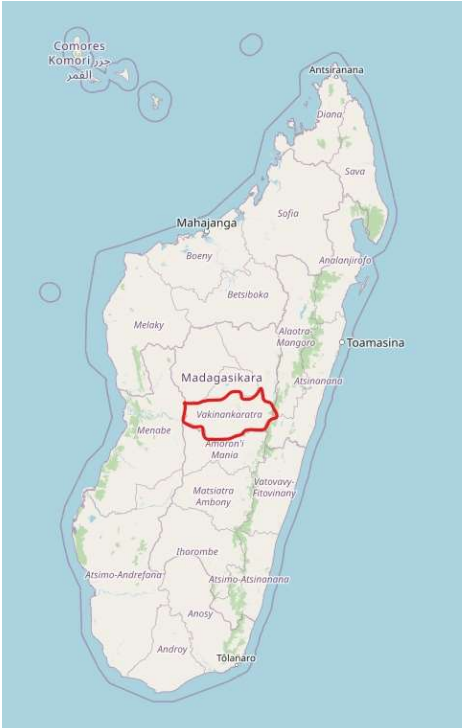
0.4 Organization of the rest of dissertation

Chapter 1 summarizes key features of the study site, and then describes how rice cultivation and its productivity enhancement are connected with rural livelihood of Malagasy farmers. Chapter 2 explores profitability of chemical fertilizer application is examined and examine whether the profitability is different between lowland rice and upland rice plots[5]. Chapter 3 focuses on upland rice cultivation in the study area. Unlike other SSA countries where upland rice is promoted as new cash crop, Madagascar has long tradition of rice cultivation in lowlands. The analyses of determinants of upland rice cultivation and its impact on household's welfare are conducted to explain why lowland rice growers additionally grow rice in uplands despite the innated disadvantages of upland rice against lowland rice[6]. Then, in Chapter 4, the roles of information based on soil quality for promotion of chemical fertilizer in lowland plots are examined by means of randomized controlled trial (RCT). Finally, key findings of each chapter are summarized and policy implications for rice productivity growth in Madagascar will be presented in conclusion section.

[5] This part has been published from Japanese Journal of Agricultural Economics

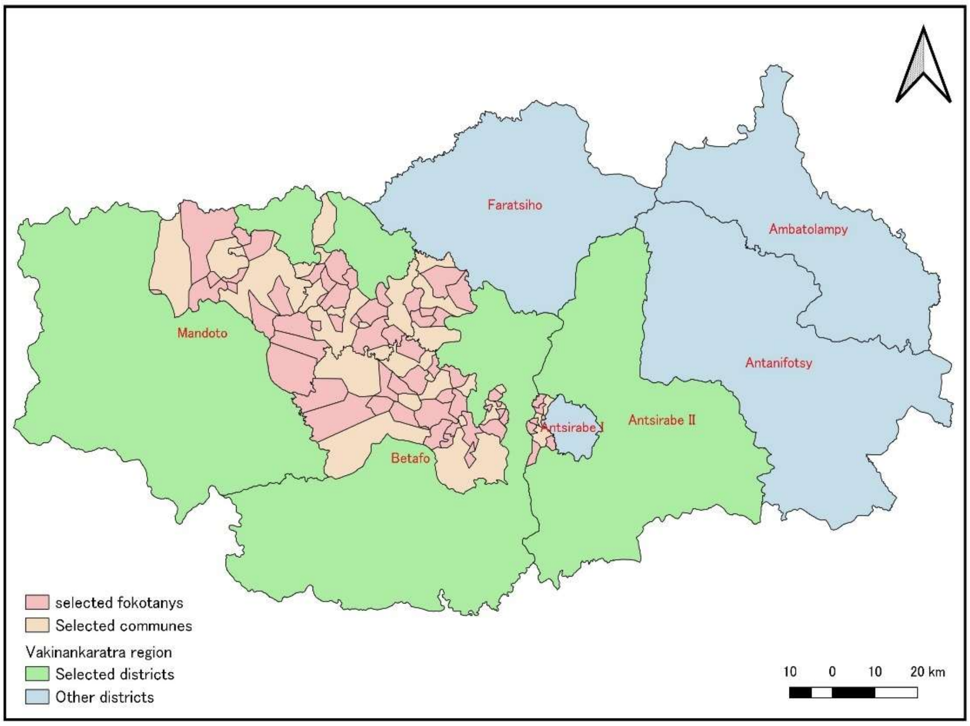
[6] This work has been published from Japanese Journal of Agricultural Economics

Figure 0.1: Map of Madagascar with borders of regions



Source: The author made uing © OpenStreetMap contributors

Figures 0.2: Locations of targeted villages



Source: Authors created based on data obtained from Humanitarian Data Exchange (HDX)
https://data.humdata.org/dataset/madagascar-administrative-level-0-4-population-statistics

Figure 0.3: Schedule of survey rounds

ROUNDS	YEAR	MONTH	TIMING	NOTES
1	2018	JUNE -JULY	SOON AFTER HARVEST	BASELINE SURVEY
2	2019	FEBRUARY - MARCH	LEAN PERIOD	
3	2019	MAY-JUNE	SOON AFTER HARVEST	
4	2019	OCTOBER - NOVEMBER	5 MONTHS AFTER HARVEST	
5	2020	FEBRUARY - MARCH	LEAN PERIOD	
(6)	(2020)	(JUNE-JULY)	(SOON AFTER HARVEST)	CANCELLED
6	2020	OCTOBER-NOVEMBER	5 MONTHS AFTER HARVEST	
7	2021	FEBRUARY - MARCH	LEAN PERIOD	
8	2021	JULY - AUGUST	SOON AFTER HARVEST	

Notes: The round (6) was cancelled due to COVID-19. Information that were supposed to be collected in (6) were collected in the following round.

CHAPTER 1
ASSOCIATION OF RICE PRODUCTION AND POVERTY IN STUDY AREA
1.1 Introduction

This chapter aims to describe the livelihood of rural farmers with focus on their consumption levels and poverty status. The poverty profile analysis based on the household's consumption is presented with its associations with some socio-demographic characteristics. The importance of rice in a rural household's economy is discussed by showing the share of rice in the total consumption and income. Then, the correlations between rice production and poverty-related indicators are examined.

1.2 Madagascar

Madagascar is an island nation in the Indian ocean. It covers 587,295 square meters and has a population of 25.67 million people. As in other SSA countries, it is experiencing a rapid population growth at an annual rate of 2.6% on average (World Bank 2020b). It is predicted to reach 30 million by 2024, which is three times larger than it was in 30 years ago (United Nations, 2019). Madagascar is an agrarian country with the rural population accounting for 80.7% of the total population, according to the latest national census in 2018 (INSTAT, 2020).

The nation consists of 22 regions. Regions are the largest administrative units (See Figure 0.1 in the previous chapter). Each region has several districts that are further divided into several communes. There is a sub-category under communes, "fokotany" in the local language[7]. In this study, we refer to this unit as village.

1.3 Vakinankaratra region

Among the 22 regions of Madagascar, the Vakinankaratra region has a population of 2.08 million which is the second largest in the nation and accounts for 8.1% of the total population (INSTAT, 2020). Population density is also the nation's second highest at 116.3 people/km^2 whereas the national population density is 43.4 people/km^2 (INSTAT, 2020). Geographically, Madagascar has 4 ecological zones: Central highlands, North, East, and the South and West zone. The Vakinankaratra region is located in the southern part of the central highlands zone which is characterized by hilly landscape. The altitude varies from 600 to 2600 meters above sea level. According to the variation of altitude, the Vakinankaratra region has three sub-

[7] There is a further smaller administrative unit that is locally called "hamlet". This unit is used in the experimental study in the Chapter 5.

agroecological zones. The highland area is a sub-part where the altitude is over 1600 meters above sea level with characteristics of cold temperature and high rainfall. The medium altitude ranges from 1,200 to 1600 meters above sea level with moderate temperatures, high rainfall, and high land pressure due to relatively high population density. The other sub-zone is called Midwest where the altitude is less than 1200 meters above see level. It has warmer temperatures, a relatively lower rainfall, and lower population density than the other two. (Rakotoasrisoa, et al., 2016).

1.4 Profiles of the sample households from our baseline survey

1.4.1 Demography

Table 1.1 summarizes household level characteristics of the sample households at the time of baseline survey in June of 2018. The number of household members is 4.97 on average. The average number of adult[8] members is about 3.2 and that of children is 1.8. 89% of households are headed by a male. Household heads are 46 years old and have 5 years of education, on average. Approximately, 65% of the heads were born in the village where they currently live. Only 3% of them immigrated from outside the Vakinankaratra region. The majority of household heads in our dataset belong to the dominant ethnic group, Merina.

1.4.2 Land endowment

Land endowment is a basis of livelihood for agrarian households. Table 1.2 shows that the sample households cultivate 0.67 ha of land on average, implying they are typically small holder farmers. Interestingly, in all quintiles in terms of the total land size, 31% of the land is used for rice cultivation with a slightly higher percentage in the 2nd quintile. This implies that the land size for rice increases in accordance with the total land size. The major means of land acquisition is inheritance. In our dataset, households acquired almost 60% of their land from either the husband's parents or the wife's parents by inheritance. There are two types of lands, namely lowlands and uplands[9]. Traditionally, lowlands are used for rice production and uplands are for cassava, maize, beans, and potatoes. Recently, upland rice has been diffused in the central highland zone and planted on lands where these traditional upland crops used to be planted (Rakotoarisoa et al., 2016). Livestock, especially cattle, has socio-cultural value in Malagasy culture and it potentially functions in the household economy as an important income source and risk coping strategy

[8] Adult is defined as age of 15 years or older.
[9] Lowlands are locally called "Tany vary" whereas uplands are called "Tany antanety".

(Hänke and Barkmann, 2017), and a source of manure for crop production. However, the importance of cattle in the study area seems relatively small since the sample households have only 1.4 cows on average[10].

1.4.1 Income source

Table 1.4 summarizes income sources for sample households from January to December in 2019[11]. The mean total income was approximately 2,158.53MGA, which is equivalent to US$1831.06[12]. By nature of panel data construction, all but one exceptional household had at least some income from crop cultivation. Income from working in other places are another major channel for income. Almost 70% of households have at least one household member working as a farm laborer. The total crop revenue[13] was 981980 MGA on average, which is approximately 37% of the total revenue. The average revenue from rice was 740130 MGA, which is more than 75% of the total crop revenue. The costs for rice and non-rice crop production were calculated as the summation of all the paid-out costs from land preparation to cleaning of harvested grains. As this calculation does not account for unpaid costs such as shadow price of family labor, recycled seeds, and own-produced manure[14], the values presented do not mean net profit of crop cultivation. In addition, 50% of households received any type of non-labor income that include remittance from extended family, rent for rented-out land, and credit. Only 18% of the total sample households received some money as the form of credit[15], implying that credit is not easily accessible or available for most sample households (see Table A1.4 in Appendix).

1.5 Poverty

1.5.1 Trend of Poverty in Madagascar

Madagascar is one of the poorest countries in the world. Under the definition of absolute poverty in the Sustainable Development Goals (SDGs) as a population who live on less than $1.90 a day (UN.org), its poverty headcount ratio reaches 80%, which is the 5th largest in the world as of 2018 (World Bank, 2020c). More importantly, poverty in Madagascar increased in numbers during the 2010s (World Bank, 2014), and

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[10] The role of livestock in Malagasy farms are discussed intensively. Discussion is briefly summarized in Hänke and Barkmann (2017).
[11] This table was made using data in 2019 only.
[12] Values in MGA were converted to USD by using PPP of US$1.00 = 700.228 MGA as of 2011 after deflating the value to that of 2011 based on CPI.
[13] Crop revenue are defined as value of products which is calculated by multiplying quantity of production multiplied and selling price. If a crop product was not sold, the average selling price at each village was applied.
[14] The author is aware of importance of these shadow prices because these unpaid costs substantially affect profitability of crop cultivation. However, the profitability is not the major interest in this chapter.
[15] Our questionnaire asked the usage of two types of credits, namely loan for investment and loan for consumption, separately. However, the number of households applied for loan for investment is negligible, and so I include both types of credits in the calculation of the percentage.

this trend seemingly continues. The Malagasy economy is 41% poorer today than in the 1960s (World Bank, 2020). Therefore, poverty reduction in Madagascar is one of the acute problems that is receiving attention from the international community.

Group-wise tendencies of poverty may explain why poverty in Madagascar is persistent. Stifel (2010) found evidence of group-wise differences in welfare among Malagasy people. Merina people, the dominant ethnic group, are better off than those of other ethnic groups. Low education level, gender of the household head, and remoteness are clearly associated with the low consumption level (Stifel, 2010). These factors require long-run and large-scale investment to be addressed by policy measures. Poverty in Madagascar is also closely linked with land degradation and deforestation. The land productivity has been declining over time due to soil erosion, and consequently has led farmers to overusing their land with short cycle cultivation, jeopardizing future productivity (Harper GJ, et al., 2007).

1.5.2 Poverty profile from sample households in the panel dataset

In our dataset, poverty is widespread as in other publicly available statistics. Based on the level of household consumption per capita and international poverty line of US$1.90, 84.5 % of the sample households were in poverty[16] as of June in 2018 (see Figure 1.5). This percentage is slightly higher than the nationally representing statistics, but it is still realistic because our data does not include the urban population whose consumption levels are considered to be substantially higher than the rural population. The mean consumption[17] per capita was 908 MGA per capita after deflating the value of currency to the level of 2011, which was already below the poverty line.

Table 1.3 presents the poverty profile[18] which investigates associations of several household level characteristics with the household’s consumption level. Generalized FGT poverty measures are calculated for each type of sub-groups of sample households. Generalized FGT poverty measures are defined as below (Foster et al., 1984, Kurosaki, 2009).

$$P_\alpha = \frac{1}{n}\sum_{n=1}^{q}\left(1-\frac{C_i}{z}\right)^\alpha \qquad \ldots..(1)$$

[16] In the identification of the poor, the value of the consumption expenditure was delated to the value of 2011 by using Consumer Price Index, and then converted to US$ by using PPP.
[17] Calculation formula is in Table A1.3 in the appendix.
[18] the style of the profile follows Kurosaki (2008) that presented poverty profile of Pakistan in 1996.

When α = 0, the indicator (P_0) captures the ratio of households in poverty over the total number of households. More specifically, it shows the proportion of households whose consumption level, C_i, is less than a certain threshold of z over the total sample size. When α = 1, this measure indicates the poverty gap index. While the poverty headcount ratio does not imply anything about how poor they are, a larger value of this index implies that the consumption level is far from the poverty line.

In addition to the high poverty ratios in general, various household characteristics seem associated with the level of consumption and poverty and its severity. Poverty headcount ratio is higher among those households with no or a relatively less educated and younger head. Larger households are more likely to be in poverty. Land endowment also shows associations with poverty indicators. Poverty headcount ratio is clearly higher among the group of households with the smaller land size per capita. As the land size increases, the poverty head count ratio decreases.

In addition to these socio-economic characteristics, consumption level as well as poverty measures largely vary across communes[19]. Among 15 communes, the highest mean consumption level in Belazao commune, 1283MGA, is close to twice as high as that in Mahaiza commune whose mean consumption was 666MGA. In 5 out of 13 communes, more than 90 % of households were in poverty (Table 1.6). Where poverty headcount ratio is high, the poverty gap index is also high, implying that the poverty is severe in places where poverty is more prevalent.

Seasonal fluctuation of consumption level was also observed. In the Table 1.7, the levels of per-capita consumption are compared across survey rounds that are carried out three different times a year. In the surveys soon after harvesting months, the mean consumption expenditure was 972.03 MGA [20]while it declines to 963.83MGA in the survey in 4 months after the harvesting months, and then drops to 875.56 MGA in the surveys conducted during February and March, a lean period before the next harvesting of crops. The poverty ratio in the survey during the lean periods is 5 percentage points higher than in the surveys right after harvesting. The higher poverty ratio in the lean period implies that some households whose consumption level was higher than the poverty line after harvest fell into poverty within a year.

Data presented in this section so far suggests the importance of policy efforts for improvement in rural livelihood by highlighting not only the widespread high poverty ratio across the region but also the depression

[19] Commune is a sub-unit of administrative division under district.
[20] The mean value is difference from Table1.3 and 1.4 because data from all survey rounds are used in the computation whereas previous tables only used the baseline survey data.

of consumption level in the lean months as well as the geographical variation of the poverty gap. Among the literature proposing evidence of the role of agricultural sector in the rural poverty reduction, Minten and Barret (2008) provided empirical evidence for the link between agricultural performance and the rural poverty in the context of Madagascar. Using commune-level data, they found that higher crop yields as a result of higher rates of adoption of improved agricultural technologies contribute to better welfare indicators as well as lower food prices and higher real wages for unskilled workers.

1.6 Importance of rice as a strategic crop for rural poverty reduction

1.6.1 Rice in the national policy for poverty reduction

Rice is one of the most promising strategic crops for rural development in SSA. One of the reason is its transferability of technology from the tropical Asia (Balasubramanian et al., 2006; Otsuka and Larson, 2013). Among various crops grown in Madagascar, rice is a far more important crop in the national policy for the economic growth, poverty reduction, and food security (World Bank 2020, Minten et al., 2006). Rice is important not only because it is the traditional staple food but also the agricultural sector largely depends on rice. Nationwide, it is estimated that 56% of agricultural land was devoted to rice cultivation and 89% of households in the agricultural sector are engaged in rice cultivation as of 2019 (World Bank, 2019).

In the 1980s, the Malagasy government implemented the reform of rice sector[21]. The main purpose of the reform was to increase rice production to save the foreign currency spent on importing rice, and ultimately to become an exporter of rice (Bernier and Dorosh 1993). Since then, contrary to the national ambition to be an major exporter in Africa, the quantity of rice import has increased by ten-fold from 59,000 tons in 1990 to 600,000 tons in 2018 (FAOSTAT), which exposes the Malagasy economy to the international food price shocks (World Bank, 2020b).

1.6.2 Rice in the households' economy

. To understand the importance of rice production in household economy, Figure 1.2 shows a breakdown of households' consumption expenditure by poverty status and the timing of data collections. Rice accounts for approximately 40% of the total household expenditure. Poor households have a higher share of rice in their total consumption than the non-poor. The difference between the two groups is approximately 10 percentage-point. The non-poor households increase the share of consumption of pulses and non-food items,

[21] The reform was mainly market side. Bernier and Dorosh(1993) summarizes the contents of the reform.

implying that they spend more on nutritious food. In addition, there are seasonal variations of the consumption pattern. The highest proportion of rice consumption was found from the surveys in the lean period. As these months are far from months of main harvesting of crops, it seems that when facing money and food shortages, rural households reduce the consumption on non-rice items before reducing it on rice.

In addition, it should be worth noted that farmers produce rice but approximately 30% of the sample farmers purchase rice in a year. 187 out of 600 households reported that they purchased rice at least one during June in 2018 to March 2020 (Figure A1.1). Table A1.1 lists the number of households who purchased rice for the first time after the rice harvesting in 2018. While the peak is in December when 47 households start to buy, more than 100 households reported that they start buying rice within 5 months from June to October. This seems to imply that production is insufficient to meet their demand.

1.6.3 Relationship between rice production and consumption level

Quantity of rice production varies every growing season due to several factors such as precipitation, input use, and size of land where rice is planted. Since rice production is the main income source for most farmers, the rice productivity[22] will have an substantial influence on the household consumption level and poverty status around a year. The relationship between rice productivity and consumption expenditure is examined by the following fixed effect model by using panel data[23]. Fixed effect model is appropriate in this setting because the total rice production is typically endogenous[24]. Unobservable factors such as management skills, personality, risk preference in the error term affect consumption level while it may also be correlated with rice production. These omitted variables in the error term result in bias of coefficient estimation.

$$Y_i^k = \beta_1 Rice_{it} + \beta_2 VC_{it} + \beta_3 year_t + \beta_4 year * village + \beta_5 year * IC_i + \alpha_i + u_{it}$$

$$t \in (2018, 2019, 2020)$$ [25] $$k \in (1, 2)$$

Y_i^k is an outcome variable of household i in year t. k denotes the survey timing from which the outcome variable was calculated. Two types of outcome variables are examined, the total consumption per capita and

[22] In this section, only the rice production in rainy season is taken into consideration to simplify our discussion whereas some farmers in favorable condition with irrigation grow rice also in the counter cropping season.
[23] In this analysis, we used strongly balanced panel data with households who appear in all survey rounds because of our interest to examine the relation of rice production and outcome variables in different time of a year.
[24] Another potentially appropriate model is random effect model which imposes the strong assumption of no correlation between error term and any of the explanatory variables in the model. As mentioned in the notes of the result table, this assumption was declined by Housman test.
[25] Data from the rainy season of 2020-2021 was not used in this analysis because no outcome data in the lean period is available yet.

poverty status that takes a value of one if the total consumption expenditure is less than the value of international poverty line converted to the local currency, MGA. We explore the relationship between rice productivity and these outcome variables from two different survey timings, soon after harvest (k=1) and the following lean period (k=2). $Rice_{it}$ is the average rice yield in kg/ha in the rainy season for household i in year t. VC_{it} is a vector of time variant variables. Total land area per capita in hectare and household size are included. These variables were chosen because they are related to household consumption level as shown in poverty profile. IC_i is a vector of time-invariant variables, including distance from national road in kilometers, sex, age, and years of education of the household head. Sex of the household head is usually considered to be time-invariant except for some special cases in which the a household lost their head. Education level of the head is also time-invariant because in most cases household heads had already finished their school program. $village$ is a vector of 59 dummy variable that capture the village level characteristics such as climate conditions, market access, and other unobservable factors at each village. The effects of these time invariant variables, IC_i and $village$ cannot be observed in fixed effect model. Thus, this model includes the interaction terms of these covariates and year dummy variable, $year_t$ to capture the effects. β_1 is a key parameter of interest. When the poverty status is used as the dependent variable, this model is linear-probability model. In both cases, parameters can be interpreted as marginal effects of each factor.

1.6.4 Descriptive statistics for regression analysis and results

For this analysis, only households who appeared in all the survey rounds are included. The total number of sample households became 521. As for the outcome variables, the total consumption per capita[26] soon after harvesting was 922.18 MGA[27], which is equivalent to US$1.32. If the data from surveys conducted in the lean period, the value decreases to 879.70 MGA. Although there are differences in the mean consumption per capita by years, the relationship between the two timings is common. Average rice yield was 3551.93 and average rice production per capita was 209.42 kg in this dataset. The total land size per capita was 0.17 ha and the number of household member was 4.79 on average. Almost 89% of households are headed by a male and the average age and years of education of household heads were 48 years old and 5.4 years, respectively. On average household live 5.27 km away from the national road, suggesting from poor accessibility to urban markets.

[26] Table A1.3 provides the list of items used in consumption variable construction.
[27] MGA is the local currency of Madagascar. It stands for Madagascar ariary. The value presented in the main text and the relevant table is after deflation to the value of 2011 using Consumer Price Index (CPI).

The result shows the strong correlation of rice productivity with the household consumption level and poverty status particularly soon after harvesting[28]. Household size is negatively associated with consumption level, which is consistent with the poverty profiling. Having one additional member in household is associated with 5% higher probability of falling into poverty in the lean period. As a robustness check, the same model with rice production in kg per capita as the key explanatory variable was run and the results are presented in Table A1.2. Although the quantity per capita showed significant association with households' consumption level even in the lean period. No other difference was observed from the Table 1.8.

From the strong correlation of both rice productivity and household size with these welfare variables, it appears that Madagascar currently faces three adversely affecting factors for rice production, namely population growth, soil erosion, and climate change. The rapid population growth will not allow farmers to even maintain the already low consumption level in the future as a household will have to meet the increasing consumption demand by cultivating smaller land than they do at present. The soil erosion will make it more difficult for farmers to harvest as much rice as they currently do from a unit of land. Even without these two factors, recent climate change will threaten future rice production and household welfare with more frequent occurrences of harsh weather events such as drought and cyclone (Azzarri and Signorelli, 2020, Thomas and Gaspart 2015). Thus, it is inevitably urged to realize rice productivity growth. The desirable way is intensification that enhances crop productivity per unit of land.

While Barret (2006) showed the importance of improved agricultural technologies and the mechanism by which rice intensification positively stimulates the rural economy, the use of chemical fertilizer in Madagascar is still at the lowest level in the world. In the panel dataset, among the total 1007 rice plots in lowlands, the number of plots where chemical fertilizer was applied in the season of 2018-19 was 49, which is less than 5%. Thus, a research to propose a way to encourage the use of these technologies is important.

1.7 Conclusion of Chapter 1

Madagascar has one of the highest poverty headcount ratios in the world. As most population live in the rural area, improvement of rural livelihood has been the priority of the national poverty reduction policies. For the rural poverty reduction, increasing crop productivity, especially rice, is the key strategy. This is supported by findings from descriptive statistics and poverty profiling based on the unique panel dataset.

[28] In this model, rice yield in kg/ha was used as key explanatory variable. As robustness check, results of another model in which rice production per capita in kg is presented in appendix (Table A1.2). In that model, the coefficient of rice production per capita shows significant positive association with outcome variables in the lean period.

Sample households are typically “poor” farmers in the definition of the absolute poverty of SDGs, and they further decrease their consumption level in the lean period. Higher rice productivity is found to be strongly associated with higher consumption level and lower probability of falling into poverty. Although the importance of intensification is clear, how to promote intensification remains unsolved. Not only in Madagascar but also in many SSA countries, the rates of adoption of improved agricultural technologies remains low. In the next chapter, therefore, the current rice cultivation practices and the profitability of nitrogen fertilizer use as a typical strategy for yield improvement will be explored.

Table 1.1 Summary statistics of household characteristics from baseline survey

	Unit	Mean	Min	Max
Household structure				
Household size	number	4.97	1	13
		(1.95)		
Number of male members	number	2.54	0	8
		(1.38)		
Number of adults	number	3.21	1	8
		(1.40)		
Number of children	number	1.76	0	7
		(1.36)		
Dependency ratio	%	68	25	100
		(0.22)		
Household head				
Sex (takes 1 if male)	%	89.15	0	1
Age	yeas old	46.13	19	88
		(14.11)		
Years of education	years	5.39	0	19
		(3.67)		
Born in the village of residence (takes 1 if yes)	%	64.94	0	1
		NA		
Immigrated from outside of the region (takes 1 if yes)	%	3.17	0	1
		NA		
French literacy (takes 1 if he/she can read it)	%	62.6	0	1
		NA		
Ethnic group (takes 1 if he/she belongs to Merina)	%	95.99	0	1
		NA		
Observations		596		

Source) Author made from the panel dataset
Notes) Four households were excluded due to missing data. Standard deviations for continuous variables are in parentheses.

Table 1.2 Summary statistics of household Land holding from baseline survey

	Unit	Mean	Min	Max
Land endowment				
Size of lowland	ha	0.29	0.04	5.99
		(0.43)		
Size of upland	ha	0.38	0	7.5
		(0.69)		
Size of total land	ha	0.67	0.04	10.13
		(0.96)		
Size of total land per capita	ha	0.15	0.07	2.16
		(0.22)		
Size of low land per capita	ha	0.07	0.01	1.5
		(0.11)		
Share of lowland	%	50.20	1	100
		(24.16)		
Share of land inherited from parents	%	58.86	0	100
		(42.03)		
Other household characteristics				
Number of cattle holding	number	1.4	0	15
		(1.97)		
Observations		596		

Source) Author made from the panel dataset
Notes) Four households were excluded due to missing values in data. Standard deviations for continuous variables are in parentheses.

Table 1.3 : Share of size of land devoted to rice (Unit: %)

Quintiles	1st	2nd	3rd	4th	Total
Mean	0.31	0.34	0.31	0.31	0.32
s.d.	0.36	0.38	0.37	0.37	0.37

Source) Author made from the panel dataset
Notes) Quintiles are based on the total land size

Table 1.4 Income structure from sample households in 2019
(N = 546 Unit: 1000MGA except for column (4))

Type of income source	% of household	(1) Revenue mean	(1) Revenue s.d.	(2) Cost mean	(2) Cost s.d.	(3) Income mean	(3) Income s.d.	(4) Income (USD)
Crop	**99.82**	**981.98**	1099.18	**196.12**	218.28	**778.75**	918.45	660.61
Rice	97.99	740.13	820.32	160.27	177.21	579.86	710.11	491.89
Other crops	75.09	156.92	236.46	23.82	42.11	198.89	441.72	168.72
Noncrop production	**58.06**	**180.33**	546.08	NA	NA	**180.33**	546.08	152.97
Labor	**94.51**	**1330.40**	2647.01	**318.84**	2010.42	**1056.04**	1277.20	895.83
Farm labor	69.23	373.08	439.27	NA	NA	373.08	439.27	316.48
Non-farm labor	63.92	957.33	2711.78	318.84	2010.42	638.49	1420.66	541.63
Non-labor income	**50.37**	**147.86**	396.57	NA	NA	**147.86**	396.57	125.43
Total	**100**	**2640.58**	3155.31	**514.96**	2043.51	**2158.53**	1791.28	1831.06

Source: Author made using data in 2019 from the panel dataset.
Values in MGA were converted to USD by using PPP of US$1.00 = 700.228 MGA as of 2011 after deflating the value to that of 2011 based on CPI.
The cost accounts only for paid-cost. No imputed costs of family labor, recycled seeds, own produced manure are not included to cost calculation.

Table 1.4 poverty profile by household characteristics from baseline survey

Variables		N	Proportion in all sample households (%)	Mean daily consumption per day per capita (MGA)		FGT indicators with 1,330 MGA/day/capita (=US$1.90/day/capita) as poverty line		
				Mean	s.d.	P(0):	P(1):	(P2):
Overall		596	100	908.53		0.845	0.380	0.207
Education level of head (F value is 560.62***)	No school	44	7.38	694.80	373.19	0.911	0.502	0.318
	Primary achievement	396	66.44	853.14	527.14	0.877	0.410	0.229
	Secondary or more	156	26.17	1120.40	614.37	0.744	0.269	0.121
Household size (F value is 508.39***)	Small (< 5 people)	383	64.27	1034.60	610.35	0.797	0.315	0.157
	Large (>5 people)	213	35.73	689.89	349.58	0.930	0.498	0.298
Household head age (F value is 95.27***)	40 years old or below	225	37.75	845.07	396.58	0.889	0.392	0.209
	from 41 to 60 years old	275	46.14	872.81	495.77	0.865	0.397	0.218
	Over 61 years old	96	16.11	1177.45	880.83	0.677	0.286	0.148
Household sex (F value is 13.71***)	Male	531	89.09	917.94	551.64	0.844	0.372	0.197
	Female	65	10.91	858.06	599.31	0.846	0.422	0.251
Size of lowland per capita (F value is 12.41***)	1st quintile (Less than 0.02ha)	161	27.01	792.02	393.15	0.907	0.425	0.240
	2nd quintile (0.02ha - 0.04ha)	153	25.67	827.49	412.60	0.882	0.409	0.224
	3rd quintile (0.04ha-0.08ha)	144	24.16	909.98	527.08	0.840	0.378	0.198
	4th quintile (0.08ha or larger)	138	23.15	1145.22	779.42	0.732	0.285	0.143
Size of total land per capita (F value is 9.66***)	1st quintile (Less than 0.05ha)	173	29.03	784.21	421.41	0.908	0.441	0.251
	2nd quintile (0.05ha - 0.09ha)	154	25.84	871.09	452.03	0.857	0.386	0.203
	3rd quintile (0.09ha-0.19ha)	139	23.32	921.19	496.94	0.820	0.363	0.191
	4th quintile (0.19 ha or larger)	130	21.81	1117.97	787.41	0.769	0.297	0.153

Notes)
1. Four households are excluded due to missing data in consumption expenditure
2. MGA stands for Madagascar Ariary. Conversion is based on PPP of US$1.00 = 700.228 MGA as of 2011. Value in 2018 was deflated to that in 2011 using CPI.
3. F-value is presented to show statistical significance of grouping the whole sample by each type of categories.
4. *, **, *** show 10%, 5%, and 1% of significance level, respectively.

Table 1.5: Poverty profile by 13 communes from baseline survey

Communes	N	Proportion in all sample households (%)	Mean daily consumption per day per capita (MGA)		FGT indicators with 1,330 MGA/day/capita (=US$1.90/day/capita) as poverty line		
			mean	s.d.	P(0)	P(1)	(P2)
Overall	596	100	908.53		0.845	0.380	0.207
Mahaiza	50	8.39	666.35	(488.80)	0.920	0.538	0.338
Antanambao Ambary	40	6.71	666.61	(264.72)	0.975	0.507	0.285
Inanantonana	30	5.03	703.95	(299.15)	0.967	0.478	0.269
Antohobe	30	5.03	720.41	(343.26)	0.933	0.479	0.268
Soavina	30	5.03	858.67	(543.87)	0.900	0.424	0.230
Ambohimasina	50	8.39	864.99	(373.75)	0.840	0.363	0.198
Ankazomiriotra	80	13.42	902.08	(474.10)	0.850	0.368	0.198
Vinany	50	8.39	908.31	(417.31)	0.840	0.354	0.185
Antanimandry	40	6.71	983.03	(491.38)	0.775	0.321	0.167
Mandoto	49	8.22	986.33	(794.59)	0.878	0.348	0.172
Ambohimanambola	58	9.73	1013.39	(764.30)	0.810	0.356	0.193
Betafo	59	9.90	1168.59	(538.30)	0.746	0.233	0.091
Belazao	30	5.03	1283.97	(727.58)	0.567	0.220	0.106
F-value			4.97***				

Notes)
1. Four households are excluded due to missing data in consumption expenditure
2. MGA stands for Madagascar Ariary. Conversion is based on PPP of US$1.00 = 700.228 MGA as of 2011. Value in 2018 was deflated to that in 2011 using CPI.
3. F-value is presented to show statistical significance of grouping the whole sample by each type of categories.
4. *, **, *** show 10%, 5%, and 1% of significance level, respectively.

Table 1.6: Poverty profile by Season

	N	Proportion in all sample households (%)	Mean consumption expenditure per day per capita (MGA)	FGT indicators with 1,330 MGA/day/capita (=US$1.90/day/capita) as poverty line		
				P(0): Headcount ratio	P(1): Poverty gap ratio	(P2): Squared poverty gap ratio
Overall	4519	100	931.82	0.838	0.363	0.189
			(530.01)			
Soon after harvesting months	1720	38.06	972.03	0.815	0.347	0.179
sd			(578.13)			
After 4 months after harvesting months	1118	24.74	963.83	0.827	0.344	0.173
sd			(534.73)			
Before harvesting months	1681	37.20	875.56	0.867	0.388	0.207
sd			(466.41)			
F-value			16.53***			

Notes)
1. All calculation reflects the difference in numbers of observation by weighting.
2. The number of observation in the second group is smaller than the other two groups because we had to skip one survey that was supposed to be carried out in June and July in 2020 due to the influence of Covid-19.
3. MGA stands for Madagascar Ariary, the local currency of Madagascar. Conversion is based on PPP of US$1.00 = 700.228 MGA as of 2011. Value in each year was deflated to that in 2011 using CPI.
4. F-value is presented to show statistical significance of grouping the whole sample by each type of categories.
5. *, **, *** show 10%, 5%, and 1% of significance level, respectively.

Table 1.7 Descriptive statistics of sample observations for regression

	Total		2018		2019		2020	
	N = 1563		N = 521		N = 521		N= 521	
Outcome Variable	Soon After	Lean Period.	Soon After	Lean Period.	Soon After	Lean Peorid	Soon After	Lean Peiod.
Total consumption per capita (Ariary)	922.18	879.70	915.28	748.88	929.07	874.26	1099.34	1015.85
Poverty ratio (%)	84.84	86.44	84.45	92.51	85.22	87.52	73.70	79.27
Explanatory Variables	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
Average rice yield (kg/ha)	3551.93	2065.81	3721.77	1965.84	3594.33	2101.48	3461.87	2228.88
Rice production per capita (kg)	209.42	277.81	218.66	284.09	200.84	247.47	208.66	299.44
Time variant variables								
Total land size per capita (ha)	0.17	27.10	0.14	0.21	0.16	0.25	0.18	0.30
Household size (people)	4.79	1.94	4.98	1.90	4.89	1.95	4.73	1.96
Time invariant variables								
Sex of head (%)	88.96		90.21		89.44		88.96	
Education level of head (years)	5.40	3.69	5.40	3.65	5.40	3.68	5.41	3.73
Age of head (years old)	47.97	13.88	46.44	13.95	47.53	13.86	48.20	13.85
Distance from national road (km)	5.27	5.03	5.27	5.03	5.27	5.03	5.27	5.03

Source: Author made from the panel dataset. For this analysis, only households who appeared in all the survey rounds are included because any missing status in a survey affects the calculation of outcome variables.

Table 1.8: Influence of rice production on household's consumption and poverty status (FE model)

	Daily consumption per capita				Poverty status (= 1 if a household is in poverty)			
	(1) Soon after harvesting		(2) Lean period		(3) Soon after harvesting		(4) Lean period	
	Coeff.	s.e.	Coeff.	s.e.	Coeff.	s.e.	Coeff.	s.e.
Explanatory Variables								
Rice yield (kg/ha)	0.03	0.01***	0.002	0.01	-0.000	<0.001***	<0.001	<0.001
Total land holding per capita (ha)	4.70	2.16**	2.94	2.07	-0.002	0.001	-0.002	0.002
Household size (people)	-156.98	22.90***	-95.89	17.20***	0.087	0.141	0.05	0.01***
Year 2019	477.89	171.99**	36.53	156.74	-0.10	0.16	0.05	0.15
Year 2020	345.31	174.64*	-71.62	155.07	-0.09	0.17	-0.05	0.16
Interaction terms of year dummy and time-invariant variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Household Fixed Effect	Yes		Yes		Yes		Yes	
No. of households	521		521		521		521	
R-square within	0.36		0.39		0.25		0.24	
R-square between	0.33		0.26		0.09		0.19	
R-square overall	0.35		0.30		0.15		0.21	
F_statistics	2.48		2.33		1.62		2.14	

Notes)
*, **, *** show 10%, 5%, and 1% of significance level, respectively. Standard errors are clustered robust standard error at village level. Only households who appear in all survey rounds are used in this analysis. In addition to the variables listed above, interaction terms of village dummy and year of harvest are included. Interaction terms of year dummy variable and each of sex, age, years of education, distance from the national road in meters are included, but none of them show significant coefficients thus excluded from the table. Housman test was conducted for each model and null-hypothesis of exogeneity are rejected in all models. F-test for joint significance rejects null-hypotheses in all models

Figure1.1
Cumulative frequency of total consumption expenditure (day/capita)
with international poverty line at US$1.90/day/capita

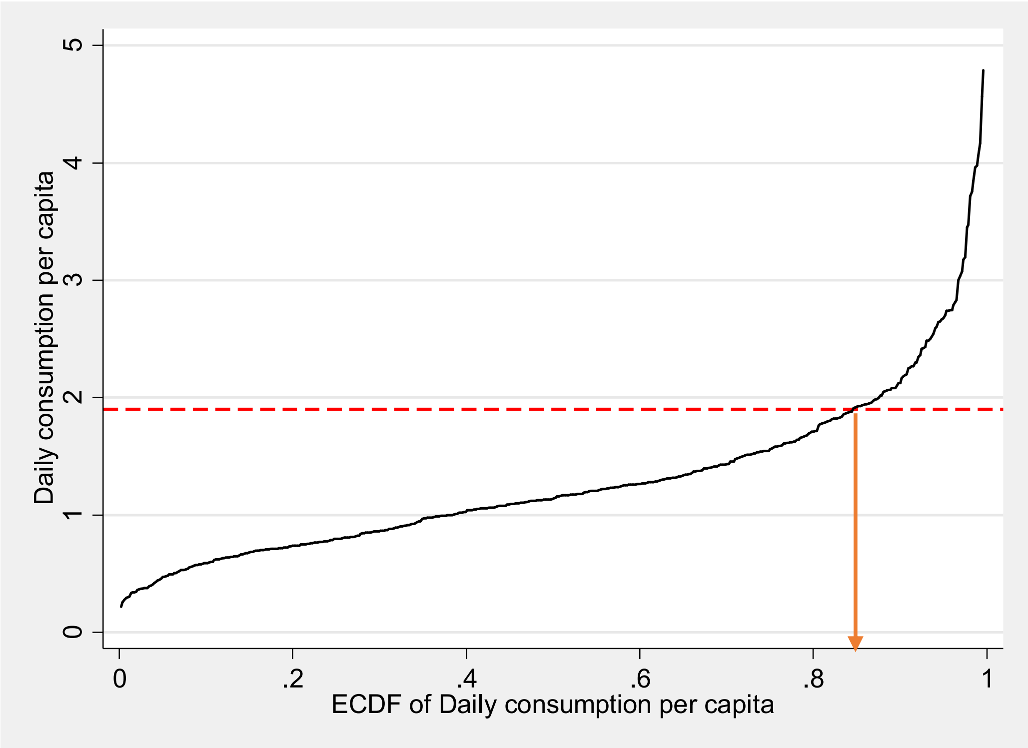
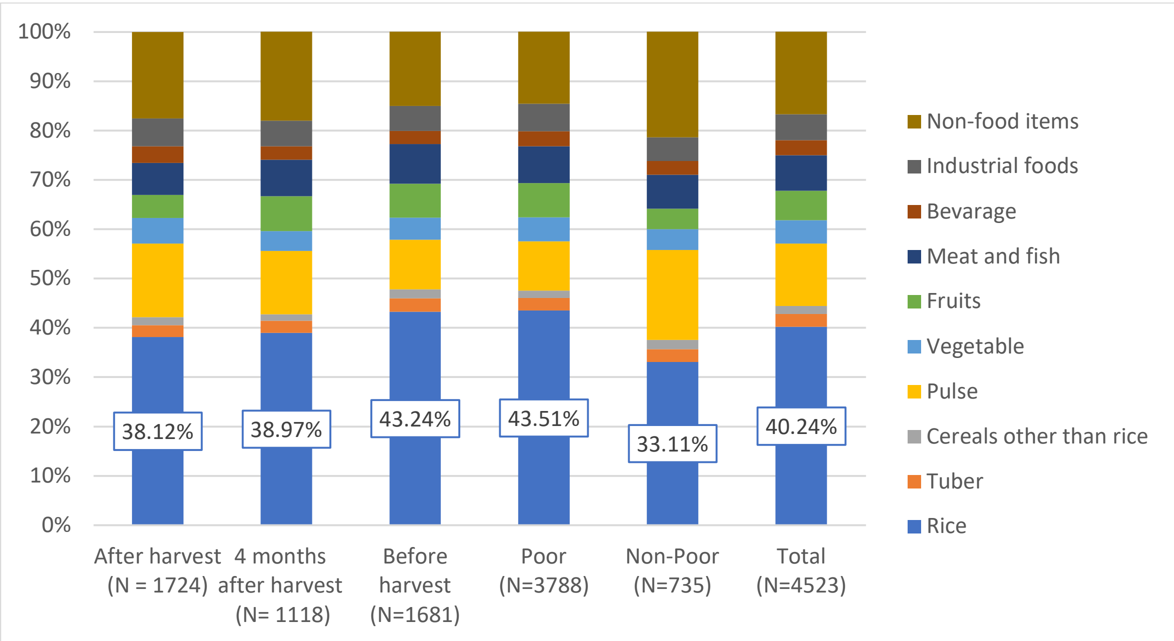
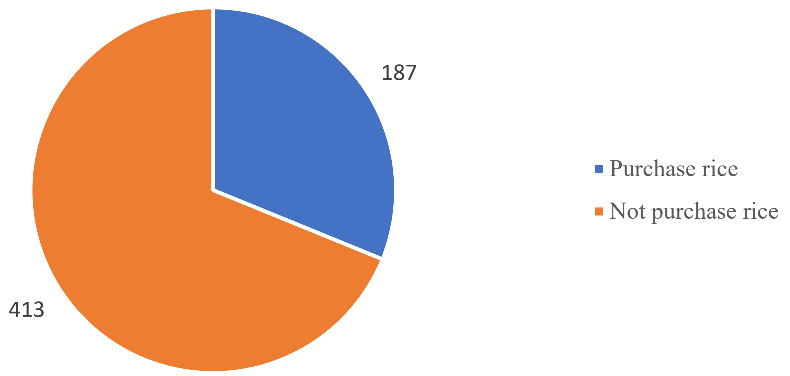


Figure 1.2
Share of rice in the total consumption by survey timing and poverty status



Appendix of Chapter 1

Figure A1.1 The percentage of household who purchase rice during June of 2018 to March 2019 (N =600)



Source: Author made from the paned dataset

Table A1.1:
When households first buy rice after harvest in 2018 till the next harvest in 2019

Month	No. of households	%
June	2	1.07
July	29	15.51
August	22	11.76
September	32	17.11
October	28	14.97
November	13	6.95
December	13	6.95
January	47	25.13
February	0	0.00
March	1	0.53
Total	187	

Source: Author made from panel data

Table A1.2: Influence of rice production on household's consumption expenditure and poverty status

	Daily consumption per capita				Poverty status (= 1 if a household is in poverty)			
	(1) Soon after harvesting		(2) Lean period		(3) Soon after harvesting		(4) Lean period	
	Coeff.	s.e.	Coeff.	s.e.	Coeff.	s.e.	Coeff.	s.e.
Explanatory Variables								
Rice production (kg/capita)	0.49	0.20**	0.25	0.11**	-0.000	<0.001***	<0.001	<0.001
Total land holding per capita (ha)	1.75	1.95	1.45	2.14	-0.002	0.001	-0.002	0.002
Household size (people)	-146.65	17.78***	-86.22	14.96***	0.083	0.014***	0.052	0.014***
Year dummy	Yes		Yes		Yes		Yes	
Interaction terms of year dummy and time-invariant variables	Yes		Yes		Yes		Yes	
Household Fixed Effect	Yes		Yes		Yes		Yes	
No. of households	521		521		521		521	
R-square within	0.38		0.38		0.25		0.24	
R-square between	0.43		0.0		0.15		0.22	
R-square overall	0.42		0.33		0.18		0.23	
F_statistics	4.15		4.22		2.29		2.17	

Notes)
*, **, *** show 10%, 5%, and 1% of significance level, respectively. Standard errors are clustered robust standard error at village level. Only households who appear in all survey rounds are used in this analysis. In addition to the variables listed above, interaction terms of village dummy and year of harvest are included. Interaction terms of year dummy variable and each of sex, age, years of education, distance from the national road in meters are included, but none of them show significant coefficients thus excluded from the table. Housman test was conducted for each model and null-hypothesis of exogeneity are rejected in all models. F-test for joint significance rejects null-hypotheses in all models

Table A1.3 Items for consumption variable construction

Food consumption								**Non-food consumption**			
7 days recall						30 days recall		30 days recall		4 month recall	
Cereals		Fruit		Vegetables			Industrial foods (Food 2)	nonFood1			nonFood2
1	Rice	24	Banana	47	Pumpkin	1	Vinaigrette	1	Water service	1	Vacation_travel
2	Maize	25	Orange or lemon	48	Tomatoes	2	Sugar	2	Transportation	2	Umbrella_raincoat
3	Bread	26	Avocado	49	Onions	3	Salt, pepper, and spices	3	Soap or washing powder	3	Torch or flashlight
4	Rice flour	27	Guava	50	Carrot	4	Milk powder	4	Recharge phone cards	4	Other insurance
5	Pasta	28	Apple	51	Chayote	5	Jams or Honey	5	Petrol	5	Other family event
6	Wheat	29	Pear	52	Leaves	6	Formula Milk	6	Personal caregoods	6	Mats_mattress
7	Other cereals	30	Grape	53	Garlic or leek	7	Cooking oil	7	Newspaper	7	Health insurance
8	Pulse	31	Peach	54	Green pepper	8	Condensed milk	8	Motor vehicle repair parts	8	Health expenditure
9	Cowpea	32	Mango	55	Cucumber	9	Butter Margarine	9	Methane gas	9	Donations
10	Lima bean	33	Pineapple	56	African eggplant	10	Biscuits or candies	10	Matches	10	Cooking utensils
11	Common bean	34	Persimmon	57	Cabbage	11	Baby cereal	11	Kerosene	11	Cleaning utensils
12	Bambara bean	35	Rotra	58	Cassava leaf	12	Baby Food	12	Internet service	12	Circumcision
13	Peanut	36	Tapia	59	Haricot green bean		Bevarage (Food 3)	13	Houserent	13	Children education
14	Soja	37	Papaya	60	Table beets	1	Soft drinks or bottled water	14	Firewood	14	Kids' clothes, shoes, diapers
15	Mung bean	38	Currant	61	Taro leaf	2	Coffee	15	Electronicdevicecharge	15	Carpet, rugs, or linens
16	Lentil	39	Other fruits	62	Pumpkin leaf	3	Alcoholic drinks	16	Electricity	16	Car insurance
17	Other pulses		Meat and Fish	63	Green peas	4	Tea	17	Diesel	17	Bowls, glassware, plates
	Tubers	40	Chicken Duck	64	Other vegetables			18	Charcoal	18	Adults' clothes or shoes
18	Cassava	41	Beef	65	Prickly pear			19	Candle	19	Administrative fees
19	Taro	42	Pork					20	Bicycleservice_repairparts	20	Annual education fees
20	Sweet potato	43	Sausage					21	Battery		Excluded items
21	Potatoes	44	Fish							1	Building items
22	Yam	45	Egg							2	Marriage ceremony
23	Other roots or tubers	46	Other meat fish							3	Funeral
										4	Famadihana (ritual ceremony)

$$Total\ comsumption_{h_t} = \frac{1}{7}\sum_{i=1}^{65} Food1_i + \frac{12}{365}\sum_{k=1}^{12} Food2_k + \frac{12}{365}\sum_{l=1}^{4} Food3_l + \frac{12}{365}\sum_{m=1}^{21} nonFood1_m \frac{3}{365}\sum_{n=1}^{20} nonFood2_n$$

Table A1.4 Type of non-labor income in 2019 (N=546)

	N	%
Any type of non-labor income	275	50.37
Remittance	90	16.48
Rent out asset	14	2.56
Rent out animal	108	19.78
Credit	97	17.77
Other (pension, food aid, cash transfer)	30	5.49

Source: Author made from panel dataset

CHAPTER 2
PROFITABILITY OF CHEMICAL FERTILIZER APPLICATION: COMPARISON OF LOWLAND AND UPLAND RICE CULTIVATION IN MADAGASCAR[29]

2.1. Introduction

The previous chapter revealed the strong association of rice production and households' consumption levels particularly in some months after harvesting. This implies that rice productivity growth will contribute to improvement of households' welfare. Increase in rice production is achieved either enhancing rice yield per unit of land or expansion of area of rice plots. This chapter focuses on the former. Following the description of rice cultivation in the study area, the main part of this chapter analyses the profitability of chemical fertilizer application based on the marginal product of nitrogen fertilizer and compares the marginal products between lowland rice plots and upland rice plots.

2.2 Description of rice cultivation practices in the study area

Table 2.1 presents the summary statistics of plot-level information of rice production from the panel dataset that was used in the analysis of Chapter 1. Using data during 2018 and 2021, the mean value of yield from the total 5314 rice plots was 3283.4 kg/ha which is smaller than the yield of 5187.2 kg/ha presented in FAOSTAT as of 2019[30]. The standard deviation of yield was 2320.13. Approximately 30% of plots are in uplands in our dataset. The average size of rice plot was 0.19 ha. Regarding land preparation, use of oxen in ploughing and puddling appears to be common as more than 70% of plots were either ploughed or puddled by oxen. More importantly, levelling, which is one of the basic but effective practices for increasing rice yield is practiced in 88% of the rice plots (Otsuka and Larson, 2013). Also, in most plots, rice was planted in line whereas only 6 % of plots where rice seedlings were randomly planted.

Rice cultivation is labour-intensive especially in areas where mechanization has not been progressed. In our study site, use of tractor is virtually absent. In more than 90% of plots, farmers hired laborers in addition to labor supply from household members. Hired laborers accounts for 52% of the total days of labour[31] (Table 2.1). In Table 2.2, the gender ratio of hired laborers in each activity of cultivation is summarized. There is a division of work by gender although there appears no perfect separation of works by gender. Typical male

[29] This study has been published from Japanese Journal of Agricultural Economics (2021): 23 pp119-124. https://doi.org/10.18480/jjae.23.0_119

[30] Yield reported by FAO can be found in https://www.fao.org/faostat/en/#data/QCL (Last accessed on 14/12/2021). The difference from the yield in the FAO website is probably because this dataset does not cover the Alaotra-Morogoro region where rice is grown with irrigation canals (Nishigaki et al., 2020) while most plots in this dataset do not depends on less reliable natural water source such as river, pond, or rainfall.

[31] The labor was quantified in terms of man-day.

jobs include seedling production, land preparation, harvesting, and threshing. Relatively higher rates of female laborers are found in transplanting (66.77%) and weeding (34.63%). The ratio of female laborers throughout the rice cultivation process reaches 40.5%.

Use of quality seeds and fertilizer application are the major concerns in the study area. Own recycled seeds were planted in more than 60 % of plots whereas the percentage of the plots where seeds obtained directly from any of a seed company, input supplier, or extension worker was only 4.3%, which is consistent with the findings by Arouna et al. (2021) [32]. Seeds obtained by exchanging or purchasing from other farmers and local markets are also regarded as recycled seeds. With these "old" seeds, the varietal purity is hardly maintained in the farmers' fields. If management of seeds purity leads to higher productivity, almost 95 % plots could potentially improve the productivity by using pure seeds.

Rice productivity enhancement may also be achieved through improvement in planting practices. Although many farmers select seeds by winnowing or eye inspection, seed selection with water that allows farmers to distinguish empty grain from full grain is rarely practiced in our study area. Key components of the system of rice intensification (SRI), which are originally developed in Madagascar and have diffused abroad, were not often observed. Although SRI requires the seedlings to be planted in its very early days, farmers in the study site typically used rice seedlings that had grown more than 25 days, which accounted for more than 90% of the lowland plots. In addition, contrary to the general recommendation of SRI to reduce the number of seeds per hill, the most common numbers of seedlings per hills or seeds per hole are from three to five. In more than 73% of plots, rice was planted with spacing of less than 20 cm.

Table 2.3 shows the percentages of plots receiving fertilizers by plot types and years of harvest. both organic fertilizer and chemical fertilizer need to be promoted. The percentage of rice plots where organic fertilizer was applied was 35% and 13.5% as for chemical fertilizer. If compared to data about 6 other SSA countries presented in Sheahan and Barret (2017), the percentage of chemical fertilizer use in this dataset is the second lowest.

Comparing two types of rice plots, both types of fertilizers were more frequently used in upland rice plots. In lowland rice plots, 80% of the plots did not receive any type of fertilizer and the number of plots where chemical fertilizer was applied was only 157 out of 3730, accounting for only 4.2%. On the other hand, in uplands, the percentage of the number of plots receiving organic fertilizer is 75%. Chemical fertilizer was

[32] Arouna et al. (2021) shows in Table 1 in her paper that the percentage of use of certified seeds is less than 1% in Madagascar although the definition of "certified seed" may be different from a way of defining seed types in this study.

also used in 35% of upland plots. At household level, decisions of fertilizer use vary year by year. Figure 2.1 presents dynamics of chemical fertilizer adoption decisions by sample households. This figure shows that every year almost 50 to 60 households change their decisions from not-using chemical fertilizer to using. Meanwhile, more than 60 households stopped using it although they had used it in the previous year.

If the market access or input price is the singly critical constraint for farmers to use chemical fertilizer use, these clear differences by the plot type and dynamics by years would not have been observed. Taking advantage of the unique situation, we explore whether rice farmers apply chemical fertilizer based on the expected returns to rice cultivation. This paper assesses the profitability of the two types of rice cultivation to understand the current practice. Then, it attempts to derive policy implications towards the promotion of chemical fertilizer in rice production.

2.3 Literature of chemical fertilizer application in SSA and its profitability

It is expected that chemical fertilizer will be a driver of agricultural productivity growth which consequently enhances economy-wide outcomes such as GDP (McArthur and McCord, 2017) and food security (Holden, 2018). On the other hand, the adverse environmental effect by intensive use of chemical fertilizer have been increasingly reported (Pan et al., 2016)[33]and transforming to organic farming or soil management without use of chemicals have been recommended (Meng et al., 2017).

However, these adverse effects are to be generated in the case of overuse. The situation in SSA is still far from the level of excessive use. Its application is generally limited in sub-Saharan Africa (SSA) compared to other parts of the world (see Figure A2.1). Regarding the application rate, Madagascar is even left behind within SSA. Although the nitrogen use has risen especially since the 2010s while the cropland has increased only slowly, the intensity of application is relatively lower than other 10 SSA countries that take rice productivity growth as important policy targets[34] (see Figure A2.2 and A2.3). Therefore, encouraging farmers to use chemical fertilizer in proper manner is still a sound strategy in this country.

Morris et al. (2007) described that profitability is the first and most obvious factor that explains the low adoption rate of chemical fertilizer in SSA. Profitability of chemical fertilizer use is affected by various factors: price of input, quality of input, cost for accessing input market (Suri 2011, Liverpool-Tasie, 2017),

[33] Many environmental assessments of intensive use of nitrogen fertilizer have been conducted especially in China. For example, Smith and Siciliano (2015) focused on the effect of nitrogen fertilizer on water pollution and Tian et al. (2012) argue the importance of reduction of nitrogen fertilizer application to reduce N_2O emission which contributes to global warming.

[34] These 10 countries are selected as they belong to the first group of Coalition for African Rice Development (CARD) (https://riceforafrica.net/card-countries Last accessed on 12/12/2021).

application practice, and crop yield response to chemical fertilizer. Soil nutrient as well as other factors such as irrigation and precipitation determine crop yield response to fertilizer (Tsujimoto et al., 2019, Tanaka et al., 2013) In economics, Marenya and Barret (2009) found heterogeneous profitability of chemical fertilizer use in maize cultivation due to a large variation in soil nutrients within a village. However, except for a few empirical studies such as Liverpool-Tasie et al. (2017) and Sheahan et al. (2013)[35], there is scant evidence that farmers rationally adjust their practice depending on the low and heterogeneous profitability of chemical fertilizer application. Thus, the literature gap exists in the relationship of heterogeneous profitability of chemical fertilizer and farmers' choice of plots to apply it.

Madagascar is appropriate for this topic for two reasons. First, as discussed in Chapter 1, rice is the single dominant food crop as well as the main income source for rural farm households. Thus, the improvement in rice yield through intensification with chemical fertilizer is highly important.

Second, in Madagascar, farmers with long experience in lowland rice cultivation have adopted upland rice cultivation[36]. Rice is traditionally grown in lowland plots[37]. Since the early 2000s, upland rice cultivation[38] has been introduced with new varieties, and it has rapidly diffused in some part of the country including the Vakinankaratra region – our study site. This unique situation enabled us to address the relationship between profitability and the choice of where to apply.

2.4 Research Questions and Hypotheses

Whether the difference of chemical fertilizer use between lowlands and uplands are consistent with difference in profitability is investigated. The hypothesis is that farmers use chemical fertilizer in the plot with the higher profitability.

2.5. Analytical Framework

We assume that households decide to apply chemical fertilizer, pursing for optimizing activities at each plot as well as overall farm activities. Following the procedure of Sheahan *et al*. (2013) and Liverpool-Tasie

[35] They examined the profitability of chemical fertilizer application to maize cultivation in Nigeria and Kenya, respectively,

[36] Upland rice has been promoted in other SSA countries, but in most cases, it is in areas where lowland rice cultivation is not common or difficult to practice.

[37] Madagascar is a hilly island, and lowland is the lower portion of landscape like valley bottoms, where lowland rice is grown with water accumulated on the surface of soil by bunds either under irrigated or rainfed conditions.

[38] Upland is the upper portion of the hilly landscape, usually sloping, and rice is grown in non-bunded, no-terraced fields with naturally well-drained soils without water accumulation on the surface like maize and cassava. Note that upland and lowland are not related to the altitude of homestead location.

et al. (2017), we first estimate the production function to capture how much extent the chemical fertilizer application increases rice yield. The production function is estimated using the following three specifications:

$$Y_{iht} = \beta_0 + \beta_1 N_{iht} + \beta_2 X_{iht} + \beta_3 UP_{ih} + \beta_4 N * UP_{ih} + \beta_5 INT_{iht} + \beta_6 N * vil + \beta_7 yr_t + \beta_8 vil + \epsilon_{iht} \ldots(1)$$

$$Y_{iht} = \beta_1 N_{iht} + \beta_2 X_{iht} + \beta_3 UP_{ih} * yr_t + \beta_4 N * UP_{ih} + \beta_5 INT_{iht} + \beta_6 N * vil + \beta_7 yr_t + \beta_8 vil * yr_t + HHFE_{ih} + e_{iht} \ldots(2)$$

$$Y_{iht} = \beta_1 N_{iht} + \beta_2 X_{iht} + \beta_3 UP_{ih} * yr_t + \beta_4 N * UP_{ih} + \beta_5 INT_{iht} + \beta_6 N * vil + \beta_7 yr_t + \beta_8 vil * yr_t + PFE_i + \varepsilon_{iht}$$
(3)

where Y_{iht} is yield defined as rice production in kg per hectare (ha) of plot *i* of household h in time *t* in all three equations. N_{iht} is the quantity of nitrogen in kg/ha applied using any type of fertilizer product to plot *i* of household h in time *t*. In the study site, the frequently observed chemical fertilizer that contains nitrogen as nutrients are urea and NPK composite fertilizer. Usually, urea contains only nitrogen and 46% of the weight of urea is the weight of nitrogen in it. As for NPK, there are several variations in proportions, but in this study assumes that a unit of NPK composite fertilizer contains 11% of Nitrogen, 22% of Phosphorus, and 16 % of potassium since this is the most frequently observed proportion in the field survey by the author. Using this proportion, N_{iht} was calculated from the weight of each type of the chemical fertilizer product actually used in each plot. X_{iht} is a vector of plot-and year-specific variables. Seed rate in kg/ha, plot size in ha, quantity of organic fertilizer in kg/ha, labor input for each plot in days, subjective report of production shock, and late planting are included (see Table A2.1 for definitions). In addition, square terms of the quantity of nitrogen, seed rate, labor inputs are included to see whether or not non-linearity of effects of these variables exists. UP_{ih} is a dummy variable which takes value of one if the plot is in uplands. yr_t is a vector of year dummy variables that take value of one when data comes from survey in each of 2019, 2020, and 2021. INT_{iht} is a vector of interaction terms. Interactions of N_{iht} and UP_{ih}, square term of N_{iht} and UP_{ih}, organic fertilizer quantity and UP_{ih}, and organic fertilizer quantity (kg/ha) and N_{iht} are included. In the specification (1), ϵ_{iht} is the error term.

By nature, the use of production inputs is an endogenous decision of plot manager. The error term may include some unobservable characteristics of plot and plot manager that affect both the input use and crop yield, resulting in loss of consistency of estimation results. Thus, fixed effect (FE) model, in the specification

(2) and (3), are employed to control the effects of time invariant factors in addition to specification (1), a simple pooled OLS[39]. Specification (2) uses household fixed effect which can address the time-invariant household characteristics only. On the other hand, specification (3) can control time-invariant characteristics of both household and plot level. β_1, β_4, and β_6 are the parameters of particular interest. β_1 will show the partial effect of an increase of nitrogen application rate by 1kg/ha on yields. When β_4 becomes statistically significant, it would imply that the effect of nitrogen fertilizer application is different between in lowlands and uplands. β_6 would show that heterogeneity in the effectiveness of nitrogen fertilizer exists across villages if it becomes statistically significant.

Next, the marginal physical products (MPP) and the average physical products (APP) of nitrogen application are calculated for each plot in order to estimate the expected average value cost ratio (AVCR) and the expected marginal value cost ratio (MVCR). MPP is derived for each plot by taking the first derivative of the production function with respect to quantity of nitrogen applied. APP is calculated as difference between the estimated yield with nitrogen application ($Yield^{W}$) and the estimated yield without it ($Yield^{WO}$) over the amount of nitrogen applied[40].

$$MPP_{iht} = \frac{\partial Yield_{iht}}{\partial Quantity\ of\ nitrogen} \qquad (3)$$

$$APP_{iht} = \frac{Yield^{W} - Yield^{WO}}{Quantity\ of\ nitrogen\ applied} \qquad (4)$$

$$M(A)VCR_{iht} = \frac{(Price\ of\ rice_{ct} * M(A)PP_{iht})}{Price\ of\ nitrogen_{dt}} \qquad (5)$$

where the mean of the selling price of 1 kg of rice of each commune ($Price\ of\ rice_{ct}$) and the mean of the price of nitrogen of each district ($Price\ of\ nitrogen_{dt}$) are used for the calculation of MVCR and AVCR.

Assuming that farmers are risk-neutral and maximizing profit at plot level as well as farm level, farmers have an incentive to use chemical fertilizer when AVCR is greater than 1, which implies that the value of additional product by the use of a certain amount of the chemical fertilizer is greater than the cost of the

[39] For this dataset, random effect (RE) model, correlated random effect (CRE) model, and correlated random effect model with control function approach (CRE-CFA) are also applicable. However, the author chose FE model because the first two models were not suitable due to the strict assumptions which are necessary to be held will not be met conceptually. The CRE-CFA model may be an promising alternate than FE model as it can estimate the coefficients of time-invariant variables. However, any instrumental variable was not available in this dataset.
[40)] This definition follows Liverpool-Tasie *et al*. (2017).

chemical fertilizer. MVCR of 2 is suggested as a benchmark for chemical fertilizer to be adopted, considering the production risks and transportation costs (Sheahan *et al*., 2013).

2.6 Data and Descriptive Statistics

This study uses 3 year panel dataset using the plot-level information about 2018-2019, 2019-2020 and 2020-2021 rainy season[41]. Among the total of 3699 rice plots, 2631 are lowland rice plots and 1068 are upland rice plots. Due to the nature of sampling, all the farmers have lowland rice plots. Those who have upland rice plots are farmers who grow rice in at least two plots one of which is in lowlands and another one is in uplands. Among lowlands, only 100 plots received nitrogen fertilizer during the 3 rainy seasons. On the other hand, in 341 out of 1068 upland rice plots, nitrogen fertilizer was used.

Table 2.4 presents descriptive statistics of sample plots[42]. Comparing lowland rice plots with upland rice plots, the average yield is higher in the former than in the latter with the difference of 1 ton per ha. The gaps in average yields between plots with and without nitrogen fertilizer are also larger in lowlands than uplands. Whereas the gap was approximately 400kg in uplands, lowland plots where nitrogen fertilizer was applied had almost 1500kg more production per hectare than lowland plots without the application. Although chemical fertilizer is less frequently used in lowland rice plots, the intensity of application was higher in lowlands than in uplands. The quantity of nitrogen conditional on its use was 67.86 kg/ha in the former and only 14.49 kg/ha in the latter[43].

The purpose of the analysis is to examine whether the degree of difference in yield between plots with and without nitrogen fertilizer is resulted from the difference in yield response between lowlands and uplands. Comparing plots receiving chemical fertilizer with those not, there are some variables showing statistically significant difference in both types of land. Probability of organic fertilizer use, number of days of work are significantly larger in plots where the nitrogen fertilizer was applied. While the intensify of organic fertilizer use is higher in plots with nitrogen fertilizer than without in the case of uplands, significant difference did not appear in lowlands. On the other hand, plot size, average daily precipitations during rainy season, highest and lowest temperatures were strongly significantly different depending on nitrogen fertilizer use only in the

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[41] Data from 2017-2018 season was not used because data of nitrogen amount applied to upland plots is not available

[42] Sixty plots are excluded because of two reasons. First, plots resulted in no harvest or produced less than 100 kg per hectare. These plots are dropped because there should be a serious crop failure. Second, plots whose size are less than 1 Are (0.1 ha) are dropped because these plots seem too small to be important plots for households in terms of crop production.

[43] According to our field observations, the major composition of nutrient is 11-22-16 for NPK and 46-0-0 for urea. We used this composition to calculate the quantity of nitrogen applied and the price of nitrogen in this study.

case of lowlands. These variables suggest that there may be a systematic difference between lowland plots with nitrogen fertilizer application and without, and more importantly, and the differences may also explain some part of the yield difference.

2.7 Results and discussion

2.7.1 Production function estimates

Table 2.5 shows the result of production function estimates. Three models with different level of controls over endogeneity are presented. The first model is pooled OLS using specification (1) where potential endogeneity of nitrogen application is not controlled. The second column is household fixed effect model. While it can eliminate the effect of unobservable factors such as personality of the head that affect both decision of input use and rice yield across all plots each household cultivate is controlled, effects of time-invariant factors that is attributed to plot level still potentially bias the coefficients of interest. The third column is plot level fixed effect where all the time-invariant factors at plot level including household characteristics are controlled. In all these three models, quantity of nitrogen did not show significant association with the rice yield. nor the FE model shows statistically significant impact of nitrogen use on the yield. However, in the FE model, the interaction term of upland rice plots and nitrogen application has a significantly positive coefficient, implying that the yield response to nitrogen is 43.38 kg/ha higher in upland rice plots than in lowland rice plots. This explains why the probability of receiving chemical fertilizer is higher in upland rice plots than in lowland rice plots.

Some attempts to explain the relatively higher effectiveness in uplands than in lowlands may be possible. First, upland rice plots with nitrogen application tend to receive more organic fertilizer as Table 2.4 showed. Sileshi et al., (2019) showed that application of moderate rates of cattle manure combined with moderate doses of nitrogen fertilizer optimizes the nutrient efficiency and increases maize yield response in SSA. However, as the interaction term of nitrogen quantity and organic fertilizer quantity did not show a significant coefficient, the synergy of two types of fertilizer does not seem to explain the relative effectiveness in uplands. Second, farmers may be using improved variety that has a responsive trait to fertilizer without knowing. As mentioned earlier, while lowland rice cultivation has long history in Madagascar, upland rice was newly introduced, especially to the central highland zone[44]. Since the two new upland rice varieties, Chomoron

[44] Although upland rice has been cultivated even before 2000s in some other part of the country, it was not common in the central highland zone and the production was negligible.

Dhan and NERICA 4 were disseminated in the early 2000s, the number of upland rice growers has rapidly increased (Raboin et al., 2014). NERICA 4 has a trait of strong response to chemical fertilizer While this might be the case, however, there is almost no means of confirming this scenario because farmers call a rice variety in local name different from its official name. The local names of rice varieties made it complicated to identify scientific varietal traits of the seeds in the farmers' fields. In the panel data, 74 local names for upland rice varieties have been collected in the first 3 seasons although only 17 upland rice varieties had been officially released[45]. More importantly, even if this scenario partly explains the relative higher effectiveness in uplands, it does not explain why nitrogen fertilizer does not increase yield in lowlands. To explore the mechanism requires more sophisticated agronomic discussion which is beyond the scope of this study.

In Table 2.5, the numbers of interaction terms of dummy variable of each village and Nitrogen quantity that had any statistically significant coefficient are reported by the signs of those coefficients. These interaction terms show that nitrogen quantity has heterogeneous effects on yield depending on where a sample household lives. In the model of pooled OLS, there are 17 villages whose interaction terms with nitrogen quantity had significantly negative coefficients, implying that nitrogen quantity is less effective than the reference village. On the other hand, 5 villages had positive coefficients showing higher effectiveness. As more unobservable factors in the error term of specification (1) get controlled by household level fixed effect and plot level fixed effect, the number of villages with significant coefficients increased.

2.7.2 Profitability

Table 2.6 presents the mean of MPP, APP, MVCR, and AVCR, calculated based on the production function in Table 2.5. Two kinds of AVCR and MVCR with different nitrogen sources are presented: one is from NPK, the other is from urea because the proportion of nitrogen in nutrients is lower in NPK than urea (or in other words, urea is a cheaper nitrogen source). In addition, two kinds of rice price were used. One was commune-level average rice price and the other one was the average rice price in the highest month in a year. This arrangement aimed to see whether profitability changes depending on seasonal price fluctuation. However, the result suggests that no scenario proposed any attractive profit for farmers. While MVCR greater than 2 and AVCR greater than 1 are suggested to encourage farmers to invest, the mean values were far below the required levels. From this result, the fact that Madagascar has one of the lowest level of the fertilizer

[45] All the 17 varieties including NERICA 4 can be found in the pamphlet, Des variétés améliorées de riz pluvial adaptées à la haute et moyenne altitude à Madagascar, available online at https://www.dp-spad.org/content/download/4375/32703/version/1/file/POCHVAR.pdf (last accessed on 13/12/2021).

application does not look strange. Also, because upland plots have relatively preferable scores in MVCR and AVCR in all scenario to lowland plots, farmers' practice of using fertilizer more in upland than in lowland is understandable.

It is important to note that these results might be still optimistic because of two reasons: the assumption of risk-neutrality and no transportation cost in calculation. The profitable case in this study may become unprofitable due to transportation costs, especially in remote areas, as suggested by Liverpool-Tasie *et al.* (2017).

2.8 Conclusion of Chapter 2

For improvement in crop yield, "GEMS interactions" are important. GEMS stands for Genotype by Environment by Management by Society[46]. This concept helps us to find a clue for understanding the complex situation where various factors simultaneously affect crop performance. Using the data from Vakinankaratra region of Madagascar, this study mainly explored M, management, with interactions of other letters. In terms of the interaction of M by G, genotype by management, data from the panel dataset showed that using pure seeds has potential to improve the productivity as recycled seeds are planted in almost all plots. It was also found that Management in land preparation such as animal ploughing and levelling and planting method such as line-planting are relatively well-practiced in the study area to other part of SSA, which comes from long tradition of rice cultivation and thus interaction of M by S. Thus, one key challenge is in the interaction of M by E, management by environment. Many agronomic studies have revealed that "poor" soil without sufficient macro-nutrients for crop growth largely limit the rice yield (Tsujimoto et al.,2019). Since the use of chemical fertilizer in Madagascar is among the lowest in the world, the application needs to be encouraged despite of some potential adverse environmental effects in the case of overuse.

Under this motivation, the profitability of fertilizer application was explored. The first finding of this study was that the adoption rate of chemical fertilizer was higher in upland rice plots than lowland rice plots. Also, a substantial number of farmers changes the decision of whether or not to use chemical fertilizer from year to year. This suggests that the conventional discussion which emphasizes the market access and input price as critical factors to affect the profitability of fertilizer use may not be sufficient to describe farmers' behavior.

[46] Brief explanation is available on website of International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) (http://gems.icrisat.org/ Last accessed on 14/12/2021) .

Using the fixed effect model, this study found that nitrogen application was more effective in upland rice plots than in lowland rice plots. Observed farmers' practice is consistent with the difference in expected returns. In addition, the heterogeneous effects of nitrogen fertilizer were also found across villages.

The profitability analysis based on MVCR and AVCR suggests that purchasing fertilizer is too low to be an attractive investment for farmers. Although upland rice plots show relatively higher marginal productivity and profitability, the profitability is still far below the suggested level for encouraging the use. The important contribution of this study to literature is that the considerably low profitability may not be solved by changing price of fertilizer or improving accessibility to input market. The result implies that Madagascar faces a fundamental issue of low crop yield response to fertilizer.

Policy implications derived from this study are as follows. First, there is an urgent need to address the low profitability of fertilizer application. As the cause of low profitability is not only from high input price but low marginal productivity of chemical fertilizer, G by M or E by M approach will be more promising than S approach such as input price controls. Second, although this study shows the advantage of upland rice plots in terms of marginal productivity of chemical fertilizer use, it does not necessarily suggest that farmers should increase investment in upland rice. Upland rice still accounts for only a small part of the total rice production in the study area. More importantly, upland rice production is less stable due to its vulnerability to adverse climatic events, and its yield is substantially lower than lowland rice production. Therefore, in the long run, policies to promote technological development[47] to agronomically improve crop yield response to chemical fertilizer in lowland rice plots, and thereby make its application profitable would have higher potential to enhance welfare than policies to encourage further investment in upland rice cultivation.

[47] For example, development of new rice varieties with higher response and innovative practical methods enhancing efficiency of nutrient uptake by plants.

Table 2.1 Summary statistics about all rice plots during 2018-2021 rainy seasons (N=5314)

	Unit	Mean (S.D.)	Min	Max
Rice yield	kg/ha	3283.37 (2320.13)	0	9983.03
Plot size	ha	0.19 (0.32)	0.04	10.00
Upland plot	%	29.81		
Seed Acquisition				
Commercial seeds[1]	%	4.26		
Seeds recycled from own fields	%	63.81		
Exchange/gift/purchase from farmers	%	21.36		
Purchase from local markets	%	9.08		
Land Preparation				
Animal use in plowing or puddling	%	71.00		
Leveling	%	88.36		
Planting practice				
Seed rate	kg/are	178.63 (221.64)	1.33	2796.95
Seed selection (water)	%	1.02		
Seed selection (eye inspection)	%	8.77		
Seed selection (winnowing or other)	%	62.25		
No seed selection	%	27.96		
Age of seedling at planting time (More than 25 days)	%	91.87		
Seedling per hole (1 or 2)	%	21.05		
Seedling per hole (3 or 5)	%	70.57		
Seedling per hole (6 or more)	%	8.38		
Spacing (less than 20 cm)	%	73.04		
Spacing (20cm-24cm)	%	20.94		
Spacing (random planting)	%	6.03		
Other practices				
Organic fertilizer use	%	34.63		
Rate of application[3] (conditional on using)	kg/ha	12474.87 (21056.26)	0.33	419729.1
Chemical Fertilizer use	%	13.51		
Other chemicals use	%	2.28		
Times of weeding	Number	1.51 (0.59)	1	5
Rotary weeder use in weeding	%	30.34		
Hired labor use	%	91.10		
Proportion of hired labor in total labor	%	52.16 (30.96)	0	100
Percentage of female labor	%	40.49 (27.10)	0	100

Notes: 1) Yields over 10 tons /ha, which are not realistic, were considered to be measurement error either in plot size or number of bags harvested from the plot, and therefore these values were replaced by the mean yield of the plot over 4 years. 2) Commercial seeds include seeds obtained directly from seed company, extension services, or input supplier. 3) Some large values are observed when small amounts of Guanomad are applied to relatively large plots.

Table 2.2 : Hired labor use and ratio of female laborer		
Activities	Percentage of plots where hired labor was employed in each activity (%)	Ratio of female laborers (%) conditional of hired labor use
Seedling production	17.46	0.33 (5.10)
Land preparation	54.46	0.25 (4.34)
Planting (transplanting)	70.96	66.77 (45.02)
Weeding	50.21	34.63 (43.82)
Harvesting	63.53	5.63 (15.78)
Threshing	56.64	3.15 (13.27)
Cleaning	12.68	11.38 (31.29)
Other task[1]	35.32	5.10 (19.41)
All tasks	91.10	40.49 (27.10)

Notes:
Examples of other tasks include chemical application, transporting rice from field to homestead.
Standard deviations are in parentheses.

Table 2.3 Number of plots receiving fertilizer

	All rice plots (N= 5314)				Lowland rice plots (N= 3474)				Upland rice plots (N=1840)			
	Organic fertilizer was used		Chemical fertilizer was used		Organic fertilizer was used		Chemical fertilizer was used		Organic fertilizer was used		Chemical fertilizer was used	
	No. of plots	% in total	No. of plots	% in total	No. of plots	% in total	No. of plots	% in total	No. of plots	% in total	No. of plots	% in total
2018	405	28.32	227	15.87	229	22.74	49	4.87	176	41.61	178	42.08
2019	553	42.05	173	13.16	227	24.05	45	4.77	326	87.87	128	34.50
2020	459	35.36	164	12.63	112	12.42	30	3.33	347	87.63	134	33.84
2021	423	33.28	154	12.12	74	8.44	33	3.76	349	88.58	121	30.71
All year	1840	34.63	718	13.51	642	17.21	157	4.21	1198	75.63	561	35.42

Source: Author made from panel dataset

Notes: Organic fertilizer include animal manure, green manure, compost, crop residue and straw, guanomad, Ash and household waste. Chemical fertilizer include NPK and Urea.

Figure 2.1 Dynamic of chemical fertilizer adoption decisions by sample households (N= 507)

	Adoption in 2019	
Adoption in 2018	Non-Adopter	Adopter
Non-adopter	294	61
Adopter	96	56
	Adoption in 2020	
Adoption in 2019	Non-Adopter	Adopter
Non-adopter	332	58
Adopter	63	54
	Adoption in 2021	
Adoption in 2020	Non-Adopter	Adopter
Non-adopter	346	49
Adopter	66	46

Source: Author made from the panel dataset
Notes: The number of sample households are not 596 because only households who appeared all survey rounds necessary to follow their decisions are used to make this table.

Table 2.4 Descriptive statistics of sample plots

	(1) All plots		(2) Lowland plots					(3) Upland plots				
			(2A) All		(2B) With N	(2C) W/O N	Diff.	(3A) All		(3B) With N	(3C) W/O N	Diff.
	Mean	s.d.	Mean	s.d.	Mean	Mean	|t|	Mean	s.d.	Mean	Mean	|t|
Yield (kg/ha)	3311.46	2301.23	3635.59	2258.10	5030.73	3580.47	6.34***	2512.98	2210.90	2789.54	2383.26	2.81***
Plot size (ha)	0.15	0.17	0.16	0.16	0.07	0.16	5.07***	0.15	0.18	0.16	0.15	1.43
Nitrogen use (0/1) (%)	11.92	NA	3.80	NA	100.00	0	NA	31.93	NA	100.00	0	NA
Nitrogen quantity (kg/ha)	3.17	21.58	2.58	19.36	67.86	0	NA	4.63	26.23	14.49	0	NA
Organic fertilizer use (0/1) (%)	36.36	NA	15.24	NA	58.00	13.55	12.48***	88.39	NA	83.87	90.51	3.17***
Organic fertilizer quantity (100kg/ha)	42.43	96.86	16.26	57.46	87.85	13.43	74.42	106.91	136.12	118.63	101.41	17.21*
Seed rate (kg/ha)	172.87	194.92	169.77	189.60	159.06	170.19	0.58***	180.51	207.34	203.74	169.62	2.51**
Number of days of work (days)	489.08	507.93	478.01	483.09	669.13	470.46	4.05***	516.36	563.79	593.17	480.33	3.06***
Daily precipitation (mm/day)	6.75	0.65	6.75	0.66	6.88	6.75	0.13**	6.76	0.62	6.75	6.76	0.003
Highest temperature in rainy season (Degree Celsius)	26.25	2.27	26.13	2.23	24.89	26.18	1.28***	26.56	2.36	26.51	26.65	0.14
Lowest temperature in rainy season (Degree Celsius)	15.81	2.11	15.70	2.06	14.56	15.74	1.18***	16.09	2.18	16.17	16.05	0.13
Late planting (0/1) (%)	15.03	NA	20.87	NA	7.00	21.41	3.49***	0.66	NA	0.29	0.83	1.00
Observations	3699		2631		100	2531	-	1068		341	727	-

Notes) * ,** and *** indicates differences at 10%, 5% and 1% level, respectively. s.d. stands for standard deviation. The amount of nitrogen was calculated from the amount of chemical fertilizer applied to each plot and the typical nutrients' composition rates: 46(N)-0(P)-0(0) for urea and 11(N)-22(P)-16(K) for NPK fertilizer. To deal with extreme values of organic fertilizer application rate and seed rate, values at the highest 1 percent of these variables were replaced by values at 99 percent.

Table 2.5 Production Function

Outcome: rice yield (kg/ha)	(1) OLS	s.e.	(2)H_FE model	s.e.	(3)P_FE model	s.e.
Nitrogen quantity (kg/ha)	4.90	6.05	-8.30	9.02	-12.50	9.53
Square of Log of N quantity	0.01	0.03	0.03	0.025	0.05	0.03
Organic fertilizer amount (kg/ha)	-0.002	0.01	0.01	0.01	0.01	0.01
Upland rice (Yes =1 No =0)	-1842.77	89.14***	-1510.95	122.82***	Omitted	
Upland rice x N amount (kg/ha)	31.36	11.66**	41.44	11.17***	43.38	14.73***
Upland rice x sq. of N amount	-0.09	0.04**	-0.13	0.04***	-0.08	0.045*
Upland rice x Org. fertilizer qty.	0.02	0.01**	0.01	0.01	-0.001	0.014
Nitrogen qty. x Org. fertilizer qty	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Seed rate (kg/ha)	6.90	0.71***	6.01	0.71***	1.72	0.83**
Square of seed rate	-0.01	<0.01***	-0.01	<0.01***	-0.001	0.01**
Labor use (days)	2.79	0.33***	2.88	0.32***	1.60	0.30***
Square of labor use	-0.01	<0.01***	<-0.001	<0.01***	<-0.001	<0.01***
Late planting (Yes =1 No =0)	-269.85	82.06 ***	-347.93	86.01***	-243.40	88.46***
Production shock (Yes =1 No =0)	-686.63	71.31***	-602.11	70.32***	-568.66	70.33***
Average daily precipitation in rainy season	-234.76	177.76	93.60	240.75	398.03	231.00*
The highest temperature in rainy season	-610.93	306.52**	-283.57	295.25	-193.88	285.26
The lowest temperature in rainy season	709.29	343.21**	-407.27	684.89	-920.41	666.56
No. villages where N is less effective than the reference	17		15		20	
No. villages where N is more effective than the reference	5		5		7	
Plot level Fixed Effect (P_FE)	No		No		Yes	
Household Fixed Effect (HH_FE)	No		Yes		Captured by P_FE	
Village Fixed Effect (V_FE)	Yes		Captured by HH_FE		Captured by P_FE	
Year Fixed Effect (Y_FE)	Yes		Yes		Yes	
No. of observation	3699		3686		3111	
(Adj.) R-squared	0.524		0.648		0.656	

Notes) N stands for nitrogen. The amount of nitrogen was calculated from the amount of chemical fertilizer and the typical nutrients' composition rates: 46(N)-0(P)-0(0) for urea and 11(N)-22(P)-16(K) for NPK fertilizer. Standard errors are clustered at plot level in all models. *, **, and *** are significant at 10, 5, and 1% levels, respectively. The observations from the season of 2018 were excluded because data of nitrogen amount applied to upland plots is not available. Hausman test rejected the null hypothesis of strict exogeneity of unobserved factors in the error term for both FE models.

Table 2.6. Profitability analysis

	MPP	APP	MVCR_NPK	MVCR_UREA	AVCR_NPK	AVCR_UREA
All	-37.96	3.26	0.16	-3.15	0.13	-3.69
All (high)	NA	NA	0.10	-4.22	0.05	-4.90
Lowland	-41.97	-21.19	-0.53	-3.90	-0.72	-4.82
Lowland(high	NA	NA	-0.71	-4.98	-0.95	-6.16
Upland	-22.21	-14.39	0.40	-1.52	0.42	-1.19
Upland (high)	NA	NA	0.10	-4.22	0.05	-2.13

Source: Authors' estimates from the production function.
Notes) "high" indicates the use of rice price at the highest average in each commune.

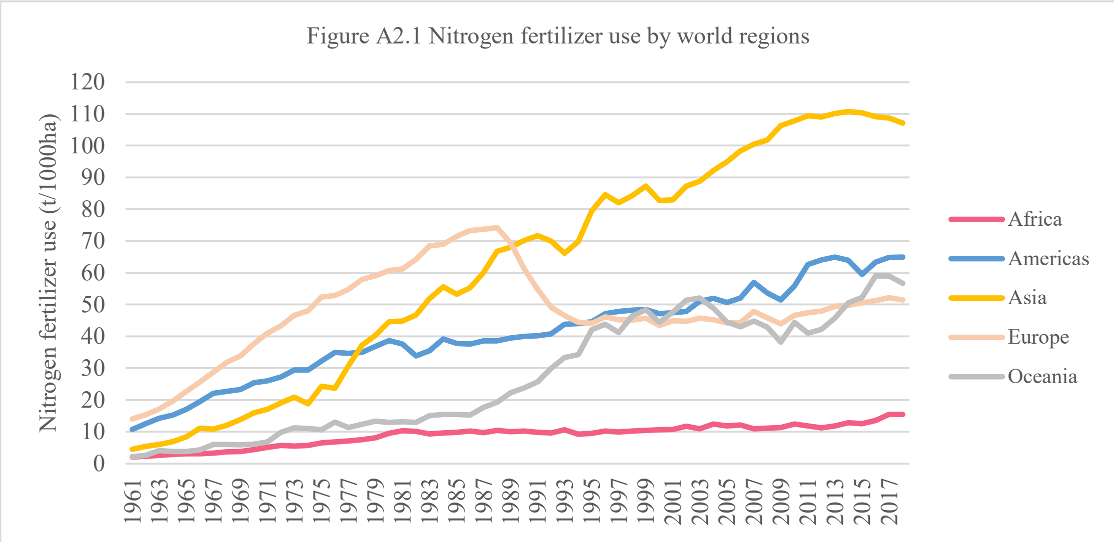


Figure A2.1 Nitrogen fertilizer use by world regions

Source: Author made from FAOSTAT

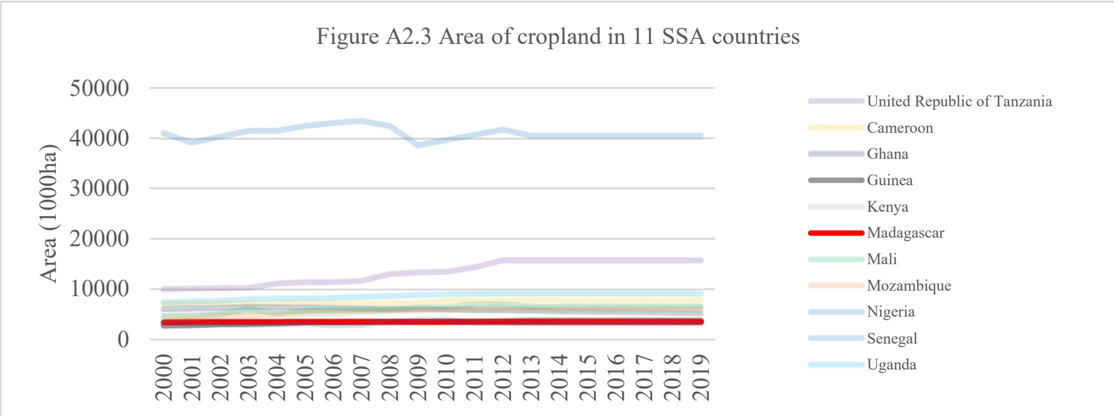


Figure A2.3 Area of cropland in 11 SSA countries

Source: Author made from FAOSTAT

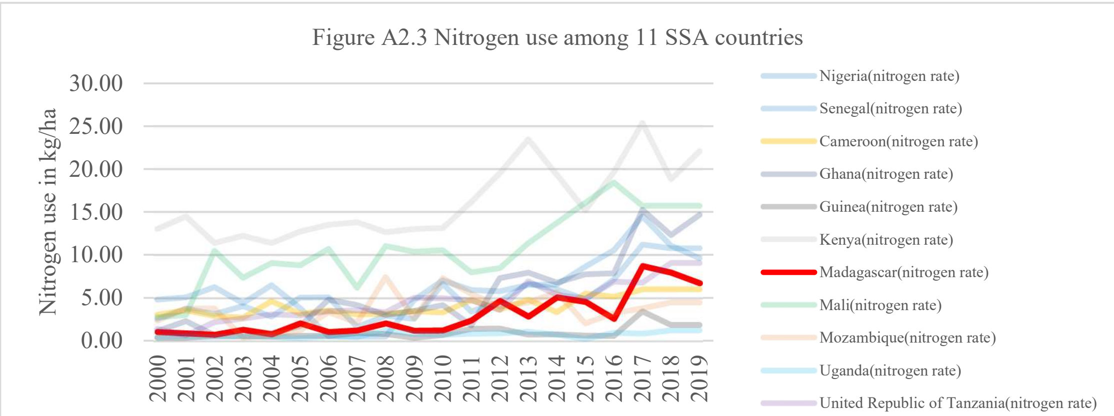


Figure A2.3 Nitrogen use among 11 SSA countries

Source: Author made from FAOSTAT

Table A2.1 Definitions of explanatory variables in the production function

Variables	Type	Unit	Definition
Nitrogen quantity	Continuous	kg/ha	Quantity of nitrogen applied in kilogram per hectare
Square of N quantity	Continuous	NA	Squared value of "Nitrogen quantity"
Organic fertilizer amount	Continuous	kg/ha	Quantity of organic fertilizer applied in kilogram per hectare
Upland rice (Yes =1 No =0)	Dummy	NA	Whether a plot is in uplands. It takes value of one if yes, and zero if no.
Upland rice x N amount (kg/ha)	Continuous	NA	Interaction term of "Nitrogen quantity" and "Upland rice"
Upland rice x sq. of N amount	Continuous	NA	Interaction term of "Square of N quantity" and "upland rice"
Upland rice x Org. fertilizer qty.	Continuous	NA	Interaction term of "Organic fertilizer amount" and "upland rice"
Nitrogen qty. x Org. fertilizer qty	Continuous	NA	Interaction term of "Nitrogen quantity" and "Organic fertilizer amount"
Seed rate	Continuous	kg/ha	Quantity of seeds used in a plot
Square of seed rate	Continuous	NA	Squared value of "Seed rate"
Labor input	Continuous	days	The number of total days worked in the plot. This includes both hired labor and family labor.
Square of labor use	Continuous	NA	Squared value of "Labor use"
Late planting (Yes =1 No =0)	Dummy	NA	Whether or not planting month was in January or later in the year of harvesting. It takes value of one if yes, and zero if no.
Production shock (Yes =1 No =0)	Dummy	NA	Whether or not any production shock occurred in the plot. It takes value of one if yes, and zero if no.
Average daily precipitation in rainy season	Continuous	mm/day	Average daily precipitation during November to May each year
The highest temperature in rainy season	Continuous	Degree celsius	The highest temperature recorded during November to May each year
The lowest temperature in rainy season	Continuous	Degree celsius	The lowest temperature recorded during November to May each year

CHAPTER 3
THE ADOPTION OF UPLAND RICE BY LOWLAND RICE FARMERS AND ITS IMPACTS ON THEIR FOOD SECURITY AND WELFARE IN MADAGASCAR

3.1 Introduction

Rice is the most fundamental staple food for people in Madagascar and the main income source for rural households as well. Sharma and Razafimanantsoa (2016) introduces statistics showing that rice provides 41.9% of the total generated agricultural income of farm households and rice consists of more than half of the total calorie intake for rural households. Hence, the improvement of rice production should be closely related to the welfare of rural households.

Generally, crop production is improved through either yield improvement or land expansion. This Chapter, in turn, focuses on farmers decisions related to the latter. In the context of Madagascar, the expansion of lowland rice fields is almost impossible due to lowland scarcity and population increase. In addition to the analysis of Chapter 2 in which low profitability of nitrogen fertilizer application was revealed, it has been claimed that the adoption of yield enhancing technologies has remained at low level due to liquidity constraints, high labor requirement, and unstable weather condition (for example, Harvey et al., (2014), Minten, Randrianarisoa, and Barrett (2007), and Moser and Barrett. (2003)).

However, a noteworthy change in rice production is currently taking place in the central highland zone of the island. An increasing number of farmers are adopting upland rice cultivation which is conducted on naturally well-drained fields without water retention on the surface. In Madagascar, except for a few regions in eastern part of the island, upland rice cultivation used to be at almost negligible in terms of production volume and planted area. In the early 2000s, new varieties developed by a series of collaborated research program of CIRAD[48] and FOFIFA[49] enabled upland rice cultivation in the central highland zone where no suitable upland rice variety had existed due to the cold temperature (a review is available in Raboin et al. (2014)). In addition, NERICA[50] varieties which are more tolerant against drought and more competitive against striga, a parasitic, seriously harmful weed, than conventional varieties began to be promoted. NERICA varieties provided farmers in drier part of the central highland zone with a chance to have better

[48] The French Agricultural Research Centre for International Development
[49] The National Center for Applied Research and Rural Development of Madagascar
[50] NERICA stands for New Rice for Africa.

and stable harvest.[51] As of 2019, 17 improved varieties of upland rice have been officially introduced to the central highland zone.[52]

It is true that the newly introduced upland rice varieties have caused the expansion of upland cultivation in the central highland of Madagascar. However, considering that few farmers had grown upland rice before the introduction of the new varieties, this study focuses on the impact of the adoption of "upland rice cultivation" rather than the adoption of any particular rice variety or varieties. In this sense, this study differs from existing studies, which analysed the impact of the adoption of particular upland rice varieties, such as NEIRCA (e.g. Kijima, Sserunkuuma, and Otsuka (2006), Kijima, Otsuka, and Sserunkuuma (2008) and Sakurai et al. (2014)).53)

More importantly, unlike in many sites in Sub-Saharan Africa where upland rice has been introduced, most Malagasy farmers grow lowland rice as traditional staple food and adopt upland rice cultivation as supplemental rice production. In particular, we observe an interesting contrast between the rapid expansion of upland rice practice and the slow progress of lowland rice intensification. However, empirical studies about upland rice are still few. The motivation of this paper is to contribute to filling this gap.

3.2 Research question and hypotheses

The main goal of this study is to examine the impacts of the adoption of upland rice cultivation on farmers who grow lowland rice. This study firstly investigates the determinants of upland rice cultivation. Then, it estimates the impacts of upland rice cultivation on households' food security and welfare.

Regarding the food security, three indicators are used. Total rice production per capita is the main indicator. It is expected that upland rice has a positive impact on it since upland rice is supposed to be supplementary to lowland rice, but it may not be the case if it substitutes for lowland rice production. The quantity of rice purchased in each month from January to March is another indicator. In Madagascar, these three months are generally recognized as lean months before the main harvest from lowland starts in April. Rice price is the highest in these three months in a year. If upland rice harvested a few weeks earlier than lowland rice is for

[51] Roughly speaking, in central part of the central highland zone lying at a high altitude cold temperature is the constraint and FOFIFA/CIRAD varieties are exclusively dominate, while in western part of the central highland zone lying at a relatively lower altitude dryness is the constraint and NERICA's are more suitable.

[44] The catalogue is available at https://www.dp-spad.org /content/download/4375/32703/version/1/file/POCHVAR.pdf (accessed on October 10, 2019). However, identifying a variety to its scientific names in the farmers' fields is not realistic because many different local names have been generated and used by farmers.

[53] In many countries in Sub-Saharan Africa, NERICA has been introduced as a new upland crop where few farmers had experience in upland rice cultivation. Thus, what was really adopted is not a new upland "rice variety" but a new upland "crop." In this sense, the situation is the same as our study site in Madagascar.

home consumption, it will reduce the quantity of rice purchased in the lean period. Furthermore, the quantity of rice consumed in a week is also used as an indicator of food security.

As the welfare indicators, the value of consumption in the last one month is used. Intuitively, upland rice cultivation should have a positive impact on welfare since it provided supplemental income. However, it may not be true in the following two cases. First, income from upland rice is negative if the paid-out costs for upland rice cultivation such as hired labor and fertilizer are higher than its value. Second, total income does not increase or even decrease if farmers reduce the production of other crops and/or reduce labor supply to off-farm/non-agricultural employment.

3.3 Analytical framework

In this study, with cross-sectional data collected in non-experimental setting, a probit model is used to identify the determinants of upland rice cultivation. Then, the impact of upland rice cultivation is analyzed using propensity score matching to address endogeneity. This study employs Kernel matching methods in order to maximize the sample size as well as precision of the analysis. Bootstrapping method is applied to estimate the standard error.

3.4 Data and descriptive statistics

Data for this study was collected through 2 steps. Firstly, a census survey was conducted in 60 villages in 13 communes across 3 districts in Vakinankaratra region from December 2017 to January 2018. The 60 villages are about 50% of the total villages in the 13 communes and were selected intentionally to have an even geographical distribution within each commune. Then, based on the household list created from the census data, 10 households that grow lowland rice were randomly selected from each of 60 villages as sample households for main survey. The main survey was conducted to the total of 600 households from June to August 2018 and collected detailed household level information via interview: it includes demography, agricultural input and output, monthly transaction (sales and purchases) of rice, monthly expenditure of food and non-food items, weekly food consumption, and non-agricultural/off-farm activities. Out of the 600 households, 34 households are dropped from the analyses: 4 households are due to incomplete data and 30 households have no upland plot to adopt upland rice cultivation.

Table 1 presents the descriptive statistics of the remaining 566 sample households. The mean size of households is around 5 people. The mean of household heads' age is 46 years old. On average, a household has 3 to 4 parcels whose total area is less than 1 ha. By agroecology, mean landholding of a household is 0.31 ha in lowland and 0.45 ha in upland.

Among the sample households, 65% of them have experienced production shocks in lowland rice due to weather related events such as cyclones and low temperature at least once in the last 10 years, and 20% of them have experienced weather-non-related production shocks in lowland rice such as crop disease and insect attack.

Among 566 households, 65% of them grew upland rice in the main cropping season of 2017/2018, which is the same percentage as found in the census survey. The mean comparison between upland rice growers and non-growers shows significant differences in many variables. With respect to household's characteristics, upland rice growers have significantly larger household size. In terms of land endowment, total area of lowland parcels, that of upland parcels, and the sum of them are significantly larger among the upland rice growers. In the meantime, upland rice growers are less likely to have irrigated lowland.

As for income source, upland rice growers are less likely to have family members engaged in off-farm and/or non-agricultural employment. In addition, values of livestock and assets are significantly smaller for upland rice growers. With respect to food security and welfare indicators, rice production per capita and total value of non-food items consumed in the last one month are significantly larger for upland rice growers.

3.5 Results

3.5.1 The determinants of upland rice cultivation

Table 2 shows the results of probit regression. Unobservable factors at the commune level are captured as commune fixed effects by commune dummy variables in the second column.

The most salient is that the upland rice adoption is significantly affected by the commune effects. By comparing the first column the second column, it is interpreted that the availability of upland, the lack of irrigation in lowland, weather-related risk in lowland, and the opportunities of non-agricultural earning are commune level factors affecting upland rice cultivation rather than household level ones. Moreover, unobservable commune level effects such as the presence of NGOs, farmers' formal associations, and farmers' informal network that promote upland rice cultivation may also be working.

As for household-level variables, French literacy of household head and weather-non-related shock experiences have significant influence on the adoption. While the former is common finding in the literature of technology adoption, for example Kijima, Otsuka, and Sserunkuuma (2011) and Olufunmilola, Bamire, and Ogunleye (2017) in the case of NERICA adoption, the latter has not been identified in existing literature and is considered to be our contribution.

3.5.2 Impact of upland rice cultivation

Common support conditions for propensity score matching estimation are shown in Figure 1 and Figure 2 for the cases of without and with commune dummies respectively. Kolmogorov-Smirnov distance measure of distributions of propensity score is 0.4063 for the former and 0.5620 for the latter. Thus, because the commune dummies worsen the common support condition, the model without commune dummies is used in propensity calculation and consequent analysis imposing common support. We also confirm that there is no statistically significant difference in the mean of each variable after matching (results are not shown). The result of impact assessment is given in Table 3, which indicates upland rice cultivation improves households' food security through the increase in the total rice production. This result is consistent with the earlier explanation by that upland rice is a supplemental production to lowland rice, rather than a substitute for lowland rice. Moreover, this analysis provides quantitative evidence that the upland rice plays an important role through the increase of 75.75kg of rice production per capita. Thus, the impact of upland rice is not negligible as both income source and food. As for household's consumption, the result shows that upland rice cultivation significantly increases household's consumption level, particularly consumption of food items as hypothesized.

However, none of the other variables related to rice purchasing behavior in lean months are significantly affected as expected. Contrary to hypothesis, per-capita quantity of rice purchased in January increased although the difference in quantity is small (just 1kg per person). It implies that households do not use the additional rice production to cope with the food shortage in the lean months.

Moreover, upland rice cultivation does not affect the amount of rice consumption at the time of interview (i.e. after harvest of main rice production), although it significantly increases the value of monthly food consumption in the same period as already shown. We do not have direct evidence, but the contrasting results may imply that additional rice production from upland contributes to the consumption of other food than rice, probably via purchasing.

Robustness check was conducted by using another matching method, nearest-neighbor matching, and similar results were obtained.

3.6 Conclusion of Chapter 3

Upland rice cultivation has rapidly become popular in the central highland zone of Madagascar. Regarding the upland rice cultivation as a new technology that is successfully adopted by rural farm households, this paper provides empirical evidence of the impact of the upland rice cultivation. The results imply that the upland rice cultivation enhances food security and improving households' welfare.

This study suggests that the upland rice is worth receiving more attention from policy makers because it is a realistic instrument for small-scale farmers to increase rice production. Promoting upland rice cultivation to low adoption areas is recommended.

The major limitations of this study are as follows. First, the endogenous factors may not be perfectly controlled in the presented framework. Thus, the construction of a panel dataset is expected to redirect the analysis of this study.

Second, the interpretation of the results of this study needs a particular care in that the results of this study does not capture the difference in length of harvesting period of different crops. Variables for households' consumption and rice purchasing behaviors are constructed based on data only from January to June. Since the main survey was conducted in August by when most alternative upland crops such as maize and beans are harvested, the outcome variable is fairly comparing farmers who grow on an upland with those who grow other alternative upland crops. On the other hand, it is true that some crops such as cassava and potatoes with longer periods for harvesting and can be harvested repeatedly for multiple months. Because the dataset only captures the crops harvested by the survey timing, if some crops was harvested after the interview, the results based on the consumption variables need to be readdressed. Thus, data covering all months may provide a new insight. In addition, future study will be expected to explore profitability and risk of upland rice cultivation in comparison with those of lowland rice cultivation and those of other crops like maize and cassava. Such studies will provide answers to questions such as which is better for farmers, intensifying lowland rice production or further expanding upland rice fields, and what is the optimal mixture of those crops.

Table 3.1 Descriptive statistics

Variables	All samples	Non-upland rice growers	Upland rice growers	Difference [1]	
Household characteristics					
Number of household members	4.99	4.78	5.11	-0.33	*
Household with male head (%)	89.75	86.87	91.30	-4.44	*
Age of household head	46.23	47.33	45.64	1.69	
Household head's literacy in French (%)	62.72	65.66	61.14	4.51	
Number of adult members (15 years old or above) in household	3.05	2.97	3.10	-0.12	
Land Endowment					
Number of parcels	3.64	3.32	3.81	-0.48	***
Total area of parcels (ha)	0.75	0.45	0.92	-0.47	***
Total area of lowland parcels (ha)	0.31	0.22	0.36	-0.13	***
Total area of upland parcels (ha)	0.45	0.23	0.56	-0.34	***
Total area of lowland parcels per capita (ha)	0.067	0.055	0.075	-0.019	**
Total area of upland parcels per capita (ha)	0.098	0.057	0.120	-0.064	***
Irrigation condition of lowland (%)	69.58	79.86	64.04	15.82	***
Subjective evaluation of lowland plot soil fertility weighted by plot size (1-3)[2]	2.15	2.12	2.17	-0.045	
Subjective evaluation of upland plot soil fertility weighted by plot size (1-3)[2]	1.92	1.89	1.92	-0.029	
Farming Characteristics					
HH[3] experienced weather-related production shocks in lowland rice (%)[4]	64.84	58.08	68.48	-10.40	**
HH[3] experienced weather-non-related production shocks in lowland rice (%)[4]	20.67	9.09	26.90	-17.81	***
Other characteristics					
Any HH[3] member is engaged in off farm employment (%)	61.84	67.68	58.70	8.98	**
Any HH[3] member is engaged in non-agricultural employment (%)	35.51	43.43	31.25	12.18	***
Livestock (Log of total value per capita)	2.91	3.08	2.82	0.26	*
Asset (Log of total value per capita)	2.94	3.19	2.80	0.38	***
Distance from the national road (10km)	0.58	0.56	0.59	-0.03	
Food security and welfare indicators					
Total rice production per capita (kg)	264.04	208.93	293.69	-84.76	***
Rice consumption in last 7 days (kg/capita)	2.28	2.35	2.24	0.12	
Total value of food items consumed in the last one month (10^3MDA/capita)[5]	51.48	50.45	52.04	-1.60	
Total value of non-food items consumed in the last one month (10^3MDA/capita)[5]	15.13	12.34	16.63	-4.29	**
Aggregated value of items consumed in the last one month (10^3MDA/capita)[5]	66.62	62.79	68.68	-5.89	
Number of Observations	566	198	368	-	-

Note

1) *, **, and *** indicate that the means are different at the significance level of 10%, 5%, and 1%, respectively.

2) Evaluation is based on three-scale category: low=3, average=2, and high=1.

3) HH stands for household.

4) "Experienced" is defined as having at least one shock in the last 10 years.

5) MDA stands for Malagasy Ariary. PPP converter of MGA to US$ is US$1.00 = 1,060.395 MDA in 2018. (World Bank)

Table 3.2 Determinants of upland rice cultivation[1]

Variables	(1)		(2)	
Household characteristics				
Number of household members	-0.01		-0.01	
Sex of household's head (=1 if male)	0.02		-0.00	
Age of household head	-0.00		-0.00	
Household head's literacy in French (=1 if the head can read French)	-0.01		0.09	***
Number of adult members (15 years old or above) in household	0.00		0.01	
Land Characteristics				
Size of lowland parcels per capita (ha)	0.02		-0.01	
Size of upland parcels per capita (ha)	1.22	**	0.61	
Irrigation condition of lowland (=1 if irrigated)	-0.15	***	0.03	
Subjective evaluation of lowland plot soil fertility weighted by plot size (1-3)[2]	0.03		-0.01	
Subjective evaluation of upland plot soil fertility weighted by plot size (1-3)[2]	0.07		0.07	
Farming Characteristics				
HH[3] experienced weather-related production shock in lowland rice (=1 if yes)[4]	0.10	**	0.06	
HH[3] experienced weather-non-related production shocks in lowland rice (=1 if yes)[4]	0.19	***	0.17	***
Other Characteristics				
Any of household member has non-agricultural income source (=1 if yes)	-0.07	*	-0.02	
Log of total value of livestock per capita	0.03		0.03	*
Log of total value of asset per capita	-0.09	***	-0.07	***
Distance from paved road (10km)	0.04		0.13	**
Commune dummy variables				
Belazao	NA		0.34	**
Antanimandry	NA		0.36	**
Betafo	NA		Reference	
Soavina	NA		0.40	***
Antohobe	NA		0.52	***
Mahaiza	NA		-0.01	
Ambohimasina	NA		0.13	
Ambohimanambola	NA		0.39	***
Inanantonana	NA		0.37	***
Ankazomiriotra	NA		0.49	***
Mandoto	NA		0.38	***
Antambao Ambary	NA		0.11	
Vinany	NA		0.78	***
Number of observations	566		566	

Note
1) Coefficients show marginal effects. *, **, and *** indicate significance level at 10%, 5%, and 1%, respectively.
2) Evaluation is based on three-scale category: low=3, average=2, and high=1.
3) HH stands for household.
4) "Experienced" is defined as having at least one shock in the last 10 years.

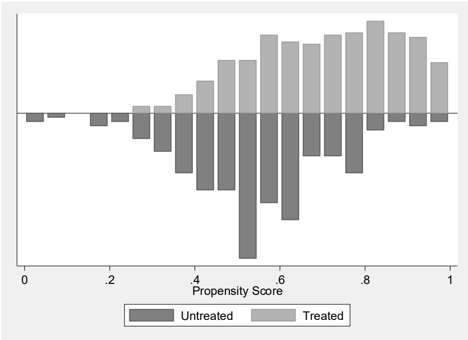


Figure 3.1. Common support without commune dummy

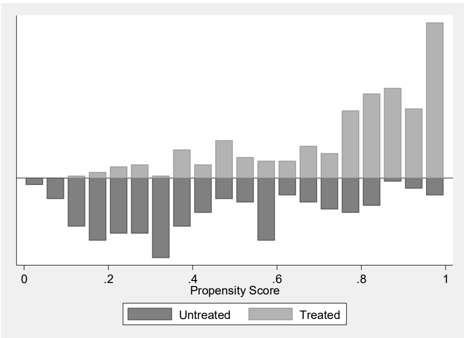


Figure 3.2. Common support with commune dummy

Table 3.3 Impact of upland rice cultivation[1]

Dependent Variables	Unit	Coefficients[1]	
Food Security			
Total rice production per capita	Kg/capita	75.75	*
Quantity of rice consumed in the last 7 days	Kg/capita	0.00	
Quantity of rice purchased in January	Kg/capita	1.30	
Quantity of rice purchased in February	Kg/capita	-0.15	
Quantity of rice purchased in March	Kg/capita	-0.56	
Total quantity of rice purchased during January and March	Kg/capita	0.59	
Welfare			
Total value of food items consumed in the last one month[2]	10^3MDA/capita	5.08	**
Total value of non-food items consumed in the last one month[2]	10^3MDA/capita	2.86	
The aggregated value of items consumed in the last one month[2]	10^3MDA/capita	7.95	**
Number of observations		566	

Note: 1) * and ** indicate significance level at 10% and 5%, respectively.
2) MDA stands for Malagasy Ariary. 1 USD = about 3275 MDA on July 18, 2018.

CHAPTER 4
IMPACT OF THE PROVISION OF SOIL QUALITY INFORMATION ON FARMERS' FERTILIZER USE: EXPERIMENTAL EVIDENCE FROM MADAGASCAR

4.1 Introduction

It is widely recognized that sustained growth of agricultural productivity in sub-Saharan Africa (SSA) requires a substantial increase in chemical fertilizer application (Vlek, 1990; Morris et al., 2007; Xu et al., 2009; Holden, 2018). The pace of increase in nitrogen fertilizer use in agriculture has been substantially slower in SSA than other parts of the world (FAO, 2020). A large body of literature has proposed various factors that help to explain the low use of fertilizer in SSA, mainly focusing on demographic as well as market-related factors. The education level of the heads and other household members affects adoption decisions of fertilizer (Asfaw, 2004). The poor accessibility to input and credit markets are constraints (Croppenstedt et al., 2003). Bold et al. (2015) proposed that low quality of inputs sold in markets discourage farmers to adopt fertilizer.

Another group of research has been shedding light on the relationship between soil characteristics and crop yield response to fertilizer which contributes to the heterogeneous rate of returns to fertilizer use. For instance, soil carbon content (SCC) (Marenya and Barret, 2009), phosphorus (Asai et al., 2020), and other factors related to soil chemistry including pH and carbon exchange capacity (CEC) (Burke et al., 2019) on crop yield response to fertilizer application have been studied.

Findings from these studies suggest that suitable types of fertilizer and appropriate application rates may be largely different from plot to plot, depending on inherent soil conditions. More importantly, farmers usually do not have any means of obtaining accurate information about the soil characteristics and thereby they make decisions without knowing how to optimize the use of fertilizer. Some studies such as Harou et al. (2018) have paid attention to the role of site-specific recommendations regarding fertilizer application rates. These studies commonly examine the effect of information on plot-level optimization, focusing on how much extent information could close the gap between required rates and actual rates of application. The recommendation is made based on the deficiency of nutrient in soil as well as required types and amount of fertilizer to fill the gap between ideal and actual levels of soil nutrition. The required amount is naturally larger in nutrient poorer soils.

However, under financial and physical limitation of access to fertilizers, applying the appropriate types of fertilizer at required level in all plots for crop production may not be feasible for farmers, especially if the degree of deficit is high. Thus, this study takes an alternative approach to help farmers optimize fertilizer use at farm level, which is a novelty of this study. We provide farmers with the information related to effectiveness of fertilizers in one main plot for rice production. This information is expected to allow farmers to take a better strategy by diverting fertilizer from plots that may not respond positively to those more responsive to it. This viewpoint has rarely been presented in the existing literature.

Contribution of this study to the literature is to provide new empirical evidence of the role of information. The research question is: does site-specific information on expected effectiveness (EE) of nitrogen fertilizer application affect farmers' decisions as to fertilizer allocation? The hypothesis is that the information helps farmers to optimize fertilizer allocation in terms of its adoption and its application rates. More specifically, information of high EE will contribute to an increase in the probability of adoption of nitrogen fertilizer as well as its application rates at targeted plots. The low-EE information will have the opposite effects because farmers might utilize the information to select another rice plot or a plot for another crop as an alternative place for using the fertilizer. Eventually, both types of information will lead to higher rice yield at farm level and improve household welfare.

This study focuses on nitrogen fertilizer because, in agronomic literature, it is generally admitted that lack of nitrogen most severely limits yield of rice in SSA (Saito et al., 2019, Rurinda et al., 2020, Tanaka et al., 2012). As a plant absorbs nutrients from soils for its growth, soil nutrients decreases unless the absorbed nutrients are replenished before following cultivation in the same plot. With data from 2907 farmers from 12 countries in SSA, Arouna et al. (2021) found that the low yields of rice are associated with low use of nutrient input and found the evidence of mining soil nutrients in low-input use plots.

Using evidence from the agronomic experiment conducted in the same region by Asai et al. (2020) that phosphorus amount in soil affects the effectiveness of nitrogen fertilizer, we designed a simple binary information about EE of nitrogen fertilizer application. We did not use nitrogen amount in soils because, unlike phosphorus, a large part of nitrogen which did not get absorbed by a plant runs off through multiple pathways without retaining in soil (Xiaoying et al., 2020), and therefore farmers basically need regular applications of nitrogen fertilizer at every cropping season regardless of nitrogen amount. Then, a randomized controlled trial (RCT) was conducted in the central highland zone of Madagascar. Treated farmers received information of either "high" or "low" in terms of the EE about one main lowland rice plot before the time of planting in addition to 5 kg of urea, while farmers in the control group received the same among of urea but not the information. Results revealed that high EE information significantly increased the rates of nitrogen fertilizer application and low EE information decreased the probability of adoption of nitrogen fertilizer and its application rates. We also found that high EE information about only one plot for each household increases total nitrogen application rates and total rice yield at farm level.

The rest of this paper is organized as follows. In section 2, we explain the context of the study site. Experimental design is proposed in section 3. Section 4 explains econometric specification applied in the analysis. Results and additional discussion are presented in section 5, followed by conclusion.

4.2 Context

4.2.1 Madagascar

Madagascar is an island nation located in the Indian Ocean with a population of 25.67 million people as of 2018 (INSTAT, 2019). Rural population accounts for 80.7% of the total population (INSTAT, 2019). Poverty head count ratio reaches over 75%, which is one of the highest in the world (World Bank, 2019). In Madagascar, rice is historically the main staple food crop as well as the major income source for rural population. 89% of the rural households are engaged in rice cultivation and 56% of agricultural land is devoted to it (World Bank, 2019). Therefore, the improvement of rice productivity has long been one of the central issues in national policies for poverty reduction and food security (World Bank, 2020).

4.2.2 Study sites

The study site is located in the Vakinankaratra region which is in the central highland zone. The study site was selected because it is one of the major rice-producing regions. The Vakinankaratra region has an asymmetric landscape: The altitude in its eastern part is high up to near 1,800 meters above the sea level and there is a long mild slope descending towards the western end of the region. This asymmetry affects agroecological environment and thus agricultural practice although rice production in lowland is a common practice. The selection of the Vakinankaratra region has another advantage. Asai et al. (2020) studied the relationship between inherent soil characteristics and the effects of fertilizer application in one of the villages we targeted for this experiment. Thus, their findings, particularly the ineffectiveness of nitrogen fertilizer in plots where phosphorus[54] is less than 100mg per kg in soil are highly applicable to our study.

[54] In Asai et al., (2020), phosphorus amount is measured as oxalate-phosphorus. Thus, the among of phosphorus in this paper also refers to oxalate-phosphorus.

4.3 Experimental design

4.3.1 Sampling procedure

Five villages across three districts in the Vakinankaratra region were chosen. Purposively, two villages from the eastern part, another two villages from western part, and the other one in between the two groups of villages were selected to evenly represent the agroecological diversity. All the five villages are located along the national road that runs east and west in the middle of the region. (Figure 1).

Each village has several smaller administrative units. Based on the units, two enumeration areas (EAs) were chosen in each village. The two EAs in a village have similar characteristics in terms of distance from the national road, population, and rice cultivation practices based on information collected in a preliminary field survey[55]. Then, we randomly selected farmers who grew rice in lowland plots in 2018-19 rainy season. Before intervention, all the sample farmers were asked to list all the agricultural plots used in that season and then to choose one most important lowland rice plot. We visited each of these targeted plots and measured its location and its size by GPS. In addition, soil was taken from three points in each plot to obtain composites of soil sample. All the soil samples were sent to national laboratory to examine phosphorus amount. Based on the result of this soil analysis, all the targeted plots selected were classified as either high EE or low EE.

4.3.2 Randomization

Figure 2. shows the assignment structure. The total number of participants was 70. Randomization was done at EA level to minimize the risk of interaction between the treatment and the control groups to take place. Randomization at EA level was more suitable than at household level because communication with treated participants might let farmers in the control group learn from information given to the treated. Since two EAs in a village are geographically apart and farmers in control EAs had no information about the selection of the treated EAs, spillover of information could be prevented by randomization at EA level.

After randomization, both the treatment and the control groups had 35 household. Regardless of the assignment status, we provided all participants with common inputs that consisted of free fertilizer (5kg of urea), the size of the targeted plot that was obtained by GPS, and general advice regarding timings and rates of urea application[56]. Provision of these common inputs was because only 24 out of 70 participants have ever

[55] When the national road passes through the target village, we selected one EA from the northern side of the national road, the other EA was selected from the southern side of the road.

[56] We recommended the rate of 1kg of urea for 1 Are of land. Recommended timings were 14 to 20 days after transplanting as basal fertilizer application and 40 to 50 days after transplanting as top-dressing application. The actual paper distributed to all participants is presented in appendix.

experienced of using chemical fertilizer in rice plots in the past. There might be substantial knowledge gap between those with experience and without. Moreover, participants without experience of chemical fertilizer use may suffer from poor accessibility even after they receive useful information. Common inputs were distributed by aiming to alleviate the effects of lack of knowledge and poor accessibility on their decision making after the intervention. When distributing the common inputs, participants were explicitly informed that there is no restriction on usage of urea from us and so they might use it to any crop at any plot, keep it, sell it, or even give it to others. The distribution was implemented in October in 2019.

Then, when the common inputs were distributed, only farmers in the treatment group additionally received the information that consisted of the EE status, the amount of phosphorus in soil of the targeted plot (mg/kg), and relative ranking among the participants in the same EA[57]. As a result, only the treated farmers could know whether urea was effective or not and use this information to make decisions about whether or not to and how much to use urea on the targeted plot. Farmers in control group had to decide how they use the given fertilizer without knowing EE status of their targeted plots.

4.4 Analytical framework

4.4.1 Definition of expected effectiveness to nitrogen fertilizer

Table 1 presents the summary of results of soil examination by EA. The amount of phosphorus was measured as oxalate phosphorus. The averages largely vary across study area from 36.96 mg/kg of Tsarazaza as the lowest to 482 mg/kg of Befaritra as the highest. One possible explanation of such a huge difference is that a volcano affects soil in its surrounding EAs including Befaritra, Amohimilemaka, Mahazina, and Morafeno[58]. Volcanic soil contains rich phosphorus, but a lot of phosphorus exists in a form which plants cannot absorb and utilize. Following Asai et al. (2020), phosphorus amount of 100 mg/kg was used as the base threshold (θ). However, application of the base threshold to all EAs resulted in no or only one variation of EE status in 6 EAs. Therefore, two different thresholds were prepared. The base threshold was applied all but 4 EAs where soil is affected by the volcano. According to a publicly available guideline for fertilizer application in Japan, required amount of phosphorus in volcanic soil is three times larger than that in non-

[57] Although our main objective was to give the information of EE status, we also provided the treated farmers with the amount of phosphorus and the ranking among the participants in the same EA. This is because farmers in the same EA tend to know plots of each other, and the additional information may help farmers relate the results of soil examination to the actual situations that they observe.

[58] Nishigaki et al.(2020) conducted soil survey covering our study site and founds that sporadic volcanic soil exists in Betafo district in which the four EAs are located.

volcanic soil (MAFF, 2008). For the 4 EAs, therefore, 300 mg/kg was employed as the threshold to deal with influence of volcanic soil. Eight out of 10 EAs embrace both sub-groups, implying that there exist substantial variations of soil quality even within a village. If phosphorus amount is more than the threshold, the plot is considered to have high EE regarding nitrogen fertilizer use, and low EE otherwise.

4.4.2 Econometric specification

Three specifications are used in the analysis. First, the impact of intervention was examined by comparing the outcome variables between target plots of treated and control groups. This analysis used data from the target plot of each participant only. In RCT setting, the effect of intervention can be obtained by simply comparing the mean values of each group of treatment and control or running Ordinary Least Squares (OLS). Furthermore, following the argument of McKenzie (2009), this study employs ANCOVA model that leads to large improvement in analytical power especially when an outcome variable of interest has high variability and has non-zero but low autocorrelation[59].

$$Y_{ih20} = \alpha_0 + \beta_1 T_{ih}^{high} + \beta_2 T_{ih}^{low} + \beta_3 Y_{ih201} + \beta_4' PC_{ih} + \beta_5' HC_h + \beta_6' village + u_i \dots (1)$$

where Y_{i20} are outcome variables in target plot i of household h in the season of 2019-2020. Two types of outcome variables are used in this model: binary variables and continuous variables. The former type is adoption status of urea, nitrogen fertilizer, organic fertilizer in the target plot. These variables take value of one if the target plot received these inputs, respectively. It is important to note that these variables capture only the adoption status of target plot and takes value of zero if the target plot does not receive these inputs even when a participant used these inputs in another plot which was not visited for soil sampling. Nitrogen fertilizer refers to any kind of chemical fertilizer product which include nitrogen as it's nutrients. In this dataset, NPK composite-type fertilizer and urea were observed in interview. The latter group include rice yield in kg/ha, application rates of urea in kg/ha, nitrogen application rates in kg/ha which is imputed from the typical nutrients composition in each type of fertilizer product[60]. When the outcome variables are binary

[59] ANCOVA stands for Analysis of Covariates. McKenzie (2009) gives income and consumption of households in poverty as examples for the appropriate cases of application of this model. Since the income of these households comes from agricultural production, we thought this model is more appropriate than simply running OLS. When experimental data is based on a single baseline and follow-up survey,

[60] For imputation of nitrogen amount, nitrogen is considered to account for 46% and 16% of the total weight in urea and NPK fertilizer available in the study area.

type, models become linear probability model where each coefficient, β, shows the marginal effect of change in one unit of each explanatory variable on the probability of adoption of each of those inputs. The key feature of ANCOVA model is inclusion of outcome variables in the previous season, Y_{i2019}, to control the effects of pre-conditions of each plot. The inclusion of the lagged dependent variable enables us to interpret the effects the impact on the change in outcome variables from the previous season.

As for the treatment variables, our treatment would affect farmers' decisions differently, depending on whether the information was high or low. Thus, two dummy variables of treatment status were separately included in the model. T_i^{high} takes 1 if a participant was assigned to the treatment group and received information that urea would be effective in the targeted plot of his household. T_i^{low} takes 1 if a participant belonged to the treatment group and information was low EE. These two dummy variables take 0 for those who belonged to the control group. PC_{ih} is a vector of plot level covariates that include plot size in ha, squared value of plot size. HC_h is a vector of household level covariates. Household size, years of education of household head, sex of household head, log of per-capita value of asset, and risk preference of household head[61] are included. These variables should be included because randomization was not at household level. Therefore, while whether or not a household could receive information of EE was exogeneous, whether the information was to be high EE or low EE might be correlated with some observable household characteristics. Dummy variables to control unobserved factors attributable to village characteristics are also included as $village$. β is a vector of parameters to be estimated and α_0 is a constant term.

The major concern of this model is the small number of observations and villages which are used as clusters in estimation process. While the ANCOVA model contributes to maintain the analytical power with small sample size, it does not fully solve the issue, especially of a few clusters. To deal with the small number of observations a typical strategy is to conduct bootstrap. However, it is also known that the ordinary bootstrap method that performs replications by resampling a pair of outcome variables and covariates at cluster level may work poorly when the number of clusters is only a few or the number of observations largely vary across clusters (Roodman et al., 2018). Since this study has only 5 villages as clusters, wild cluster bootstrapping (WCR) method is employed to make results as rigorous as possible.

The second model is to examine the impact of intervention by the following specification.

[61] Risk preference of household head was measured by a simple hypothetical game. The preference was scaled from 0 to 10 where smaller number indicates relative risk-averseness. When we could not find the household head at the time of interview, we conducted the game with another household member who respond to interview.

$$Y_{ih} = \beta_1 I_{ih}^{high} + \beta_2 I_{ih}^{low} + \beta_3 NI_{ih}^{high} + \beta_3 NI_{ih}^{low} + \beta_4 size_{ih} + \beta_5 size\_sq_{ih} + \beta_6 uprice_{ih} + HHFE_h + u_{ih} \dots (2)$$

where Y_{ih} is outcome variables in a plot i of a participating household h. The outcome variables include quantity of urea and nitrogen and rice yield. The units of these variables are the same as specification (1). T_{ih}^{high} and T_{ih}^{low} are dummy variables that take value of one if information about expected effectiveness (EE) of nitrogen fertilizer in this plot was provided. Superscripts denote the type of information: high-EE or low-EE. NI_{ih}^{high} and NI_{ih}^{low} are dummy variables that take value of one if a plot is a target plot owned by a household in the control group. If a plot is a target plot where soil samples are taken, this plot is either target plot of participant in the treatment group or plot of the control group. If it is plots of a household in the former, information of high EE or low EE was provided to the participant. If it is plots in the latter group, although the participant received no information about EE of the target plot, the amount of oxalate-phosphorus was measured in the laboratory. Thus, these four dummy variables capture all the possible patterns of assignment status for target plots. $size_{ih}$ and $size\_sq_{ih}$ are plot size in ha and its squared value of plot i of a household h. The next term of $uprice_{ih}$ is a dummy variable which takes value of one if a plot is rice plot in upland. As it is discussed in the previous chapter, upland rice cultivation is popular in the study area and many farmers in this dataset have rice plots both in lowlands and uplands, and thus non-target plot include both types of rice plots. As the growing condition is different between the two, this dummy variable intends to capture the effect of the difference. $HHFE_h$ is household fixed effect that captures effects of household's traits that commonly affect the rice cultivation on all rice plots. u_{ih} is the error term.

In addition to the explanatory variables, this model is different from the previous specification in that while the specification (1) only deals with target plots, this model uses data from all rice plots for each household. Using data of all but 10 households who have only one rice plot, impacts of treatment are estimated while controlling unobservable characteristics of households. In this specification, β_1, β_2, β_3 are the parameters of interest. Each parameter indicates whether and how each type of assignment status has effect on the outcome variables in comparison with another plot in the same household.

Third, the specifications below are used to examine the impact of the intervention on household level variables. These models focus on measuring the impact of intervention on household welfare.

$$Y_h = \alpha_0 + \beta_1 T_h^{high} + \beta_2 T_h^{low} + \beta_3' HC_h + \beta_4' village + u_h \ldots (3)$$

where Y_{h2020} is outcome variables that include crop income per capita and monetary value of the total consumption per capita of household h. Data for outcome variables were collected in August 2020, approximately 3 months after harvesting month of the year. T_h in (3) is a dummy variable which takes value of one if a household belongs to treatment group and receives information of expected effectiveness of nitrogen application in the target plot. T_h^{high} and T_h^{low} in (4) are also dummy variables which decomposes T_h by the types of information that a treated household receives. HC_h include the same list of variables in specification (1) as observable factors that also affect outcome variables. $village$ is a vector of dummy variable of village of residence.

4.5 Results

4.5.1 Descriptive statistics about households

Table 2 presents descriptive statistics of participants' households. The average size of household is 5 people. More than 90% of households are headed by males. Farms are typically small-scale as participants cultivate 0.49 ha of land on average. The size of target plot is 0.15ha on average. Within the treatment group, the mean value of this variable has significant difference at 10%. On average, household's head has 6 years of education. The number of rice plots is 3.5, implying that farmers usually have multiple choices of plots for fertilizer allocation. After randomization, 10 out of 35 households who belonged to the treatment group had plots with high EE and 25 of them had plots with low EE. Between the treatment and control group, there are no systematic difference with respect to these variables (see Table A4.1).

4.5.2 Descriptive statistics about targeted plots

Table 4.3 shows descriptive statistics of targeted plots. The number of plots is the same as the number of households because we targeted one plot from each household. The percentage of plots which had high EE was 31.4% if those in both treatment and control groups are counted. This percentage was 34.3% and 28.6% in the control and the treatment group, respectively, and the difference was not statistically significant. On average, the plot size of targeted plots is 0.15 hectares. As for experiences of fertilizer use in the previous year, the percentage of household who had applied urea in the target plot was 17%. The percentage of household who had applied any type of fertilizer product that include nitrogen as nutrients was 20%. After intervention, the percentage of plots where urea was used in the season of 2019-20 increased up to 61% in total. This suggests that farmers are willing to use fertilizer if they can obtain it. As for manure use, which is an important input in rice cultivation, 31% of the targeted plots had received manure in the previous year and the percentage did not largely change after intervention. The average rice yield had been 4795.22 kg/ha in the season of 2018-19, and 4727.80 kg /ha in the season of 2019-20.

Table 4.4 summarizes the numbers of the targeted plots by adoption of urea in each group of treatment assignment. Treatment groups were separately shown by sub-groups based on the EE. Among 25 plots owned by those who received information of low EE, urea was used in 12 plots, which is 48%. For the other treatment group, urea was used in 7 out of 10 plots where EE was high. The share of plots on which urea was applied was 68.6 % in the control group, which was in between the two treatment groups. The last column shows the result of Fisher's exact test to see whether there is a statistical difference in urea adoption by assignment status. Despite the aforementioned relationship of percentages among the 3 groups, the p-value is 0.24, suggesting that the difference was not statistically significant.

4.5.3 Impact of intervention on fertilizer application at targeted plots

Table 4.5 presents the results of regression of fertilizer use at targeted plots on treatment variables. The first two columns focus on the use of urea. After controlling the effect of difference in outcome variable in the previous year by the lagged dependent variable, the result shows that receiving information of high EE did not increase probability of adoption and application rates. However, low EE information resulted in significant decrease in the probability of urea application by 12%. No impact on quantity of urea was found for both types of information though the signs of coefficients are consistent to hypothesis. In the third and fourth columns, the models used use and quantity of nitrogen fertilizer that accommodates not only urea but also NPK as another fertilizer product which contains nitrogen as nutrients. As for the effects of low EE information, the information led to 11% of decline in the probability of application. Moreover, information of high EE had a significant positive impact on nitrogen application quantity by 41 kg/ha. In the fifth column, impact of treatment on manure use was tested because factors to change fertilizer use may also influence the use of other types of inputs. The result shows that probability of using manure in the target plot declined by 22% compared with the control group when farmers received information that would encourage urea application. In the sixth column, whether the intervention affected decisions of purchase of chemical fertilizer was examined. Receiving information that nitrogen fertilizer would not be effective led to the reduction of probability of spending money for purchasing additional chemical fertilizer in the target plot.

The last column aimed to examine the impact of the intervention on rice yield at the targeted plots. Although receiving information of high EE had positive coefficient, it was not statistically significant. To explore the reason of insignificant coefficient,

4.5.4 Impact of intervention on allocation of fertilizer within a household

Table 4.6 present results of the second specification. The question to be answered from this specification is whether the information provision affected the allocation of chemical fertilizer. As the intention is to compare the nitrogen fertilizer use between plots within a household, 10 households who have only one rice plots were not included in the analysis. Including rice plots both in lowlands and uplands, the total number of observations was 207 from the total 60 households. In this model, any household characteristics which affect all of their rice plots in common would be controlled by household fixed effect.

The first column shows that on average, quantity of urea applied to the target plots was larger than non-target plots in a household by 43.79 kg/ha. If the outcome variable extends its reach to the total quantity of nitrogen that was computed from the nitrogen contents of urea and the typical NPK composite fertilizer, the coefficient became 53.42 kg/ha with 10% of statistical significance. The third column explored the impact of assignment status on rice yield in target plots compared to non-target plots in a household. Among the rice plots in a household, rice yield became higher than non-target rice plots. The difference was 948.75 kg/ha on average after controlling the effect of being grown in a upland plot.

These results imply that information was useful to help the treated farmers optimize their fertilizer allocation based on soil characteristics. The coefficients of the variable of "Control (High EE)" in each model suggests that without information, fertilizer was evenly allocated among rice plots within a household even when a targeted plot had a sufficient level of phosphorus amount in its soil. This is possibly because they do not have any means of knowing the characteristics or maybe because farmers believe soil characteristics are not much different across plots.

4.5.5 Impacts on rice yield, fertilizer use, and welfare at household level

Table 4.7 shows the impact of the intervention on farm level variables using the specifications (3). Outcome variables include the average rice yield, average intensities of application of urea and nitrogen both of which are shown in kg/ha, crop income per capita, and monetary value of the total consumption per capita. Columns (1) to (3), the values of these outcome variables of the target plot in the previous year are included in order to mitigate the effect of pre-existing condition. The results show that both types of information did not increase yield at household level. Nitrogen application rate in column (3) increased when household received information that urea would be effective in their target plots.

To see whether the intervention contributed to welfare improvement of treated households, two outcome variables are regressed on treatment variables. First, crop income per capita was used because higher rice yield by more optimal use of fertilizer was supposed to have a positive impact on crop income. Second, the monetary value of consumption per capita during 3 months after rice harvest was used as the other outcome variable. Although hypotheses expected that these variables would increase by receiving information, both the high EE and the low EE information had no significant impacts.

4.6 Supplemental discussions

4.6.1 Additional analysis regarding impact on target plot

In the intervention. all the participants received the exact size of the target plot (see Table A4.2 and A4.3) as well as the general instruction of recommended timing of application and the application rate regardless of the treatment assignment status (see Table A4.1). The recommended rate of application was 5 kg of urea for 0.05 ha. So, the urea provided for free was not enough to cover all the area of the target plot for most participants as the average size of the target plot was 0.15 ha. Therefore, farmers might have given up using the given urea just because the amount of urea could not cover whole area. To see whether or not this was the case, additional regression was run with the following specification (1). In this model, however, plot size and square of plot size were excluded and a dummy variable of whether or not plot size is over 5 Ares was included. Also, to see more specifically examine whether the size of target plot being larger than 5 Ares reduced impact of intervention for those who received information, interaction terms between treatment assignment variables and the dummy variable were included.

Results are presented in Table A4.6. None of three newly added variables were statistically significant, implying that whether the plot size was larger than 0.05 ha did not affect the farmers' decisions.

4.6.2 Usage of free urea

Among 70 participating households, 67 households used up all 5kg of the urea provided for free (Table A4.2 in Appendix). One of the remaining 3 households had used 1kg and was keeping 4kg without using at the time of the follow-up survey. Another household used 4kg for upland rice and maize and sold 1kg at 2500 MGA/kg which was higher than the market price of around 1800 MGA/kg at that time. The other household used 3kg for upland rice and gave 2kg to other people. Among those who used all 5kg, not everyone used all 5kg to lowland rice plots. Only 30 participants used all the given urea to lowland rice plots, including both the targeted and non-targeted lowland rice plots.

Table A4.4 summarizes timings of applications in the total 46 cases of using the urea in lowland rice plots. The urea was applied 3-4 weeks after transplanting, which is the timing of the recommendation we provided, in 26 cases. 4 plots received it at the timing of 7-8 weeks after transplanting in which rice were at the stage of flowering. Thus, the recommendation of application timing was adopted in 27 cases and not in 19 cases. As shown in Table A4.5, the urea was most likely applied by broadcasting, accounting for 93% of the cases of lowland rice plots. In 2 cases, it was put in the nursery bed for seedling production.

Other than lowland rice plots, the most popular destination of the given urea was upland rice plots, followed by maize plots (Figure A4.4 in Appendix). The number of upland rice plots where the urea was applied was larger than the number of non-targeted lowland rice plots. To figure out driving factors of applying the given urea to upland rice plots instead of using it at another lowland rice plot is beyond the scope of this study. Meanwhile, one possible explanation would be that those who grow rice in both lowlands and uplands in the same season tend to have experience of using chemical fertilizer more in uplands than in lowlands. The number of participants who had ever applied chemical fertilizer on lowland rice plots was 24, which accounts for 34% of the total number of participants. As for the experience of chemical fertilizer use in rice plots for those who grow upland rice, 63% of them had ever applied chemical fertilizer in upland rice plots while only 11 % of them had used it in lowland rice plots. Therefore, the upland rice growers have incentive to use the given urea for upland rice plots especially when they received information of low EE on the targeted lowland rice plot.

4.6.3 Cost and benefit of intervention

To explore financial viability of this experiment or a similar attempt in future, Table A4.6 presents a basic cost structure based on the experience of this study. The cost of hiring an enumerator for sampling soils was approximately 70000 MGA[62]/day, which includes accommodation and other necessary items for the activity in the field. From the experience of this study, an enumerator could sample soils from 3 to 4 plots a day on average although various factors affected the efficiency of the work. Thus, sampling soil from a plot was approximately 20000 MGA[63]. Then, these samples were brought to the national agricultural research institute in the capital city of Madagascar. It is important to note that the recent technical development in examination of phosphorus amount in soil improves accuracy in the prediction of phosphorus contents in soils and speed of the examination[64]. 70 soils samples were examined a day in this experiment. Assuming that almost the same rate of wage is applicable to a enumerator and a lab-worker, the cost to examine one soil sample is 1000MGA. In addition, in this experiment, 5 kg of urea was provided for free to control the effects of different affordability of urea and accessibility to a fertilizer market among participants. At the time of the intervention, price of urea was 1800 MGA/kg, and thus the cost for 5kg was 9000 MGA. It costs 70000 MGA/day to hire the enumerator again to revisit the participants to provide the urea and the result of soil examination. An enumerator could provide them for 10 households a day, and thus the cost was 7000 MGA per participant. The summation of each cost so far suggests that it costs 37000 MGA/participant, which is equivalent to US$10.23[65], to provide the information.

As presented in Table 4.6, the target plot of the treatment group increased the yield by 948.75 kg/ha on average compared to non-target plots in the same household when the target plot had high expected effectiveness of nitrogen application. Since the average plot size was 0.15 ha, the information resulted in 142 kg of additional rice production from the target plot. Using the average farm-gate price of rice in this dataset, which was 803 MGA/kg, a typical participant in the treatment group with preferable soil characteristics benefited 114,307MGA which is equivalent to US$31.56. In this case, the benefit is three times as large as the cost for the intervention.

[62] MGA is the abbreviation of the local currency in Madagascar. It stands for Madagascar Ariary.
[63] This is calculated as 70000 MGA divided by 3.5
[64] See Rakotonindrina et al. (2020) Kawamura et al., (2021) for the details of technical development of the methodology for prediction of phosphorus contents.
[65] The official exchange rate of 3618.32 in 2019 was used to convert from MGA to US$. The rate was obtained from the World Bank website (https://data.worldbank.org/indicator/PA.NUS.FCRF?locations=MG&view=chart.) (Last accessed on 10/12/2021)

It should be noted that this estimation does not include the cost for transporting a soil sample to the research institute because the cost largely depends on the mode of the transportation and the distance between the study site and the place of the institute. If such institutions were only in the capital city, only the transportation cost may be larger than the benefit especially when a study site is far. In addition, in this experiment, only 10 households had plot with high EE. As the results of regressions did not show any positive impact in the case of low EE, the total benefit including all the case may not be larger than the total cost.

4.7 Conclusion of Chapter 4

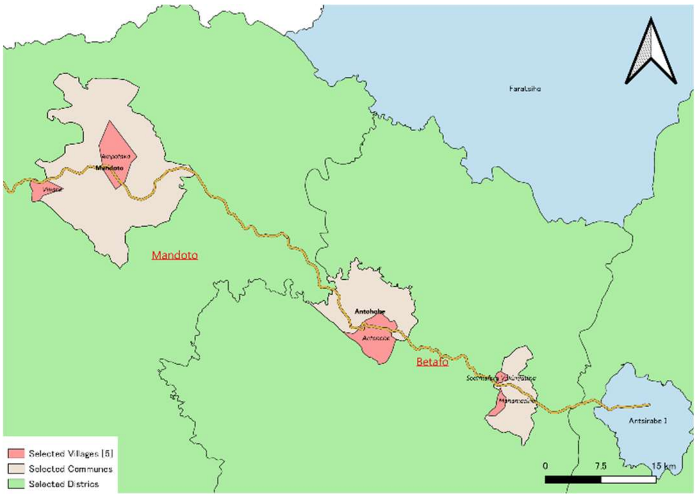
The objective of this paper is to examine whether provision of site-specific information on soil characteristics affect farmers' decisions for fertilizer allocation. Randomized Controlled Trial was carried out In Vakinankaratra region of the central highland zone of Madagascar where fertilizer use has been limited to insufficient level.

Using agronomic findings that phosphorus amount in soil has the critical role in effectiveness of nitrogen fertilizer, a simple binary information about expected effectiveness (EE) was designed. First, at the stage of soil examination, this study revealed that phosphorus amount in soil largely varies across study site and even within a village. This large variation of soil characteristics necessitates site-specific advice regarding fertilizer management because conventional blanket recommendation might result in disappointing outcome in some plots where crop yield response to the fertilizer is low. Second, this study found that high EE information significantly increased intensity of nitrogen fertilizer application while low EE information decreased the probability of nitrogen fertilizer adoption. With a viewpoint of optimization under limited accessibility to and affordability to buy fertilizer, the results of regressions imply that both types of information helped famers optimize the fertilizer allocation. As a result of optimization of fertilizer allocation, it was detected that rice yield was higher in the target plot than non-target plot for those who received information of high EE while no impact was observed in other assignment status. However, the plot level improvements of yield were not enough large to affect household level yield as well as consequential welfare variables. Since our intervention was based on soil examination that dealt with only one rice plot in a household, information that cover multiple rice plots in each household will be more useful for farmers.

Various attempts including subsidy program, credit lending, training about how to use have been implemented in SSA to promote fertilizer use by farmers. Then, this study showed that combination of information based on soil characteristics, even a simple information as used in this study, and conventional policies with focus on accessibility to inputs has potential to enhance effectiveness of these fertilizer promotion policies.

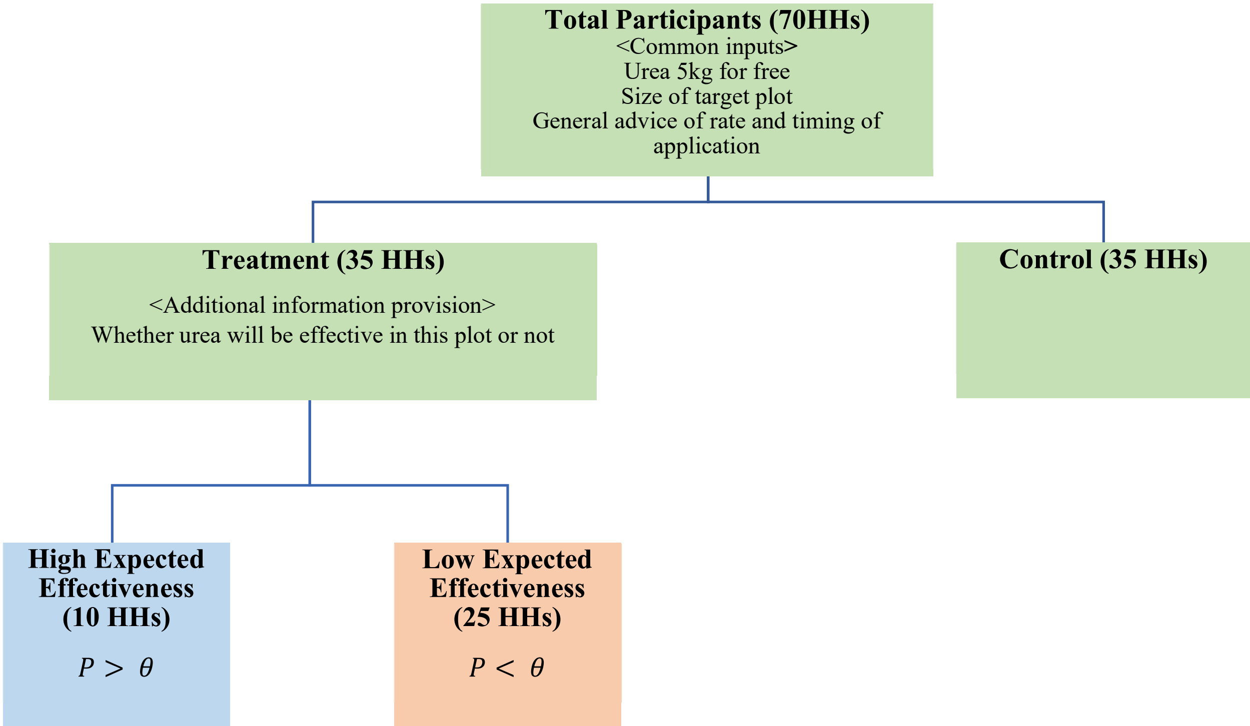
Limitations of this study are as follows. First, the experiment was implemented in only a few villages in the region and the number of observations is small. Considering criticism about external validity of many RCT studies in addition to the small sample problem, generalization of the results of this research will require a particular care. Some similar intervention with larger scale will be important to reconfirm the key findings from this study. Second, this study only examined the impact of information in the season of 2019-20 which started soon after our intervention. Additional data in the following seasons would be useful to see whether the impacts would last without free fertilizer provision. Finally, this study would also face the same criticism that Burke et al. (2019) made against Marenya and Barret (2009) as we dealt with only phosphorus, ignoring complicated structure of soil that affects crop yield response. Inclusion of multiple soil characteristics in information design will make a similar intervention more meaningful both for researchers and farmers.

Figure 4.1: Location of target villages



Source: Authors created based on data obtained from Humanitarian Data Exchange (HDX) https://data.humdata.org/dataset/madagascar-administrative-level-0-4-population-statistics

Figure 4.2. Assignment Structure



Notes: P denotes the amount of phosphorus in soil in mg/kg. Phosphorus was measured as oxalate-phosphorus following Asai et al.,(2020). θ is threshold value which define the soil sample as either high EE or low EE. Two different threshold were used because soils in 4 out of 10 EAs are considered to be affected by a volcano.

Table 4.1. Summary of variation of phosphorus amount by EAs

Name of EA	Mean	S.D.	Min	Max	Volcanic soil	θ
Befaritra	482.48	219.91	228.27	823.08	Yes	300
Ambohimilemaka	321.31	196.94	24.49	615.74	Yes	300
Mahazina	335.71	134.06	94.16	586.60	Yes	300
Morafeno	316.25	117.60	136.88	481.96	Yes	300
Ampotaka Afovoany	74.29	44.68	23.48	184.22	No	100
Ambany Ravinkazo	58.76	27.42	27.50	97.57	No	100
Tsarazaza	36.96	12.69	20.30	60.58	No	100
Soanotohizana	38.87	22.83	24.44	113.50	No	100
Antanetibe	90.20	38.00	42.54	166.81	No	100
Antohobe	70.52	26.31	34.99	135.99	No	100

Note: Unit is mg/kg of dried soil. Phosphorus amount is measured as oxalate phosphorus. S.D. stands for standard deviation.

Table 4.2. Descriptive statistics about participants' household

Variables	Unit	Overall (N=70)	Treatment High EE (N=10)	Treatment Low EE (N=25)	Control (N=35)
Explanatory Variables					
Household size	people	5.21 (1.82)	4.30 (1.06)	5.48 (2.35)	5.29 (1.51)
Sex of household head	%	92.86	90.00	92.00	94.28
Age of household head	years old	46.57 (12.12)	46.30 (13.57)	47.44 (15.25)	46.03 (9.18)
Years of education of head	years	6.00 (3.20)	5.50 (2.76)	5.76 (3.53)	6.31 (3.13)
Total size of rice plots	ha	0.49 (0.58)	0.18 (0.24)	73.74 (79.52)	39.43 (37.10)
The number of rice plots	number	3.49 (1.56)	2.90 (0.99)	3.64 (1.66)	3.54 (1.62)
Size of targeted rice plot	ha	0.15 (0.15)	0.09 (0.08)	21.48 (22.08)	12.49 (7.75)
Value of asset per capita	10^3 MGA	1464.62 (2045.56)	2013.35 (1594.55)	1454.53 (1588.88)	1315.04 (2434.18)
Risk preference (from 1 to 10)		5.53 (2.70)	6.90 (2.47)	5.36 (2.53)	5.26 (2.83)
Outcome variables					
Rice yield at farm level	kg/ha	4422.04 (2711.13)	6784.55 (3497.23)	3501.48 (2312.97)	4404.57 (2374.40)
Crop income per capita	10^3 MGA	167.21 (187.56)	91.06 (139.28)	190.45 (154.80)	172.37 (217.27)
Per capita consumption	10^3 MGA	246.99 (375.78)	319.07 (405.80)	168.88 (130.97)	282.19 (472.84)
Average nitrogen quantity applied to rice plot	kg/ha	16.21 (44.96)	13.37 (44.06)	12.44 (38.33	14.04 (48.28)
Average urea quantity applied to rice plot	kg/ha	30.69 (90.11)	27.49 (92.75)	24.87 (74.13)	29.35 (105.08)
Observations		70	35	35	

Source: Authors.

Note: MGA is local currency, standing for Malagasy Ariary, HH stands for household. Standard deviations for continuous variables are in parenthesis

T-test was conducted regarding size of targeted rice plot between treatment-high EE group and treatment -low EE group, and it detected the significant difference in at 10% of significance.

Table 4.3. Descriptive statistics of targeted plots

	2018-19 Season (Before intervention)					2019-20 Season (After intervention)				
	Overall	Treatment (N=35)		Control (N=35)		Overall	Treatment (N=35)		Control (N=35)	
Outcome variables		High EE	Low EE	High EE	Low EE		High EE	Low EE	High EE	Low EE
Rice yield at the target plot (kg/ha)	4795.22 (2709.06)	6810.48 (2746.44)	4002.15 (2943.98)	4888.37 (2352.64)	4732.46 (2267.16)	4727.80 (2902.51)	6408.25 (4587.69)	3915.13 (2748.60)	5347.54 (1978.53)	4557.16 (2310.72)
Urea use (0/1)	0.17	0.40	0.12	0.33	0.04	0.61	0.70	0.48	0.92	0.57
Urea application rate (kg/ha)	30.69 (90.11)	49.90 (73.30)	24.87 (74.13)	37.99 (74.89)	24.84 (119.15)	60.99 (103.66)	117.94 (111.50)	31.63 (57.41)	78.02 (34.76)	59.26 (147.65)
Nitrogen use (0/1)	0.20	0.50	0.12	0.42	0.04	0.60	0.70	0.48	0.92	0.60
Nitrogen application rate (kg/ha)	16.21 (44.96)	33.19 (48.94)	12.44 (38.33)	19.05 (34.00)	11.43 (54.81)	32.71 (58.64)	86.76 (93.19)	14.59 (26.40)	37.86 (17.66)	26.23 (67.50)
Manure use (0/1)	0.31	0.60	0.20	0.42	0.26	0.36	0.50	0.28	0.67	0.36
Observations	70	10 [28.6%]	25 [71.4%]	12 [34.3%]	23 [65.7%]	70	10 [28.6%]	25 [71.4%]	12 [34.3%]	23 [65.7%]

Source) Surveys by authors
Notes) standard deviations are in parentheses.

Table 4.4. Urea adoption in the target plot by assignment status

	Adopt	Not Adopt	Total	%	Fisher's exact test
Treatment (Low EE)	12	13	25	48.0	
Treatment (High EE)	7	3	10	70.0	p = 0.243
Control	24	11	35	68.6	
Total	43	27	70	61.4	

Notes:

Table 4.5 Impact of treatment on outcome variables at targeted plots

	(1) Urea quantity (0/1)	(2) Urea quantity (kg/ha)	(3) Nitrogen use (0/1)	(4) Nitrogen quantity*1 (kg/ha)	(5) Manure use (0/1)	(6) Purchase of fertilizer (0/1)	(7) Rice yield (kg/ha)
Treatment (High EE)	-0.24	40.81	-0.23	41.02	-0.22	0.03	160.38
	(0.15)	(41.73)	(0.15)	(17.77)**	(0.10) **	(0.13)	(884.27)
Treatment (Low EE)	-0.12	-17.34	-0.11	-13.99	-0.08	-0.21	-756.16
	(0.07)*	(13.83)	(0.06)*	(11.63)	(0.05)	(0.08) *	(344.63)
Urea use in the last season (0/1)	0.24						
	(0.21)						
Urea quantity in the last season (kg/ha)		0.49					
		(0.26)					
Nitrogen use in the last season (0/1)			0.09			0.13	
			(0.13)			(0.06)	
Nitrogen*1 quantity in the last season (kg/ha)				0.88			
				(0.35)			
Manure use in the last season (0/1)					-0.19		
					(0.26)		
Yield in the last season (kg/ha)							0.52
							(0.15) ***
Plot size (ha)	0.25	39.40	0.18	14.84	2.81	1.45	-10272.37
	(0.90)	(86.62)	(0.91)	(39.62)	(1.01) **	(0.73)**	(4609.47)**
Square of plot size	-0.62	-23.14	-0.56	0.53	-2.21	-0.95	7079.70
	(0.63)	(59.70)	(0.65)	(23.53)	(0.90)	(0.58)**	(3610.57)
The number of household member (number)	-0.01	-0.52	-0.01	0.75	-0.05	0.03	99.11
	(0.04)	(2.13)	(0.04)	(1.90)	(0.02) **	(0.02)	(106.10)
Age of household head (years old)	< 0.01	-0.21	< 0.01	-0.28	-0.01	-0.01	32.18
	(<0.01)	(0.43)	(<0.01)	(0.24)	(0.01) **	(< 0.01) *	(14.55) *
Sex of household head (0/1)	-0.01	-50.47	-0.04	-18.31	0.31	0.18	-1289.30
	(0.18)	(53.77)	(0.17)	(18.76)	(0.20)	(0.17)	(1813.48)
Years of education of household head	-0.01	0.31	-0.01	-0.40	-0.03	< 0.01	30.05
	(0.02)	(1.57)	(0.02)	(1.13)	(0.02)	(0.01)	(79.76)
Log of household asset value	0.37	92.01	0.28	69.12	-0.36	0.35	4551.56
	(0.57)	(56.73)	(0.54)	(53.20)	(0.33)	(0.37)	(2721.93)*
Risk preference (0 to 10)	-0.02	0.41	-0.02	1.40	-0.02	0.02	90.08
	(0.03)	(2.34)	(0.03)	(1.36)	(0.03)	(0.01) *	(127.63)
Village dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-0.02	-132.55	-0.56	-148.43	2.58	-0.75	-9450.84
	(1.54)	(154.44)	(1.12)	(153.86)	(0.79)	(0.85)	(5888.85)
Adj.R-Square	0.189	0.507	0.167	0.590	0.414	0.416	0.447
Observations	70	67	70	67	67	67	67

Note) *1 Amount of nitrogen is imputed amount from any type of fertilizer products that contain nitrogen in its composition. For imputation, urea (N46-P0-K0) and NPK (N11-P22-K16) were used. *2 The number of observations is different in (1) and (3) from other columns. This is because 3 observations were excluded in all but (1) and (3) as rice was not planted in the season of 2019-20 or only very small portion of the plot was used in these 3 observations. Not planting rice or only a little of planting rice can be considered as a form of decision of not using urea provided from us, and thus these 3 observations were included in (1) and (3). However, the rest the outcome variables should be considered as decisions related to rice cultivation, thus these 3 observation were excluded. Cluster robust standard errors before wild-bootstrapping are in parentheses. ***, ** and * indicate p<0.01, p<0.05 and p<0.1after wild bootstrapping.

Table 4.6 Impact of treatment on allocation of fertilizer within a household			
	(1) Urea quantity (kg/ha)	(2) Nitrogen quantity*1 (kg/ha)	(3) Rice yield (kg/ha)
Treatment variables			
Treatment (High EE) (0/1)	43.79 (19.09)**	53.42 (29.65) *	948.75 (474.35)**
Treatment (Low EE) (0/1)	15.26 (12.30)	7.23 (5.68)	115.70 (374.95)
Control (High EE) (0/1)	0.05 (24.17)	1.27 (10.92)	-538.95 (780.48)
Control (Low EE) (0/1)	38.89 (35.16)	16.07 (16.49)	765.99 (507.63)
Plot level covariates			
Plot size (ha)	-0.01 (<0.01)***	-0.01 (<0.01)***	-0.95 (0.26) ***
Square of plot size	<0.01 (<0.01)**	<0.01 (<0.01)***	<0.01 (<0.01)***
Upland rice plot (0/1)	28.50 (11.04)**	15.34 (5.21) ***	-759.86 (451.40)*
Household Fixed Effect	Yes	Yes	Yes
Overall R-square	0.057	0.106	0.315
Within R-square	0.079	0.120	0.189
Between R-square	0.023	0.136	0.409
rho	0.45	0.50	0.45
Observations	207	207	207
Number of groups	60	60	60

Note)

*1 Amount of nitrogen is imputed amount from any type of fertilizer products that contain nitrogen in its composition. For imputation, urea (N46-P0-K0) and NPK (N11-P22-K16) were used as major compositions of nutrients of each fertilizer products based on our field observations.

*2 The number of groups are 60 which is different from the total number of participating households because 10 households had only one rice plot. To compare outcome variables in target plots with non-target plots within a household, these 10 households were excluded.

Cluster robust standard errors are in parentheses. ***, ** and * indicate p<0.01, p<0.05 and p<0.01.

Table 4.7 Impact of intervention on household level variables

	(1) Rice yield at household level (kg/ha)	(2) Urea application rate at household level (kg/ha)	(3) Nitrogen*1 application rate at household level (kg/ha)	(4) Crop income per capita (10^3MGA)	(5) Consumption per capita in 3 months (10^3MGA)
Treatment variables					
Treatment (High EE)	545.29 (338.25)	6.54 (11.15)	20.84 (2.97)**	-66.05 (32.72)	-13.58 (149.33)
Treatment (Low EE)	-85.40 (221.00)	-6.69 (7.47)	-4.58 (6.41)	-33.59 (37.25)	-125.23 (60.74)
Other control variables					
Yield of target plot in the previous year	0.38 (0.05)***				
Urea application in target plot in the previous year		0.13 (0.13)			
Nitrogen application in target plot in the previous year			0.29 (0.25)		
Total size of rice plot	-4281.14 (1541.04)**	-31.95 (18.75)	-15.41 (10.65)	121.60 (128.88)	-503.40 (222.93)
Square of total size of rice plot	1064.22 (410.21)*	7.49 (4.27)	3.81 (2.58)	-15.57 (36.18)	192.56 (68.67)
The number of household member (number)	154.05(128.11)	2.28 (1.66)*	1.35 (1.48)	-13.98 (10.38)	11.17 (30.06)
Age of household head (years old)	27.43 (20.17)	-0.29 (0.38)	-0.32 (0.27)	1.70 (1.61)	4.81 (6.36)
Sex of household head (0/1)	-177.12 (1769.20)	-14.15 (15.03)	-3.67 (6.27)	76.67 (28.35)*	64.10 (132.71)
Years of education of household head	80.58 (96.31)	1.20 (1.17)	0.52 (0.79)	0.13 (6.63)	-5.23 (14.86)
Log of household asset value	3221.17 (2523.62)	65.21 (32.33)**	51.69 (33.63)*	460.48 (172.14)**	-71.05 (580.09)
Risk preference (0 to 10)	56.15(106.13)	0.35 (1.25)	0.59 (0.80)	-1.89 (9.27)	-2.17 (18.78)
Village dummy	Yes	Yes	Yes	Yes	Yes
Constant	-6168.03	-79.97	-95.38	-1118.02	359.78
Adj. R-Square	0.551	0.521	0.437	0.174	-0.174
Observations	70	70	70	70	70

Notes) Amount of nitrogen is imputed amount from any type of fertilizer products that contain nitrogen in its composition. For imputation, urea (N46-P0-K0) and NPK (N11-P22-K16) were used as major compositions of nutrients of each fertilizer products based on our field observations. Cluster robust standard errors are in parentheses. ***, ** and * indicate p<0.01, p<0.05 and p<0.1after wild bootstrapping

Appendix of Chapter 4

Table A4.1. Results of t-test for each variable

Variables	Unit	Control	Treatment	Pr(T > t)
Expected effectiveness (=1 if High)	%	34.29	28.57	0.613
Household size	people	5.29	5.14	0.746
Sex of household head (=1 if male)	%	94.29	91.43	0.648
Age of household head	years old	46.03	47.11	0.711
Years of education of household head	years	6.31	5.69	0.416
Total size of rice plots	hectare	0.39	0.58	0.190
The number of rice plots	number	3.54	3.43	0.761
Size of targeted rice plot	Ha	12.50	17.49	0.172
Value of asset per capita	10^3 MGA	1315.04	1614.19	0.545
Risk preference (from 1 to 10)	score	5.26	5.80	0.404
Rice yield at farm level (weighted)	kg/ha	4404.57	4439.50	0.958
Crop income per capita	10^3 MGA	172.37	162.05	0.820
Per capita consumption in 3 months	MGA	282.19	211.790	0.437
Rice yield at the target plot	kg/ha	4828.14	4268.09	0.381
Nitrogen use in the previous year(0/1)	%	17.14	22.86	0.557
Nitrogen application rate	kg/ha	14.04	18.37	0.690
Urea use in the previous year (0/1)	%	14.29	20.00	0.533
Urea application rate in the previous year	kg/ha	29.35	32.03	0.902
Manure use (0/1)	%	31.43	31.43	1.000
Observations		35	35	

Source: Authors calculation from the dataset.

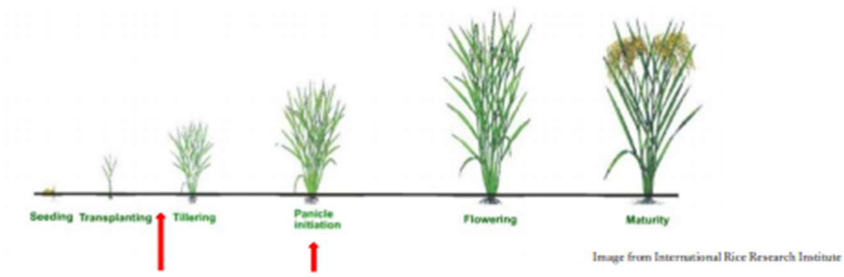
Figure A4.1. The instruction paper distributed to all participants

UREA DISTRIBUTION GUIDANCE

What is recommended area for UREA application?

For

When do we apply UREA?



<As basal fertilizer>	<As top-dressing fertilizer>
14 - 20 days after transplanting	40 - 50 days after transplanting

I have received 5 kg of UREA. I understand that there is no restriction to the usage of this UREA. It may be used for any purpose such as applying any crops, selling or giving to anyone, keeping, etc. I understand that FYVARY team will come again and I accept to cooperate for their survey. I will promise to answer all the question, including the usage of the UREA given today. I understand that I must pay 25,000Ar in case I fail to do it.

Signature	Date
	/ November / 2019

Figure A4.2 An example of information provided to the control group

List of plots with Phosphorus in MORAFENO			
Name	Plot	Dry season	Area
[redacted]	L.1.1(1)	Carrot	6.8 Ares
[redacted]	L.5.1(1)	Rice	15 Ares
[redacted]	L.2.1(1)	Fallow	18.7 Ares
[redacted]	L.7.1(1)	Onion	11.4 Ares
[redacted]	L.1.1(1)	Green Bean / Rice	7.1 Ares
[redacted]	L.1.1(1)	Carrot	6.2 Ares
[redacted]	L.1.1(1)	Onion	6.3 Ares
[redacted]	L.1.1(1)	Rice	0.7 Ares

Figure A4.3 An example of information provided to the treatment group

List of plots with Phosphorus in AMPOTAKA AFOVOANY					
UREA is effective when the amount of Phosphorus in the soil is above 100 mg/k g. Please note that UREA application may not be effective if the amount of Phosphorus is less than 100 mg/kg.					
Name	Plot	Dry season	Area	The amount of Phosphorus (mg/kg)	Expected effectiveness
[redacted]	L.1.1(3)	Vegetable	0.6 Ares	184.22	High
[redacted]	L.1.1(1)	Carotte	5.3 Ares	137.38	High
[redacted]	L.1.1	Fallow	14.9 Ares	116.71	High
[redacted]	L.1.1(2)	Tomato	0.6 Ares	101.34	High
[redacted]	L.2.1(2)	Fallow	13.3 Ares	84.64	Low
[redacted]	L.1.1(4)	Green bean	4.5 Ares	83.81	Low
[redacted]	L.1.1(1)	Fallow	23 Ares	63.39	Low
[redacted]	L.1.1	Fallow	28.2 Ares	56.55	Low
[redacted]	L.1.1	Fallow	5 Ares	55.08	Low
[redacted]	L.1.1(3)	Vary aloha	1.6 Are	54.22	Low
[redacted]	L.1.1(1)	Fallow	31.2 Ares	46.23	Low
[redacted]	L.1.1(1)	Fallow	29.2 Ares	40.79	Low
[redacted]	L.1.1(2)	Onion	3.2 Ares	39.80	Low
[redacted]	L.1.1	Fallow	20.3 Ares	26.69	Low
[redacted]	L.1.1(2)	Vary aloha	0.6 Ares	23.48	Low

Table A4.2 The usage of the free urea

	All participants
All 5kg of urea was used for crop production	67 (95.71%)
Lowland rice plots only	30 (42.86%)
Partly sold, given, or kept	3 (4.29%)
Observations	70

Source) Authors
Note) The value of the fifth row for participants without upland rice plots is not zero because some of them had grown upland rice but not the season of this experiment.

Table A4.3 Timing of Application of urea

	Number of plots	Percentage
Applied it to the nursery bed	2	4.35
1-2 weeks after transplanting	3	6.52
3-4 weeks after transplanting	23	50.00
5-6 weeks after transplanting	8	17.39
7-8 weeks after transplanting	4	8.70
9-10 weeks after transplanting	6	13.04
Total	46	100

Notes) Only urea provided for free as a part of common input was summarized. This includes cases of application in both target plot and non-target plot.

Table A4.4 Timing of Application of urea

	Total	Lowlands	Uplands
Applied it to the nursery bed	2 (2.82%)	2 (4.35%)	0
Mixed with seeds	8 (11.27%)	0	8 (32.00%)
Mixed with soil	1 (1.41%)	1 (2.17%)	0
Put on the hole with seeds	3 (4.23%)	0	3 (12.00%)
Put along the seeds without soil covering	1 (1.41%)	0	1 (4.00%)
Broadcasting	56 (78.87%)	43 (93.48%)	13 (52.00%)
Observations	71	46	25

Notes) Only urea provided for free as a part of common input was summarized. This includes cases of application in both target plot and non-target plot. The total observation exceeds 70 because this counts the number of plots where urea was applied. There was a household who apply some part of urea to a lowland plot and another part to a upland plot.

Figure A4.4. The number of non-targeted plots where urea was used by crops.

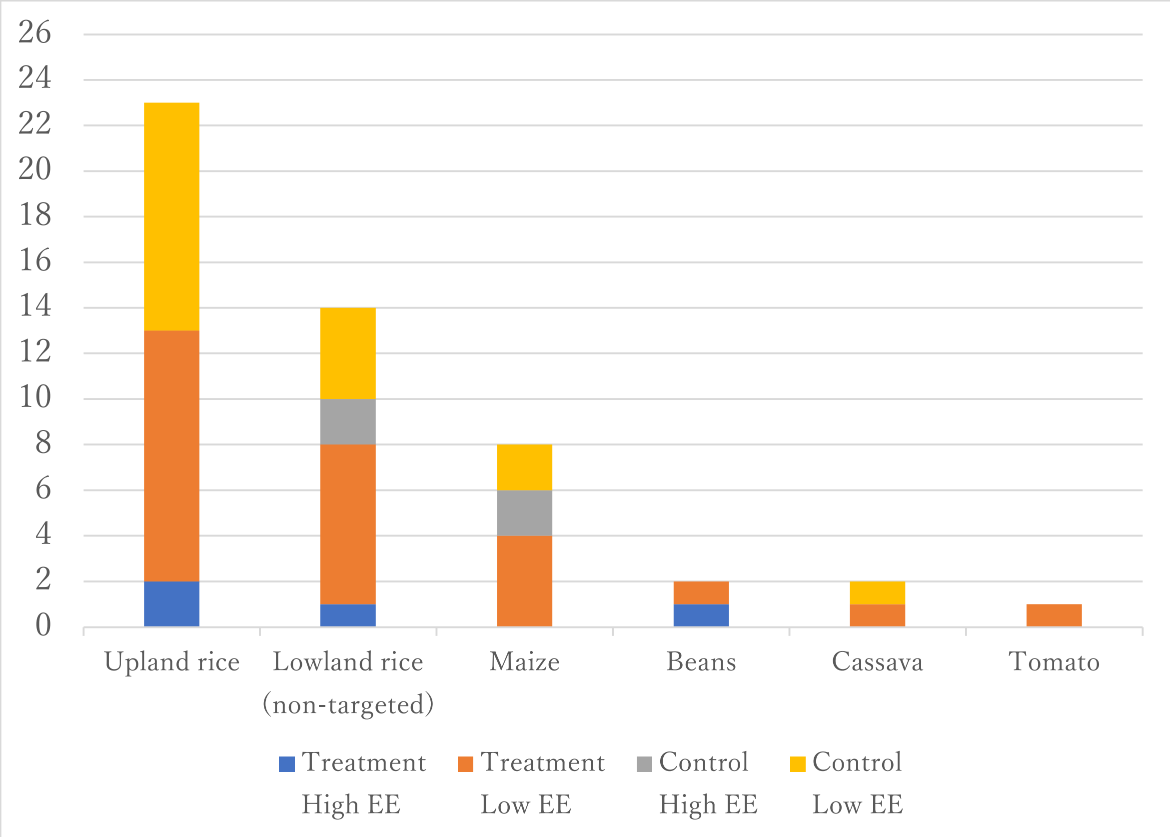


Table A4.5. Cost and Benefit of the intervention

Cost			Benefit	
Items	Rates	Unit cost*1 (MGA)	Description	Value
Soil sampling	3-4 plots / day	20000	Increase in yield of target plot*2 (kg/ha)	948.75
Lab examination	70 samples / day	1000	Farm-gate price*3 (MGA/kg)	803
Revisiting	10 HHs/day	7000	Average plot size (ha)	0.15
Urea	1800 MGA*5kg	9000		
Total cost(MGA)		37000	Total benefit (MGA)	114307
Total cost*2 (US$)		10.22	Total benefit*4 (US$)	31.60

Source) Author's experience

*1 Unit cost is the cost for one plot.

*2 This value is from Table 4.6. The coefficient of the high EE information on rice yield.

*3 This value was obtained from dataset for this study.

*4 Exchange rate of 3618.32 was obtained from the World Bank website (https://data.worldbank.org/indicator/PA.NUS.FCRF?locations=MG&view=chart.)

Table A4.6 Additional regression results using new variables related to plot size

	(1)	(2)	(3)	(4)	(5)
	Urea quantity (0/1)	Urea quantity (kg/ha)	Nitrogen use (0/1)	Nitrogen quantity[*1] (kg/ha)	Purchase of fertilizer (0/1)
Treatment (High EE)	-0.24 (0.21)	42.26 (43.66)	-0.32 (0.24)	58.61 (24.34)	-0.04 (0.27)
Treatment (Low EE)	-0.17 (0.16)*	1.70 (44.26)	-0.23 (0.17)*	-25.75 (32.53)	-0.58 (0.35)
Urea use in the last season (0/1)	0.24 (0.22)				
Urea quantity in the last season (kg/ha)		0.52 (0.13)			
Nitrogen use in the last season (0/1)			0.09 (0.13)		0.09 (0.08)
Nitrogen[*1] quantity in the last season (kg/ha)				0.87 (0.36)**	
Plot size is over 0.05ha (0/1)	<|0.00| (0.26)	22.73 (38.85)	-0.10 (0.23)	4.25 (28.79)	-0.14 (0.24)
plot size over 0.05ha x treatment (High EE)	-0.01 (0.29)	11.34 (49.71)	0.07 (0.28)	-30.81 (34.94)	0.00 (0.23)
plot size over 0.05ha x treatment (Low EE)	0.03 (0.19)	-18.15 (46.28)	0.10 (0.20)	15.89 (30.65)	0.47 (0.36)
Household level variables	Yes	Yes	Yes	Yes	Yes
Village dummy	Yes	Yes	Yes	Yes	Yes
Constant	<0.13 (1.52)	-155.35 (176.80)	0.38 (1.45)	-138.75 (135.82)	-0.55 (0.99)
Adj.R-Square	0.163	0.507	0.109	0.604	0.414
Observations	70	67	70	67	67

Note) [*1] Amount of nitrogen is imputed amount from any type of fertilizer products that contain nitrogen in its composition. For imputation, urea (N46-P0-K0) and NPK (N11-P22-K16) were used. [*2] The number of observations is different in (1) and (3) from other columns. This is because 3 observations were excluded in all but (1) and (3) as rice was not planted in the season of 2019-20 or only very small portion of the plot was used in these 3 observations. Not planting rice or only a little of planting rice can be considered as a form of decision of not using urea provided from us, and thus these 3 observations were included in (1) and (3). However, the rest the outcome variables should be considered as decisions related to rice cultivation, thus these 3 observation were excluded. Cluster robust standard errors before wild-bootstrapping are in parentheses. ***, ** and * indicate p<0.01, p<0.05 and p<0.1after wild bootstrapping.

5 CONCLUSION

Growth of agricultural productivity is expected to be an engine of rural development and poverty reduction in rural areas of SSA countries where poverty concentrates at present. Madagascar has one of the highest poverty headcount ratios in the world. Productivity enhancement of rice cultivation plays substantial influence on welfare of rural farmers. This dissertation attempted to give help better understanding about decision-making of farmers regarding rice technology adoption. What three chapters from chapter 2 to 4 consistently elicited was the farmers' active behavior to increase rice production.

This dissertation has three-fold contributions to literature. First, the discussion in chapter 2 on comparative profitability of chemical fertilizer application across lowland and upland plots contributes to literature by providing new evidence of intra-farm allocation of chemical fertilizer. In literature, adoption decisions are typically discussed in terms of whether or not to use and how much to use on a certain plot. By comparing marginal products of chemical fertilizer in two different type of plots both of which produce rice, the analysis showed that marginal products of chemical fertilizer are higher in upland rice plots than in lowland rice plots. Thereby, the seemingly irrational allocation of fertilizer between lowland rice and upland rice was at least understandable. Second, Chapter 3 contributes to the literature on dissemination of upland rice. Rice is the most promising crop for green revolution in SSA and upland rice varieties has been promoted as a new cash crop mainly to areas where lowland rice cultivation is not common or environmentally not feasible. (Otsuka and Larson, 2013) The chapter 3 explores determinants of upland rice cultivation among lowland rice growers and examine its role on households' welfare. Finally, the chapter 4 present a novel experimental design to examine the role of simple binary information about expected fertilizer effectiveness that is defined based on soil characteristics. Whereas literature dealing with relevant topic provides information of necessary amount of fertilizer to meet the nutritious requirement, this experiment provided a simple binary information of whether nitrogen fertilizer is expected to be effective or not. By this way, the intervention aimed to help farmers optimize the fertilizer allocation in two ways: increase application when the plot has High-EE and saving the fertilizer from using in plots of Low-EE. Both types of information were properly utilized on average.

Despite of some limitations of analyses in each chapter, these findings provide meaningful insights for agricultural policy in SSA. The important policy implication derived from a set of findings on chemical fertilizer use suggests that in Madagascar, improvement in financial and physical accessibilities to input market may not be enough to encourage farmers to use it for lowland rice cultivation. In addition to the conventional discussion about high input price as the major constraints of adoption of chemical fertilizer in Madagascar, development of rice varieties and innovative practices that enhances crop yield response, especially in lowlands, is vital. For example, agronomic research by Rakotoson et al. (2021) provides evidence that micro-dosing of NPK fertilizer on seedling nursery enhances the plant's nitrogen use efficiency after transplanting.

The combination of the conclusions in Chapter 2 and Chapter 4 suggests us working more on providing farmers with information about some factors used to be not available to them. Soil property was a good example. The recent developments of Internet, remote-sensing, machine learning, and other emerging digital technologies has been reducing the cost of information. Our experiment in chapter 4 gets along with the concept of the precision agriculture. Precision agriculture is a data-driven farm management approach which enable farmers to improve production efficiency. Precision agriculture utilize information related to several "R"s to improve farm management, namely the Right time, the Right amount, the Right place, the Right source, and the Right manner (Khosla, 2010). A similar example that has already been started in SSA is "Rice advise", an innovative digital support tool developed by Africa rice. It aims to remotely assist farmers by providing farm-specific advice of rice cultivation in SSA (Arouna et al. 2020). . Since farmers in developing countries have been making important decisions with facing lots of uncertainty, information based on the deep analysis of the local context may greatly help farmers increase their productivity.

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