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Profitability of Chemical Fertilizer Application: Comparison of Lowland and Upland Rice Cultivation in Madagascar

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This paper examines whether chemical fertilizer application in rice fields is profitable in the central highland of Madagascar where both lowland rice and upland rice are cultivated. The analyses reveal: (i) upland rice plots are more likely to receive chemical fertilizer; (ii) the impact of nitrogen application on yield is larger on upland rice plots than on lowland rice plots; and (iii) nitrogen application is profitable only when nitrogen is in the form of urea and applied to upland rice plots. We conclude that technological development to improve yield response to chemical fertilizer in lowland rice plots should be promoted.

Key words: chemical fertilizer, profitability, upland rice

1. Introduction

In developing countries, chemical fertilizer use is recommended to boost agricultural productivity that is widely recognized as the key to rural poverty reduction. However, the adoption rate and the extent of its application are limited in sub-Saharan Africa (SSA) compared to other parts of the world. Morris et al. (2007) describe that profitability is the first and most obvious factor that explains the low adoption rate of chemical fertilizer in SSA. However, except for a few empirical studies such as Liverpool-Tasie *et al*. (2017) and Sheahan *et al*. (2013) that examine the profitability of chemical fertilizer application to maize cultivation in Nigeria and Kenya respectively, there is scant evidence that farmers rationally adjust their practice depending on the low and heterogeneous profitability of chemical fertilizer application.

We choose our study site in Madagascar, where the application of chemical fertilizer remains at the lowest level in the world (Sharma and Razafimanantsoa, 2016). Because rice is the single dominant food crop as well as the main income source for rural farm households in Madagascar, our study focuses on rice.

Rice is traditionally grown in lowland plots[1)]. Since the early 2000s, upland rice cultivation[2)] has been introduced with new varieties and rapidly diffused in some part of the country like Vakinankaratra region - one of the major rice producing regions. This is a unique situation because farmers with long experience in lowland rice cultivation have adopted upland rice cultivation[3)]. Upland rice is supplemental since lowland rice growers who simultaneously grow upland rice have larger rice production per capita and higher consumption level than those who do not (Ozaki and Sakurai, 2020)[4)].

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.

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1) 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.
2) 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.
3) 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.
4) Most farmers in study area distinguish upland rice varieties from lowland rice varieties. But no major difference is found in the usage of paddy although the data is not presented in this paper.

2. Research Questions and Hypotheses

This study first presents fertilizer use in each type of plots and see whether there is difference in adoption rate and application dose. Then, whether the difference of chemical fertilizer use, if it exists, has something to do with profitability is investigated. The hypothesis is that farmers use chemical fertilizer in the plot with the higher profitability.

3. 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 *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 expressed as follows:

$$Yield_{ijt} = f(X_{ijt}, Z_{ijt}, u_{ijt}) \quad (1)$$

$$u_{ijt} = \varepsilon_{ijt} + c_i \quad (2)$$

where $Yield_{ijt}$ is defined as rice production in kg per hectare (ha) of plot i of household j in time *t*. X_{ijt} is plot and time specific variables such as quantity of seeds, plot size, fertilizer use, animal traction use, and labor inputs. Z_{ijt} is a vector of controls that affect the yield, including plot characteristics, distance to the nearest town, and whether the household has rights to sell the plot[5]. Some household characteristics variables such as age, gender, and education of household's head are also included. The u_{ijt} is a composite error term consisting of time invariant and time varying unobserved characteristics. 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. Therefore, fixed effect model (FE model) that can cancel out the effects of time invariant factors at plot level is employed in addition to a simple pooled OLS.

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[6].

$$MPP_{ijt} = \frac{\partial Yield_{ijt}}{\partial Quantity\ of\ nitrogen} \quad (3)$$

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

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

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 the chemical fertilizer is greater than the cost of the 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).

4. Data and Descriptive Statistics

Data was collected in the following procedure. In 2017, a census survey was carried out in 60 villages in 13 communes across 3 districts of Vakinankaratra region. The number of households identified was 5253[7]. The 60 villages are almost the half of the total villages in the 13 communes. They were selected intentionally to have an even geographical distribution within each commune. Based on the census survey data, 10 households that grew lowland rice in the season of 2017-2018 were randomly selected from each village. Trained enumerators interviewed the selected households three

5) Bellemare (2013) showed in his analysis of the relationship between land rights and agricultural productivity that household's rights to lease out a plot negatively affect productivity. Since our dataset does not have information about rights to lease out a plot, we include rights to sell it to control similar effects.

6) This definition follows Liverpool-Tasie *et al*. (2017).

7) This census survey targeted all the households residing in the main hamlet of each of 60 villages.

times a year to collect detailed information about their farm activities with a focus on rice cultivation. This study constructs a 2-year panel dataset using the plot-level information about 2017-2018 and 2018-2019 rainy season activities. The following analysis uses data of those plots appearing in both seasons.

Table 1. Fertilizer use by plot type

	Lowland rice plots	Upland rice plots	Total
No fertilizer	1,301 (74.94%)	78 (14.80%)	1,379 (60.94%)
Organic fertilizer only	348 (20.05%)	254 (48.20%)	602 (26.60%)
Chemical fertilizer only	19 (1.09%)	102 (19.35%)	121 (5.35%)
Both organic and chemical fertilizer	68 (3.92%)	93 (17.65%)	161 (7.11%)
Total	1,736	527	2,263

Among the total of 2,263 rice plots, 1,736 are lowland rice plots and 527 are upland rice plots. Due to the nature of sampling, all the farmers have lowland rice plots, but not all of them have upland rice plots. Table 1 shows that fertilizer application is not common in general: More than 60% of the rice plots did not receive any fertilizer. The percentage of plots that received chemical fertilizer is only 12.5%, including plots receiving chemical fertilizer only and plots receiving both organic and chemical fertilizer. However, differences are observed. While 75% of the lowland rice plots received no fertilizer, it is only 15% for upland rice plots. Only 5 % of the lowland rice plots received chemical fertilizer, while 37% of the upland rice plots did it.

5. Results

Table 2 presents descriptive statistics at plot level[8]. Comparing lowland rice plots with upland rice plots, the yield without chemical fertilizer is higher by more than 1 ton per ha in the former than in the latter, and the gap becomes bigger if chemical fertilizer is applied. Although chemical fertilizer is less frequently used in lowland rice plots, when it is used the dose is higher in lowland rice plots than in upland rice plots; the average amount is 36.67 kg per ha and 12.55 kg per ha, respectively[9]. Then, we compare plots receiving chemical fertilizer with those not receiving it. First, regardless of the plot location, the probability of hired labor use, the amount of organic fertilizer application, the proximity (the invers of distance) of homestead to the nearest town, and the years in education of household's head are higher in plots with chemical fertilizer. On the one hand, the use of commercial seeds[10], the number of adult members, and the altitude of homestead location are significantly different only for lowland rice plots. On the other hand, seed amount applied, experience of weather-related shock, and the rights to sell the plot are significantly different only for upland rice plots.

Table 3 shows the result of production function estimates. The dependent variable is the yield in kg per ha. Neither the pooled OLS model 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 relatively higher in upland rice plots than in lowland rice plots. This underpins the situation that the probability of receiving chemical fertilizer is higher in upland rice plots than in lowland rice plots. Additionally, plot size has a negative association with yield and its quadratic term shows that there is U-shape relationship between yield and plot size.

Column 3 shows the result of OLS regression using only 2018-2019 season data to see the marginal impact of 1 kg of nitrogen on yield[11]. Using the quantity of nitrogen and organic fertilizer applied to plots, the results show the same signs and similar significance levels with previously tested models. 1 kg of nitrogen produces more in upland rice plots than in lowland rice plots by an additional 25.79 kg per ha.

8) 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.

9) 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.

10) "Commercial seeds" mean that the farmer used seeds purchased from seed companies, input suppliers, and general stores in the seasons surveyed (i.e., not recycled).

11) For this part, we used observations of only from 2018-2019 season because the quantity of chemical fertilizer in upland rice plots in 2017-2018 season is not available in our dataset.

Table 2. Descriptive statistics

		Lowland (N=1,698)			Upland (N=505)			TOTAL (N=2203)
Chemical fertilizer application		Yes	No		Yes	No		
	Unit	(1)	(2)		(3)	(4)		(5)
Production	Kg/Ha	5,162.67	3,869.56	***	2,760.89	1,876.28	***	3,494.62
		(3,005.13)	(2,702.75)		(2,815.10)	(1,968.09)		(2,729.50)
Nitrogen applied	Kg/Ha	36.67	0	***	12.55	0	***	23.46
		(45.49)	(0)		(26.95)	(0)		(38.24)
Organic fertilizer applied	Kg/Ha	10,305.23	1,649.04	***	7,992.25	3,932.00	***	7,934.62
		(13,772.38)	(5,069.47)		(9,686.92)	(8,768.55)		(10,083.21)
Seed amount	Kg/Ha	151.07	135.41		121.47	100.00	*	128.76
		(109.83)	(96.75)		(110.11)	(99.01)		(99.22)
Commercial seeds (0/1)	Yes = 1	0.14	0.04	***	0.05	0.09		0.05
		(0.34)	(0.20)		(0.29)	(0.22)		(0.23)
The number of adults in HH	Number	2.92	3.20	*	3.30	3.18		3.20
		(1.11)	(1.40)		(1.23)	(1.35)		(1.38)
Hired labor use (0/1)	Yes = 1	0.99	0.93	*	0.91	0.81	**	0.91
		(0.12)	(0.25)		(0.28)	(0.40)		(0.28)
Plot size	Ares	10.69	18.02	***	22.06	22.52		18.79
		(9.12)	(17.43)		(20.35)	(19.02)		(17.81)
Distance from homestead	Minutes	24.43	30.68		26.52	26.99		29.61
		(24.17)	(34.16)		(29.77)	(27.95)		(32.65)
Weather-related shock (0/1)	Yes = 1	0.34	0.34		0.22	0.33	**	0.34
		(0.48)	(0.47)		(0.42)	(0.47)		(0.47)
Non weather-related shock (0/1)	Yes = 1	0.26	0.18		0.32	0.34		0.23
		(0.40)	(0.44)		(0.47)	(0.47)		(0.42)
Animal traction use (0/1)	Yes = 1	0.32	0.65	***	0.70	0.73		0.66
		(0.47)	(0.48)		(0.46)	(0.44)		(0.47)
HH has a right to sell this land	Yes = 1	0.30	0.32		0.18	0.30	**	0.31
		(0.46)	(0.47)		(0.38)	(0.46)		(0.46)
Asset value per person	10^3MGA	451.95	461.79		488.24	396.38		407.93
		(569.97)	(618.00)		(632.04)	(499.03)		(419.43)
Sex of HH's head (0/1)	Male = 1	0.92	0.91		0.90	0.92		0.91
		(0.27)	(0.28)		(0.29)	(0.28)		(0.28)
Age of HH’s head	Years old	47.34	47.32		45.82	46.56		47.13
		(12.04)	(13.41)		(11.96)	(13.65)		(13.35)
Education of HH’s head	Years	7.73	5.56	***	6.23	5.13	***	5.59
		(4.35)	(3.70)		(3.84)	(3.54)		(3.73)
Size of HH	Number	4.61	5.04	*	5.45	5.04	*	5.04
		(1.53)	(2.01)		(1.86)	(1.85)		(1.97)
Altitude of homestead	Meters	1477.51	1250.86	***	1234.61	1209.54		1250.13
		(147.12)	(244.66)		(281.15)	(212.69)		(242.26)
Distance to the nearest town	Km	6.08	13.47	***	10.27	15.67	***	13.49
		(5.09)	(9.71)		(7.74)	(10.29)		(9.79)
Observations		74	1,624		96	409		2203

Source: Authors’ calculation from our survey data.

Note: Standard deviations are in the parentheses. *, **, and *** indicate that the means are different at the significance level of 10%, 5%, and 1%, respectively. HH stands for household. MGA is local currency, standing for Madagascar Ariary.

Table 3. Production function estimates

	Unit	Pooled OLS (1)		Fixed effect (2)		OLS (3)	
Nitrogen use (0/1)	Yes = 1	-123.13		-266.57			
2018-2019 Season	Yes = 1	-459.22	***	-200.18			
Quantity of nitrogen applied	Kg/Ha					-0.37	
Upland rice plot	Yes = 1	-1494.68	***			-1843.12	***
Upland rice plot x Season				212.66			
Upland rice plot x Nitrogen use		407.23		599.92	*		
Upland rice plot x Nitrogen quantity						25.79	***
Other inputs and time-varying factors							
Organic fertilizer use (0/1)	Yes = 1	-110.18		80.36			
Quantity of organic fertilizer applied	Kg/Ha					0.04	***
Upland rice plot x Organic fertilizer use		397.27	**	-79.93			
Upland rice plot x Organic fertilizer quantity						0.02	
Seed amount	Kg/Ha	8.18	***	3.43	*	5.27	**
Seed amount squared		0.01		0.003		0.01	
Commercial seed (0/1)	Yes = 1	242.74		-99.73		396.73	
The number of adults in HH	Number	121.44	**	107.82		94.48	
Hired labor use (0/1)	Yes = 1	682.70	***	420.38	***	752.79	***
Animal traction use (0/1)	Yes = 1	-47.97		227.73	*	0.00	
Plot size	Ares	-88.01	***	-287.77	***	-97.41	***
Plot size squared		0.59	***	0.65	***	0.61	***
Upland rice x Plot size		7.08		204.32	***	17.41	*
Weather related shock (0/1)	Yes = 1	-669.50	***	-542.79	***	-749.62	***
Non-weather-related damage (0/1)	Yes = 1	-764.91	***	-496.19	***	-845.14	
Plot level covariates		YES		YES		YES	
Household covariates		YES		YES		YES	
Commune dummy		YES		YES		YES	
Plot fixed effect		NO		YES		NO	
Constant		5771.71	***	4671.59	***	2983.05	***
Observations		2203		2203		1098	
R-squared		0.551		0.117		0.554	

Source: Authors' estimates from our survey data.

Note: *, **, and *** indicate that the means are different at the significance level of 10%, 5%, and 1%, respectively. Standard errors are clustered at village level in all specifications although they are not shown in the table due to page limitation. HH stands for household. MGA is local currency, standing for Madagascar Ariary. Household level covariates include sex of HH's head, age of HH's head, years of education of HH's head, household size, distance to the nearest town, and dummy variables for high altitude area (>1600m) and medium altitude area (1600m> the altitude > 1200m).

Table 4. Profitability analysis

	MPP	APP	MVCR_NPK	MVCR_UREA	AVCR_NPK	AVCR_UREA
Overall	5.52	16.44	0.182	0.875	0.563	2.810
Upland rice	25.417	25.411	0.844	4.049	0.871	4.348

Source: Authors' estimates from the production function.

Table 4 presents the mean of MPP, APP, MVCR, and AVCR, calculated based on the production function estimated for 2018-2019 season. Two kinds of AVCR and MVCR with different nitrogen sources are presented: one is from NPK, the other is from urea because the nitrogen content is much lower in NPK than urea (or in other words, urea is a cheaper nitrogen source). On average, 1 kg of nitrogen produced 16.44 kg in all samples and 25.41kg if it is used in upland rice plots. From AVCR, it is profitable to apply urea but not so for NPK. The MVCR exceeds 2 only when nitrogen is in the form of urea and applied to upland rice plots.

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).

6. Conclusion

Using the data from Vakinankaratra region of Madagascar, this study explores the profitability of fertilizer application in two different types of rice plot. The first finding of this paper is that the adoption rate of chemical fertilizer is higher in upland rice plots than lowland rice plots.

Using a FE model, this study finds that although yield response to nitrogen is not clear as a whole, the response varies across the two types of plot: it is higher in upland rice plots than in lowland rice plots. In this sense, observed farmers' practice is consistent with the difference in expected returns.

The profitability analysis based on MVCR and AVCR suggests that whether the nitrogen application becomes profitable depends on plot type and chemical fertilizer products. In the context of the study area, MVCR of nitrogen application reaches the recommended level only when it is in the form of urea and applied to upland rice plots.

Policy implications derived from this study are as follows. First, when farmers obtain chemical fertilizer products, information about nutrient composition will help the farmers profitably use them. Second, although this study shows the advantage of upland rice plots in terms of profitability 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[12] to agronomically improve 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.

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

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References

Bellemare, F. M. (2013) The Productivity Impacts of Formal and Informal Land Rights: Evidence from Madagascar, *Land Economics* 89(2): 272-290. https://doi.org/10.3368/le.89.2.272.

Liverpool-Tasie, L. S. O., B. T. Omonona, A. Sanou, and W. O. Ogunleye (2017) Is Increasing Inorganic Fertilizer Use for Maize Production in SSA a Profitable Proposition? Evidence from Nigeria, *Food Policy* 67: 41-51. https://doi.org/10.1016/j.foodpol.2016.09.011.

Morris. M., V. A. Kelly, R. J. Kopicki, and D. Byerlee (2007) Fertilizer Use in African Agriculture: Lessons Learned and Good Practice Guidelines, World Bank.

Ozaki, R. and T. Sakurai (2020) The Adoption of Upland Rice by Lowland Rice Farmers and Its Impacts on Their Food Security and Welfare in Madagascar, *Japanese Journal of Agricultural Economics* 22: 106-111. https://doi.org/10.18480/jjae.22.0_106.

Sharma, N. and F. Razafimanantsoa (2016) Madagascar Economic Update (English), http://documents.worldbank.org/curated/en/857891480598522366/Madagascar-economic-update (accessed on May 1, 2020).

Sheahan, M., R. Black, and T. S. Jayne (2013) Are Kenyan Farmers Under-utilizing Fertilizer? Implications for Input Intensification Strategies and Research, *Food Policy* 41:39-52. https://doi.org/10.1016/j.foodpol.2013.04.008.