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Abstract

Increasing the use of chemical fertilizer is required to realize a sustained growth of agricultural productivity in sub-Saharan Africa. In addition to various constraints related to input markets and socio-economic characteristics of farmers, previous studies have shown that uncertainty about crop yield response discourages farmers to use fertilizer. This study examines how site-specific information about soil characteristics optimizes farmers' decisions as to fertilizer allocation by reducing the yield response uncertainty. Unlike existing similar works, our unique approach is the use of simple binary information on expected effectiveness (EE) of fertilizer application based on soil chemical analysis. We tested its effect in a randomized controlled trial (RCT) conducted in Madagascar. The results revealed that the binary information regarding EE at plot level induced more optimal allocation of fertilizer among plots as information of high EE significantly increased the rates of nitrogen fertilizer application and as a result achieved higher rice yield. In addition, high EE information led to increased use of nitrogen fertilizer at household level. One important implication of this study is even simple information about plot-level soil characteristics can influence farmers and induce intensification of input use

Keywords: Rice, Chemical fertilizer, Soil property, RCT, Madagascar

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I. Introduction

It is widely recognized that sustained growth of agricultural productivity in sub-Saharan Africa (SSA) requires a substantial increase in chemical fertilizer application (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 in other parts of the world (Tsujimoto *et al.* 2019). A large body of literature has identified various factors that explain the low use of fertilizer in SSA, mainly focusing on demographic as well as market-related factors. For example, education level of the heads and other household members (Asfaw and Admassie 2004), accessibility to input and credit markets (Croppenstedt *et al*. 2003), and quality of inputs sold in the market (Bold *et al*. 2015).

In addition, recently increasing publications show that site-specific recommendations about soil characteristics can influence farmers' fertilizer application. Harou *et al*. (2022) found that plot-specific information provision together with inputs voucher significantly increased farmers' investment in mineral fertilizer and consequently productivity. Van Campenhout (2021) pointed out that farmers face two types of information deficiencies: technical information for correct implementation of modern inputs and information about the returns on technology adoption. Based on the experiment in which impacts of releasing these two types of information were compared, his study concluded that information about the expected returns had a more prominent role on farmers' productivity improvement. Regarding the former type of information deficiency, the experiment of Abey *et al*. (2022) provided evidence that there were mismatches between farmers' perceptions about types of nutrients insufficient in soils and nutrients actually in need. They concluded that site-specific information provision contributed to productivity improvement because the mismatches were even yield-reducing. Their findings are particularly relevant for smallholder farmers in SSA as their fields are known to be highly heterogeneous in soil fertility or in responses to nutrient inputs even within small distances due to the influence of topography and past management practices (Kihara *et al*. 2016; Zingore *et al.* 2011; Nishigaki *et al.* 2018). Thus, there should be no doubt that site-specific information will improve productivity. But what kind of information should be provided remains to be further investigated. The present study aims to answer this question.

Prior studies on the effect of soil information typically tried to figure out which nutrient is deficient in soils at which extent and examined whether information could close the gap between required rates and actual rates of application (for instance, Harou *et al*. (2022), Ayalew *et al*. (2022), and Abey *et al.* (2022)). However, the relationship between soil analysis information and crop response to fertilizer in field is not straightforward, which is to say that the provision of comprehensive soil characteristics do not necessarily realize effective fertilizer management (Tsujimoto *et al.* 2019). Therefore, our novelty relative to the prior studies is that we adopted much simplified information of soil characteristics and showed even such an intervention could improve farmers' fertilizer use. More specifically, we provided farmers with binary information related to the effectiveness of nitrogen fertilizer in one main plot for rice production. The plot-level effectiveness was judged by a single soil property of oxalate-extractable phosphorus (Pox, hereafter), a suitable indicator to assess phosphorus-deficiency for lowland rice fields in tropics (Rakotoson *et al.* 2022). It is well known from agronomic studies that the lack of nitrogen limits rice yield in SSA most severely (Saito *et al.* 2019; Rurinda *et al.* 2020; Tanaka *et al.* 2017). However, instead of dealing with nitrogen deficiency directly, we adopted an indicator of nitrogen fertilizer effectiveness based on Pox. This single indicator is based on the following agronomic findings in the region where our study sites are located: first, phosphorus-deficiency status greatly varied from fields to fields in the region (Kawamura *et al*. 2019; Rakotoarisoa *et al*. 2020); second, rice little responded to nitrogen fertilizer when Pox value was low because phosphorus-deficiency became a primary limiting factor for rice growth (Asai *et al*. 2020).

As for the optimization of fertilizer use, we assumed that the observed sub-optimal allocation of fertilizer among the plots occurred because farmers did not know the heterogenous distribution of phosphorus in the soil. Therefore, we considered that information about expected effectiveness (EE) of nitrogen fertilizer would reduce the uncertainty in fertilizer responses and help farmers to decide in which plot and how much they should use fertilizer, or in other word to optimize fertilizer allocation. In this regard, we hypothesize that farmers will increase the probability of adoption of nitrogen fertilizer as well as its application rates in the plots with high EE, while they will decrease such probability in the plots with low EE. Thus, our optimization about the allocation of fertilizer is different from the existing studies that consider the adjustment of fertilizer application rate to the recommended level from too high rate (for example, Islam and Beg 2021) or too low rate (for example, Ayalew *et al*. 2022). Since most of small-scale farmers in SSA cannot afford sufficient amount of fertilizer, how to allocate limited amount of fertilizer is a more practical and relevant question. To our best knowledge, this viewpoint has rarely been presented in the existing literature. We further expected that the optimized fertilizer allocation would increase rice yield in plots with high EE because farmers would use nitrogen fertilizer intensively in such plots compared to plots where EE status is low or unknown. Thus, our second hypothesis is that the provision of EE information will lead to higher rice yield and as a result better household welfare than otherwise.

The rest of this paper is organized as follows. In section 2, the experimental design is explained. Analytical framework is proposed in section 3. Section 4 presents results of analysis followed by additional analysis for robustness check in Section 5. Section 6 is conclusion.

II. Experimental design

A. Study Context

The improvement of rice productivity has long been one of the central issues in

Madagascar's national policies for poverty reduction and food security as rice is historically the main staple food crop as well as the major income source for the rural population (World Bank 2020). The study site is located in the Vakinankaratra region, which is in the central highland zone, the major rice-producing area of the country. Although rice is the most important crop in this region, majority of farmers do not use chemical fertilizer for rice production in lowland (Ozaki and Sakurai 2021).

B. Soil nutrition information

We designed an experiment to provide simple binary information about expected effectiveness (EE) of nitrogen fertilizer application. Based on the Asai *et al.* (2020)'s finding, we use the Pox value as the indicator of the effectiveness of nitrogen fertilizer. More specifically, the Pox value of 100 mg/kg was used as the base threshold (θ). However, in the villages where soil is affected by the volcano, although soil is rich in phosphorus most phosphorus exists in a form which plants have difficulty in absorbing and utilizing. In such a case, the Pox value of 300 mg/kg was employed according to a publicly available guideline for fertilizer application in Japan (MAFF 2008). If the Pox value in a plot is more than the threshold, the plot is considered to have high EE regarding nitrogen fertilizer use, and if the value is less than the threshold, the plot is considered to have low EE.

C. Sampling procedure

Five villages were selected across two districts in the region of Vakinankaratra. 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[1]. All the five villages are located along the national road that runs east and west in the middle of the region (Figure 1).

[1] The Vakinankaratra region has an asymmetric landscape: The altitude of its eastern part reaches nearly 1,800 meters above 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 practices although rice production in lowland is a common practice.

Each village has several smaller administrative units. Based on these 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[2]. Then, we randomly selected farmers who had grown rice in lowland plots in the 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 call this plot "target plot"). We visited each of these target 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 samples. All the soil samples were sent to a national laboratory to examine phosphorus amounts. Based on the result of this soil analysis, all the target plots selected were classified as either high EE or low EE.

D. Randomization

Figure 2 shows the assignment structure. The total number of participants was 70. Randomization at EA level was more suitable than at household level to avoid information spillover between households within an EA. Since two EAs in a village are geographically apart and farmers in control EAs had no information about the selection of the treated EAs, information spillover across EAs could be prevented.

After randomization, both the treatment and the control groups had 35 households. Regardless of the assignment status, we provided all participants with common inputs that consisted of free fertilizer (5 kg of urea), the size of the target plot that was obtained by GPS, and general advice regarding timings and rates of urea application[3]. Because we would like to test if farmers allocate nitrogen fertilizer based on the information about EE, we provided

[2] 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.

[3] 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.

nitrogen fertilizer free to alleviate financial constraints to buy fertilizer. As for physical access to the fertilizer market, we do not think it is a problem since all the villages are located along the national road. When distributing the common inputs, participants were explicitly informed that there is no restriction on the usage of urea from us and so they might apply it to any crop in any plot, keep it, sell it, or even give it to others. The distribution was implemented in October of 2019.

Then, when the common inputs were distributed, only farmers in the treatment group received the (additional) information that consisted of the EE status, the Pox value in the soil sample of the target plot (mg/kg), and relative ranking of the Pox value among the participants in the same EA[4]. As a result, only the treated farmers could know whether urea would be effective or not and use this information to make decisions about whether or not and how much urea to apply on the target plot. Farmers in the control group had to decide how they would use the given urea without knowing the EE status of their target plots.

III Analytical framework

A. Expected effectiveness to nitrogen fertilizer

Table 1 presents the summary of results of soil examination by EA. The Pox in soil as an index of phosphorus deficiency status was analyzed as per Schwertmann (Schwertmann 1964). The mean Pox values greatly varies across EAs from 36.1 mg/kg at EA10 to 547.5 mg/kg at EA1. Relatively high Pox values were observed at EA1, EA2, EA3, and EA4[5]. Soils of these four EAs were considered to be affected by volcanic soils, and thus, the Pox value of 300 mg/kg was applied as the threshold (θ) to judge the EE. For the remaining EAs, 100 mg/kg was used

[4] Although our main objective was to give the information of EE status, we also provided the treated farmers with the Pox value and its 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.

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

as the threshold. Applying this threshold, 8 out of 10 EAs embrace both high and low EE, implying that soil P deficiency status differs even within a village.

B. Econometric specification

Three specifications are used in the analysis. The first model is to examine the impact of intervention among the target plots by comparing the outcome variables between target plots of treated households and those of control households. Thus, this analysis used only target plot data. In our RCT setting, the impact of intervention can be obtained by simple comparisons of mean values. However, following the argument of McKenzie (2012), this study employs an ANCOVA model to improve analytical power[6].

$$Y_{ih2020} = \alpha_0 + \beta_1 T_{ih}^{high} + \beta_2 T_{ih}^{low} + \beta_3 Y_{ih2019} + \beta_4' PC_{ih} + \beta_5' HC_h + \beta_6' village + u_{ih} \dots (1)$$

where Y_{ih2020} is one of outcome variables in target plot i of household h in the rainy season of 2019-2020. Two types of outcome variables are used in this model: binary variables and continuous variables. The binary variables are those for the adoption of urea, nitrogen fertilizer, and organic fertilizer in the target plot. These variables take a value of one if the target plot received these inputs. It is important to note that these variables capture only the adoption status of the target plot. Thus, they take a value of zero as long as the target plot does not receive these inputs even when a participant used these inputs in other plots than the target plot. Nitrogen fertilizer refers to any kind of chemical fertilizer products which include nitrogen as one of its nutrients such as NPK composite-type fertilizer and urea. The continuous outcome variables include rice yield in kg/ha, application rates of urea in kg/ha, nitrogen application rates in kg/ha which is calculated from the typical nutrients composition in each type of

[6] ANCOVA stands for Analysis of Covariates. It improves analytical power especially when an outcome variable of interest has high variability and has non-zero but low autocorrelation. McKenzie (2012) gives income and consumption of households in poverty as examples for the appropriate cases of application of this model.

fertilizer product[7]. When the outcome variables are binary 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 the ANCOVA model is the inclusion of the outcome variable in the previous season, Y_{ih2019}, to control for the effects of pre-conditions of each plot. The inclusion of the lagged dependent variable enables us to interpret the effects as 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_{ih}^{high} takes 1 if a participant was assigned to the treatment group and received information that urea would be effective in the target plot of his or her household. T_{ih}^{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. Thus, we expect that β_1, the coefficient for T_{ih}^{high}, is positive, and significantly different from zero, but that β_2, the coefficient for T_{ih}^{low}, is not significantly different from zero.

In addition, plot level, household level, and village level control variables are included. 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 in education of household head, age and sex of household head, log of per-capita value of asset, and risk preference of household head[8]. These variables should be included because EE might be correlated with some observable household characteristics due to the non-random selection of target plots. Village dummy variables to control unobserved factors attributable to village characteristics

[7] 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.

[8] 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 responded to interview.

are also included as $village$. $\beta_3 - \beta_6$ are vectors of parameters to be estimated, α_0 is a constant term, and u_{ih} is the error term.

The major concern in estimating this model is the small number of EAs, which were the unit of sampling and hence standard errors must be clustered at this level. In order to deal with this problem, we employed wild cluster bootstrapping (WCB) suggested by Roodman *et al*. (2019).

The second model examines the impact of intervention within a household level by comparing the target plot with non-target plots of a household. Thus, unlike equation (1), all the rice plots cultivated by the sample households including upland rice plots were used for this analysis. The model specification is as follows.

$$Y_{ih} = \beta_1 I_{ih}^{high} + \beta_2 I_{ih}^{low} + \beta_3 NI_{ih}^{high} + \beta_4 NI_{ih}^{low} + \beta_5 size_{ih} + \beta_6 size\_sq_{ih} + \beta_7 uprice_{ih} + HHFE_h + u_{ih} \quad \ldots (2)$$

where Y_{ih} is one of outcome variables in a plot i of a participating household h. The outcome variables include the quantity of urea, that of nitrogen, and rice yield. The units of these variables are the same as specification (1). All the plots are classified as either target plot or non-target plot. The target plots are further classified into four categories by expected effectiveness (EE) of nitrogen fertilizer and treatment status: namely target plots with high EE of treated households, target plots with low EE of treated households, target plots with high EE of control households, and target plots with low EE of control households. The corresponding binary dummy variables are denoted as $I_{ih}^{high}, I_{ih}^{low}, NI_{ih}^{high}$, and NI_{ih}^{low}. Note that in the case of treated households, the information about EE was provided to the households before planting rice, while in the case of control households, such information was not provided although the soil was sampled and the Pox value was obtained in the laboratory. Thus, these four dummy variables in equation (2) capture all the possible patterns of assignment status for target plots, setting non-target plots as the reference category. In this specification, β_1, β_2, β_3, and $\beta_4$are the parameters of interest. Each parameter indicates whether and how each type of assignment status has an effect on the outcome variables in comparison with non-target plots in the same household. In general, we expect that β_1 is positive and significantly different from zero, while β_2 is negative and significantly different from zero. But β_3 and $\beta_4$are not significantly different from zero.

Plot level control variables are also included. $size_{ih}$and $size\_sq_{ih}$ are plot size in ha and its squared value of plot i of a household h, and $uprice_{ih}$ is a dummy variable which takes a value of one if a plot is a rice plot in upland. Since upland rice cultivation is popular in the study area (Ozaki and Sakurai 2020) and many farmers in this dataset have rice plots both in lowlands and uplands, non-target plots include both types of rice plots. As the growing condition is different between the two, this dummy variable intends to capture the effect of being planted on uplands. $HHFE_h$ is household fixed effect that captures unobserved effects of a household's traits that commonly affect all rice plots. u_{ih} is the error term.

The third model is for household level impact. This model focuses on measuring the impact of intervention on household welfare.

$$Y_{h2020} = \alpha_0 + \beta_1 T_h^{high} + \beta_2 T_h^{low} + \beta_3' HC_h + \beta_4' village + u_h \dots (3)$$

where Y_{h2020} is one of 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 the harvesting month of the year. T_h^{high} and T_h^{low} in (3) are dummy variables which decompose 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 variables of village of residence. Since we do not have household level outcome variables in the previous year, we cannot apply ANCOVA specification to the household level analysis. However, in the case of rice yield and fertilizer applications, we use the values in the previous year at the target plot instead of household level data to control for the levels before the intervention.

IV. Results

A. Descriptive statistics about households

Table 2 presents descriptive statistics of participants' households. A household consisted of 5 people, and cultivated a total area of 0.49 ha of land on average. The number of rice plots was 3.5 per household on average, and one of them was the target plot whose mean size was 0.15 ha. The description indicates that the participants were small-scale, but had 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 the control groups, there were no systematic differences with respect to these variables (see Table A1).

B. Descriptive statistics about outcomes

Table 3 shows descriptive statistics of rice yield and fertilizer use in the target plots. The number of plots was the same as the number of households because we targeted one plot from each household. In the last rainy season before the intervention, 20% of these plots had received any nitrogen-containing fertilizer, of which 17% was urea. After the intervention, the percentage of urea-applied plots was increased to 61%. This suggests that more than half of farmers are willing to use fertilizer if they can obtain it. The percentage of manure-applied plots little changed before and after the intervention. The average rice yield was 4795.22 kg/ha before the intervention, and 4548.10 kg/ha after the intervention.

After the intervention, urea was applied in 7 out of the 10 target plots or 70% in high EE sub-groups and 12 out of 25 plots or 48% in low EE sub-group (Table 4). We expect that the share of urea applied plots in the control group should be between the two treatment sub-groups. Although the share, 68.6 %, fell between the two, it is very close to the high EE group. Anyway, the shares are not statistically different as shown in the last column of the table.

C. Impact of intervention on fertilizer application in target plots

Table 5 presents the results of the regressions of specification (1) regarding fertilizer use at the target plots on the treatment variables. The impact of the intervention is examined by comparing between target plots of treated farmers and those of control farmers.

After controlling for the pre-intervention level of outcome variables, the result shows that receiving information of high EE did not affect urea application compared with control plots (columns (1) and (2)), but it had a significant positive impact on nitrogen application quantity by 41 kg/ha (column (4)). On the other hand, low EE information resulted in a significant decrease in the probability of urea application by 12% points and nitrogen application by 11% points compared with control plots (columns (1) and (3)). Moreover, low-EE information had a significantly negative impact on fertilizer purchase (column (6)). Please note that the adoption and the quantity of nitrogen fertilizer accommodate not only urea but also NPK as a source of nitrogen. No impact on the quantity of urea is found for either type of information though the signs of coefficients were consistent with the hypothesis (column (2)).

The insignificant impact of high-EE information on the use of urea can be attributed to the high adoption rate of urea among control farmers: 24 out of 35 farmers in the control group used the provided urea as shown in Table 4. Considering that the high-EE information had a significant impact on the application rate of nitrogen, its insignificant coefficients on urea use may be because 5 kg of urea was distributed to all participants equally before planting. Although 70% of farmers who received information of high-EE applied the given urea to their target plot, it was not sufficiently different from the percentage in the control group. On the other hand, low-EE information significantly reduced the use of urea because control farmers tended to use distributed urea to their target plots.

The fifth column shows that probability of using manure in the target plot declined by 22% points compared with the control group when farmers received information that would encourage urea application. This result indicates that farmers with high EE information substituted manure with nitrogen, i.e. urea and/or NPK.

The last column shows that there is no significant impact on rice yield in spite of the several significant changes in fertilizer use due to the intervention. However, if the decision of not using nitrogen fertilizer reduce the production cost without compromising yield, the information provision will contribute to the efficiency gain among rice farmers.

D. Impact of intervention on fertilizer allocation within a household

Table 6 presents regression results of specification (2). This model compares target plot and non-target plots in each household that had at least two rice plots controlling for unobserved household characteristics by household fixed effect. Hence, 10 households who had only one rice plot were excluded from the analysis. Including rice plots both in lowlands and uplands, the total number of observations was 207 from the total of 60 households.

We expect that in the case of positive information (i.e. high-EE information) farmers are likely to follow the information regardless of their subjective assessment of soil characteristic unless they have a very strong belief against the information. On the other hand, in the case of negative information (i.e. low-EE information), in which plots farmers will use urea cannot be predicted, and hence their decisions will not be different from control farmers who do not receive any information.

The first row shows the impact of the provision of high-EE information: it significantly increased the quantity of urea and the quantity of nitrogen applied to the target plot by 43.79

kg/ha and 53.42 kg/ha as shown in columns (1) and (2) respectively. These results imply that farmers followed the positive information as expected. As a result, it is found that rice yield was significantly higher in the target plot than non-target rice plots. The difference is 948.75 kg/ha on average after controlling for upland plots as well as household unobserved characteristics as shown in column (3).

The second row presents the impacts of low-EE information on the target plot. There are no significant differences between the target plot and non-target plots in terms of the quantity of urea, the quantity of nitrogen, or rice yield, which is also as expected. Since low-EE information does not tell in which plot the farmer should use urea or nitrogen unlike high-EE information, the insignificant effect seems to be natural.

The coefficients in the third and fourth rows are also estimated to be insignificant, suggesting that without information, participants in the control group evenly allocated fertilizer among rice plots within a household. The results imply that farmers do not know the effectiveness of nitrogen in their plots and providing such information will help their decisions.

E. Impact of intervention at household level

Table 7 shows the impact of the intervention on household level variables using specification (3). Outcome variables include the average rice yield, average intensities of application of urea and nitrogen to rice, crop income per capita, and monetary value of the total consumption per capita.

Column (1) shows that neither high-EE nor low-EE information affected rice yield at household level. But although it is not statistically significant, the sign and the size of the coefficient of high-EE seems to be reasonable. They did not have any impact on urea application rate at household level either as shown in column (2). However, nitrogen application rate in column (3) increased when a household received information that urea would be effective in their target plots. The results can be interpreted that farmers did not use more urea than they equally received, but they increased nitrogen use by purchasing if their plots are judged as high EE. The intensified nitrogen use was sufficient to have a statistically significant effect on the yield.

To see whether the intervention contributed to welfare improvement by enhancing rice production efficiency, two outcome variables were regressed on treatment variables. But neither crop income per capita nor consumption per capita were significantly affected by the information provision, as shown in columns (4) and (5). Since the impact on rice yield was not large enough, the intervention could not have significant effect on household welfare.

V. Robustness check

A. Impact of plot size

In the intervention, all the participants received information about the exact size of the target plot (see Figures A2 and A3) as well as the general instruction of fertilizer application regardless of the treatment assignment status (see Figure A1). The recommended rate of application was 5 kg of urea for 0.05 ha. 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 urea just because the size of their plot is larger than 0.05 ha, areas that could be covered by the free urea. To see whether or not this was the case, an additional regression was run by using specification (1). In this model, instead of plot size variables, a dummy variable for the plot whose size is over 0.05 ha, and its interaction terms with treatment assignment variables were included. Results are presented in Table A6. None of three newly added variables are statistically significant, implying that whether the plot size was larger than 0.05 ha did not affect the farmers' decisions.

VI. Conclusion

The 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 due to inherent soil properties. However, what kind of site-specific information will influence farmers' soil fertility management and improve crop yield remain largely unknown. In order to answer this question, we created a unique binary indicator about fertilizer effectiveness and tested if such simple information could work. The indicator was based on Pox value in the soil and firmly supported by agronomic evidence. However, we did not know if such simple information can motivate farmers to shift from current practices with no or low fertilizer use to improved practice with more fertilizer.

We conducted a randomized controlled trial in Madagascar and found that the provision of plot-level simple information regarding expected effectiveness (EE) of nitrogen fertilizer could optimize farmers' fertilizer use and enhance rice yield: high EE information significantly increased application rate of nitrogen fertilizer and its consequent rice yield compared with the case of low EE information and no information.

Considering the general needs of increase in nitrogen use in SSA rice cultivation, this study made an important contribution to the discussion by showing that there is a possibility to simplify the design of intervention by focusing on a single soil property. Various attempts, including subsidy programs, credit lending and training about how to use fertilizer have been implemented in SSA to promote fertilizer use by farmers, but they are not so successful. The policy implication of this study is that even simple information will make conventional fertilizer policies more effective to promote fertilizer use.

The use of simple indicator of nitrogen effectiveness is the uniqueness of this study because prior studies dealt with multiple soil properties to show what and how much of mineral fertilizer to be applied in each plot. This idea is agronomically sound because increased number of soil properties in the information does not necessarily improve the accuracy of the information (Tsujimoto *et al.* 2019), but also practically important considering the cost and time to examine many soil properties and the feasibility of interventions with multiple soil properties. Of course, we should not simplify the reality too much, and agree with Burke *et al*. (2019)'s comments on Marenya and Barret (2009) suggesting that crop yield response is affected by complicated soil structure. With this respect, further studies to explore whether complex information that consisted of multiple soil properties leads to higher or lower impacts on farmers' practices than simple information based on a single soil property as used in this study, taking account of the cost of information generation, will be meaningful for both researchers and policy makers.

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 interventions with larger scale will be important to confirm the key findings from this study. Second, this study only examined the impact of information in the season of 2019-20 which started just after our intervention. Additional data in the following seasons would be useful to see whether the impacts would last without free fertilizer provision.

References

Abay, Kibrom A., Mehari H. Abay, Mulubrhan Amare, Guush Berhane, and Ermias Aynekulu. 2022. “Mismatch between Soil Nutrient Deficiencies and Fertilizer Applications: Implications for Yield Responses in Ethiopia.” *Agricultural Economics*53;215-230).

Arouna, Aminou, Jeffrey D. Michler, Wilfried G. Yergo, and Kazuki Saito. 2021. “One Size Fits All? Experimental Evidence on the Digital Delivery of Personalized Extension Advice in Nigeria.” *American Journal of Agricultural Economics* 103 (2): 596–619.

Asai, H.,.A. Andriamananjara, M. Rabenarivo, T. Nshigaki, T. Takai, Y. Tsujimoto. 2020. “Lowland rice yield and N use efficiency as affected by P fertilizer and farmyard manure application in P deficient soils in the central highlands of Madagascar”. *Nihon Sakumotsu Gakkai Koenkai Yoshi Shu*, 249, 16-16.

Asfaw, Abay and Assefa Admassie. 2004. “The Role of Education on the Adoption of Chemical Fertiliser under Different Socioeconomic Environments in Ethiopia.” *Agricultural Economics* 30 (3): 215–28.

Ayalew, Hailemariam, Jordan Chamberlin, and Carol Newman. 2022. “Site-Specific Agronomic Information and Technology Adoption: A Field Experiment from Ethiopia.” *Journal of Development Economics* 156 (May): 102788.

Bernier, Rene and Paul A. Dorosh1993. “Constraints on Rice Production in Madagascar: The Farmer’s Perspective.” Working paper no. 34, *Cornell Food and Nutrition Policy Program* .

Bold, Tessa, Kaizzi Kayuki, Jabok Svensson, and David Yanagizawa-Drott. 2015. “Low Quality, Low Returns, Low Adoption: Evidence from the Market for Fertilizer and Hybrid Seed in Uganda.” HKS Faculty Research Working Paper Series, no. RWP15-033 June: 1–25.

Burke, William J., Emmanuel Frossard, Stephen Kabwe, and Thom S. Jayne. 2019. “Understanding Fertilizer Adoption and Effectiveness on Maize in Zambia.” *Food Policy* 86 (July): 101721.

Croppenstedt, Andre, Mulat Demeke, and Meloria M. Meschi. 2003. “Technology Adoption in the Presence of Constraints: The Case of Fertilizer Demand in Ethiopia.” *Review of Development Economics* 7 (1): 58–70.

Harou, Aurélie P., Malgosia Madajewicz, Hope Michelson, Cheryl A. Palm, Nyambilila Amuri, Christopher Magomba, Johnson M. Semoka, Kevin Tschirhart, and Ray Weil. 2022. “The Joint Effects of Information and Financing Constraints on Technology Adoption: Evidence from a Field Experiment in Rural Tanzania.” *Journal of Development Economics* 155 (March): 102707.

Holden, Stein T. 2018. “Fertilizer and Sustainable Intensification in Sub-Saharan Africa.” *Global Food Security* 18 (September): 20–26.

Islam, Mahnaz, and Sabrin Beg. 2021. “Rule-of-Thumb Instructions to Improve Fertilizer Management: Experimental Evidence from Bangladesh.” *Economic Development and Cultural Change* 70 (1): 237–81.

Kihara, Job, Generose Nziguheba, Shamie Zingore, Adama Coulibaly, Anthony Esilaba, Vernon Kabambe, Samuel Njoroge, Cheryl Palm, Jeroen Huising. 2016 “Understanding variability in crop response to fertilizer and amendments in sub-Saharan Africa.” *Agriculture, Ecosystems and Environment* 229:1–12

Mathilde, Sester, Lours-Marie Raboin, Alain Ramanantsoanirina, and DidierTharreau 2008. “O.36 - Toward an Integrated Strategy to Limit Blast Disease in Upland Rice.” Paper presented at the ENDURE International Conference 2008, La Grande-Motte, France, October 12-15.

McKenzie, David. 2012. “Beyond Baseline and Follow-up: The Case for More T in Experiments.” *Journal of Development Economics* 99 (2): 210–21.

Marenya, Paswel P., and Christopher B. Barrett. 2009. “Soil Quality and Fertilizer Use Rates among Smallholder Farmers in Western Kenya.” *Agricultural Economics* 40 (5): 561–72.

MAFF (Ministry of Agriculture, Forestry and Fishery of Japan). 2008. *Dojo Shindan no Katsuyo to Hoho (Method and application of soil examination),* in Aomori prefecture, Kenko na Tsuchi Dukuri Gijutsu Manyuaru, 8-30.

Minten, Bart, Jean Claude Randrianarisoa, and Christopher B. Barrett. 2007. “Productivity in Malagasy Rice Systems: Wealth-Differentiated Constraints and Priorities.” *Agricultural Economics*

Morris, M. L. 2007. Fertilizer Use in African Agriculture: Lessons Learned and Good Practice Guidelines. World Bank Publications.

Nishigaki, Tomohiro, Kenta Ikazaki, Yasuhiro Tsujimoto, Andry Andriamananjara, Tovohery Rakotoson, and Tantely Razafimbelo. 2020. “Soil Survey of the East Coast and the Central Highlands Indicates Need to Update Madagascar Soil Map.” *Soil Science and Plant Nutrition* 66 (3): 469–80.

Rakotoarisoa, Njato Mickaël, Yasuhiro Tsujimoto, and Aung Zaw Oo. 2020. “Dipping Rice Seedlings in P-Enriched Slurry Increases Grain Yield and Shortens Days to Heading on P-Deficient Lowlands in the Central Highlands of Madagascar.” *Field Crops Research* 254 (September): 107806.

Rakotonindrina, Hobimiarantsoa, Kensuke Kawamura, Yasuhiro Tsujimoto, Tomohiro Nishigaki, Herintsitohaina Razakamanarivo, Bruce Haja Andrianary, and Andry Andriamananjara. 2020. “Prediction of Soil Oxalate Phosphorus Using Visible and Near-Infrared Spectroscopy in Natural and Cultivated System Soils of Madagascar.” *Agriculture* 10 (5): 177.

Rakotoson Tovohery, Yasuhiro Tsujimoto, and Tomohiro Nishigaki. 2022. “Phosphorus management strategies to increase lowland rice yields in sub-Saharan Africa: A review." *Field Crop Research* 275: 108370.

Roodman, David, Morten Ørregaard Nielsen, James G. MacKinnon, and Matthew D. Webb. 2019. “Fast and Wild: Bootstrap Inference in Stata Using Boottest.” *The Stata Journal* 19 (1): 4–60.

Rurinda, Jairos, Shamie Zingore, Jibrin M. Jibrin, Tesfaye Balemi, Kenneth Masuki, Jens A. Andersson, Mirasol F. Pampolino, et al. 2020. “Science-Based Decision Support for Formulating Crop Fertilizer Recommendations in Sub-Saharan Africa.” *Agricultural Systems* 180 (April): 102790.

Saito, Kazuki, Elke Vandamme, Jean-Martial Johnson, Atsuko Tanaka, Kalimuthu Senthilkumar, Ibnou Dieng, Cyriaque Akakpo, et al. 2019. “Yield-Limiting Macronutrients for Rice in Sub-Saharan Africa.” *Geoderma* 338 (March): 546–54.

Sheldrick, William F., J. Keith Syers, and John Lingard. 2002. “A Conceptual Model for Conducting Nutrient Audits at National, Regional, and Global Scales.” *Nutrient Cycling in Agroecosystems* 62 (1): 61–72.

Schwertmann, Udo. 1964. The differentiation of iron oxides in soils by extraction with ammonium oxalate solution. Z. Pflanz. Bodenkd. 105, 194–202.

Tanaka, Atsuko, Jean-Martial Johnson, Kalimuthu Senthilkumar, Cyriaque Akakpo, Zacharie Segda, Louis P. Yameogo, and Ibrahim Bassoro. 2017. “On-Farm Rice Yield and Its Association with Biophysical Factors in Sub-Saharan Africa.” European Journal of Agronomy85 (April): 1–11.

Tsujimoto, Yasuhiro, Tovohery Rakotoson, Atsuko Tanaka, and Kazuki Saito. 2019. “Challenges and opportunities for improving N use efficiency for rice production in sub-Saharan Africa” *Plant Production Science* 22:4, 413-427

Van Campenhout, Bjorn. 2021. “The Role of Information in Agricultural Technology Adoption: Experimental Evidence from Rice Farmers in Uganda.” *Economic Development and Cultural Change* 69 (3): 1239–72.

World Bank. 2019. “Madagascar Economic Update, October 2019: A New Start?” World Bank. https://elibrary.worldbank.org/doi/abs/10.1596/32636.

World Bank. 2020. Madagascar Country Economic Memorandum: Scaling Success-Building a Resilient Economy. World Bank.

Xiaoying, Zhan, Zhang Qingwen, Zhang Hui, Hafiz Athar Hussain, Muhammad Shaaban, and Yang Zhengli. 2020. “Pathways of Nitrogen Loss and Optimized Nitrogen Management for a Rice Cropping System in Arid Irrigation Region, Northwest China.” *Journal of Environmental Management* 268 (August): 110702.

Xu, Zhiying, Zhengfei Guan, T. S. Jayne, and Roy Black. 2009. “Factors Influencing the Profitability of Fertilizer Use on Maize in Zambia.” *Agricultural Economics* 40:437-446.

Yamano, Takashi and Tomoya Matsumoto. 2009. “Soil Fertility, Fertilizer, and the Maize Green Revolution in East Africa.” Accessed August 2,, 2022.

https://openknowledge.worldbank.org/bitstream/handle/10986/19960/WPS5158.pdf?sequence=1&isAllowed=y..

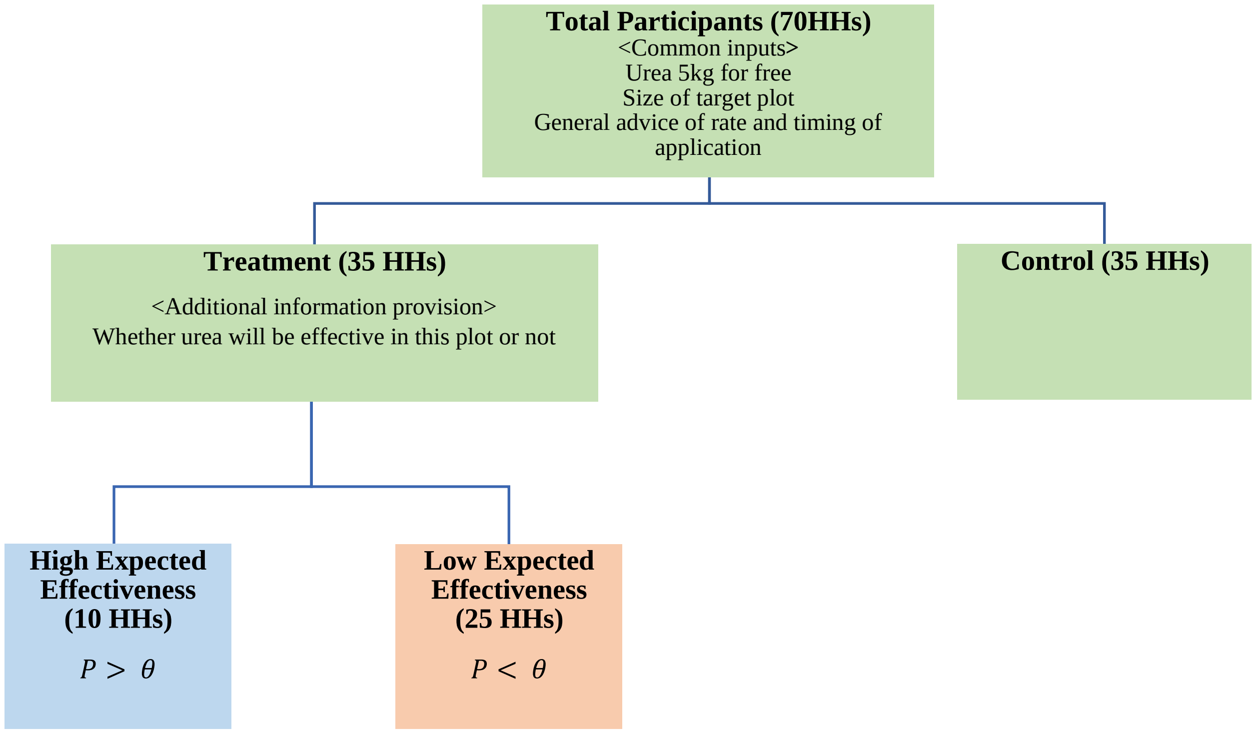
Zingore S, Tittonell P, Corbeels M, van Wijk MT, Giller KE. 2011. “Managing soil fertility diversity to enhance resource use efficiencies in smallholder farming systems: a case from Murewa District, Zimbabwe.” *Nutrient Cycling in Agroecosystems*. 90:87–103

Figures and Tables

Figure 1: Location of study sties

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 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 defines the soil sample as either high EE or low EE. Two different thresholds were used because soils in 4 out of 10 EAs are considered to be affected by a volcano.

Table 1 Summary of variation of phosphorus amount by EAs

Villages	EA	Mean	S.D.	Min	Max	Volcanic soil	θ
1	1	547.53	228.82	228.27	823.08	Yes	300
1	2	335.54	175.34	66.56	576.31	Yes	300
2	3	321.71	145.13	94.16	586.60	Yes	300
2	4	316.25	117.60	136.88	481.96	Yes	300
3	5	122.38	38.51	98.60	166.81	No	100
3	6	74.74	26.55	44.61	108.24	No	100
4	7	64.13	29.81	26.69	116.71	No	100
4	8	57.29	22.09	30.26	89.78	No	100
5	9	37.14	11.97	22.76	57.83	No	100
5	10	36.13	12.04	25.02	63.22	No	100

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

Table 2 Descriptive statistics about participants' household

Variables	Unit	Overall (N=70)	Treatment High EE (N=10)	Treatment Low EE (N=25)	Control (N=35)
Household size	number	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	46.57 (12.12)	46.30 (13.57)	47.44 (15.25)	46.03 (9.18)
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)	0.73 (0.79)	0.39 (0.37)
Number of rice plots	number	3.49 (1.56)	2.90 (0.99)	3.64 (1.66)	3.54 (1.62)
Size of target rice plot	ha	0.15 (0.15)	0.09 (0.08)	0.21 (0.22)	0.12 (0.08)
Value of asset per capita	10^3 MGA	146.46 (204.56)	201.34 (159.46)	145.45 (158.89)	131.50 (243.42)
Risk preference	0-10	5.53 (2.70)	6.90 (2.47)	5.36 (2.53)	5.26 (2.83)

Source) Authors.

Notes) MGA is local currency, standing for Malagasy Ariary. Standard deviations for continuous variables are in parenthesis.

T-test was conducted regarding size of target rice plot between treatment-high EE group and treatment-low EE group, and it detected a significant difference at 10% level.

Table 3 Descriptive statistics about outcome variables

Variables	Unit	Overall (N=70)	Treatment High EE (N=10)	Treatment Low EE (N=25)	Control (N=35)
Plot level (target plots)					
Before intervention					
Rice yield	kg/ha	4795.22 (2709.06)	6810.48 (2746.44)	4002.15 (2943.98)	4785.91 (2263.91)
Urea use	(0/1)	0.17	0.40	0.12	0.14
Urea application rate	kg/ha	30.69 (90.11)	49.90 (73.30)	24.87 (74.13)	29.35 (105.08)
Nitrogen use	(0/1)	0.20	0.50	0.12	0.17
Nitrogen application rate	kg/ha	16.21 (44.96)	33.19 (48.94)	12.44 (38.33)	14.04 (48.28)
Manure use	(0/1)	0.31	0.60	0.20	0.31
After intervention					
Rice yield	kg/ha	4548.10 (2651.25)	5984.01 (4016.77)	3581.68 (2306.09)	4828.15 (2205.97)
Urea use	(0/1)	0.61	0.70	0.48	0.69
Urea application rate	kg/ha	60.99 (103.66)	117.94 (111.50)	31.63 (57.41)	65.69 (120.74)
Nitrogen use	(0/1)	0.61	0.70	0.48	0.69
Nitrogen application rate	kg/ha	32.71 (58.64)	86.76 (93.19)	14.59 (26.40)	30.22 (55.51)
Manure use	(0/1)	0.36	0.50	0.28	0.37
Household level (after intervention)					
Rice yield at household 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)
Nitrogen quantity applied to all the rice plots	kg/ha	22.82 (33.05)	55.97 (67.22)	12.33 (15.41)	20.84 (21.09)
Urea quantity applied to all the rice plots	kg/ha	42.23 (48.71)	75.19 (69.89)	26.12 (33.85)	44.32 (46.89)

Source) Authors.
Notes) MGA is local currency, standing for Malagasy Ariary. Standard deviations for continuous variables are in parenthesis

Table 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	

Source) Authors

Table 5 Impact of soil characteristics information on outcome variables at target plots

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Urea use (0/1)	Urea quantity (kg/ha)	Nitrogen use (0/1)	Nitrogen quantity[*1] (kg/ha)	Manure use (0/1)	Purchase of fertilizer (0/1)	Rice yield (kg/ha)
Treatment (High EE)	-0.24 (0.15)	40.81 (41.73)	-0.23 (0.15)	41.02 (17.77)**	-0.22 (0.10)**	0.03 (0.13)	160.38 (884.27)
Treatment (Low EE)	-0.12 (0.07)*	-17.34 (13.83)	-0.11 (0.06)*	-13.99 (11.63)	-0.08 (0.05)	-0.21 (0.08)*	-756.16 (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 (0.90)	39.40 (86.62)	0.18 (0.91)	14.84 (39.62)	2.81 (1.01)**	1.45 (0.73)**	-10272.37 (4609.47)**
Plot size squared	-0.62 (0.63)	-23.14 (59.70)	-0.56 (0.65)	0.53 (23.53)	-2.21 (0.90)	-0.95 (0.58)**	7079.70 (3610.57)
Number of household members	-0.01 (0.04)	-0.52 (2.13)	-0.01 (0.04)	0.75 (1.90)	-0.05 (0.02)**	0.03 (0.02)	99.11 (106.10)
Age of household head (years)	< 0.01 (<0.01)	-0.21 (0.43)	< 0.01 (<0.01)	-0.28 (0.24)	-0.01 (0.01)**	-0.01 (< 0.01)*	32.18 (14.55)*

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Sex of household head (0/1)	-0.01 (0.18)	-50.47 (53.77)	-0.04 (0.17)	-18.31 (18.76)	0.31 (0.20)	0.18 (0.17)	-1289.30 (1813.48)
Years of education of household head	-0.01 (0.02)	0.31 (1.57)	-0.01 (0.02)	-0.40 (1.13)	-0.03 (0.02)	< 0.01 (0.01)	30.05 (79.76)
Log of household asset value	0.37 (0.57)	92.01 (56.73)	0.28 (0.54)	69.12 (53.20)	-0.36 (0.33)	0.35 (0.37)	4551.56 (2721.93)*
Risk preference (0 to 10)	-0.02 (0.03)	0.41 (2.34)	-0.02 (0.03)	1.40 (1.36)	-0.02 (0.03)	0.02 (0.01)*	90.08 (127.63)
Village dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-0.02 (1.54)	-132.55 (154.44)	-0.56 (1.12)	-148.43 (153.86)	2.58 (0.79)	-0.75 (0.85)	-9450.84 (5888.85)
Adj.R-Square	0.189	0.507	0.167	0.590	0.414	0.416	0.447
Observations*2	70	67	70	67	67	67	67

Notes)

*1 Amount of nitrogen is imputed from any type of chemical 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. Since no or a little planting rice can be considered as a decision of not using urea provided from us in the target plot, these 3 observations were included in (1) and (3). However, since the rest the outcome variables should be considered as decisions related to rice cultivation, these 3 observations were excluded.

Robust standard errors clustered at EA level before wild bootstrapping are in parentheses. ***, ** and * indicate p<0.01, p<0.05 and p<0.1 obtained by wild bootstrapping.

Table 6 Impact of soil characteristics information 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)	-134.40 (49.10)***	-67.32 (22.80)***	-9506.06 (2645.23)***
Plot size squared	95.85 (36.97)**	47.58 (17.23)***	5314.64 (1871.00)***
Upland rice plot (0/1)	28.50 (11.04)**	15.34 (5.21)***	-759.86 (451.40)*
Household Fixed Effect	Yes	Yes	Yes
Observations	207	207	207
Number of groups	60	60	60

Note)

[*1] Amount of nitrogen is imputed from any type of chemical 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 Robust standard errors clustered at household level are in parentheses. ***, ** and * indicate $p<0.01$, $p<0.05$ and $p<0.01$.

Table 7 Impact of soil characteristics information at household level

	(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 (ha)	-4281.14 (1541.04)**	-31.95 (18.75)	-15.41 (10.65)	121.60 (128.88)	-503.40 (222.93)
Total size of rice plot squared	1064.22 (410.21)*	7.49 (4.27)	3.81 (2.58)	-15.57 (36.18)	192.56 (68.67)
Number of household members	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) [*1] Amount of nitrogen is imputed from any type of chemical 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.

Robust standard errors clustered at EA level before wild bootstrapping are in parentheses. ***, ** and * indicate p<0.01, p<0.05 and p<0.1 obtained by wild bootstrapping.

Table A1. Results of t-test for each variable

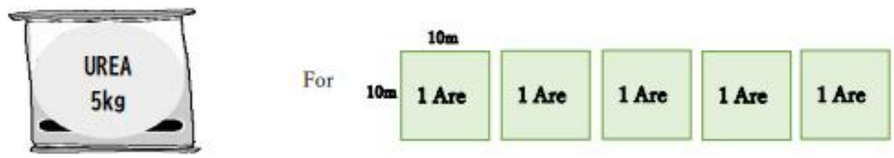
Variables	Unit	Control	Treatment	Pr(T > t)
Expected effectiveness (=1 if High)	%	34.29	28.57	0.613
Household size	people	5.29	5.14	0.746
Sex of household head (=1 if male)	%	94.29	91.43	0.648
Age of household head	years old	46.03	47.11	0.711
Years of education of household head	years	6.31	5.69	0.416
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 target rice plot	ha	0.12	0.17	0.147
Value of asset per capita	10^3 MGA	131.50	161.42	0.545
Risk preference (from 0 to 10)	score	5.26	5.80	0.404
Rice yield at household 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 in the previous year	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.
Notes) MGA is local currency, standing for Malagasy Ariary.

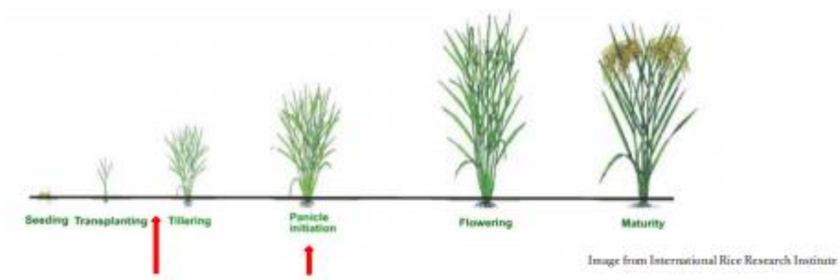
Figure A1. The instruction paper distributed to all participants

UREA DISTRIBUTION GUIDANCE

What is recommended area for UREA application?



When do we apply UREA?



<As basal fertilizer>
14 - 20 days after transplanting

<As top-dressing fertilizer>
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 A2 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 A3 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 A2 Additional regression results using plot size dummy

	(1) Urea use (0/1)	(2) Urea quantity (kg/ha)	(3) Nitrogen use (0/1)	(4) Nitrogen quantity[*1] (kg/ha)	(5) Purchase of fertilizer (0/1)
Treatment (High EE)	-0.23	52.66	-0.25	35.73	-0.15
	(0.15)	(38.42)	(0.16)	(19.71)	(0.27)
Treatment (Low EE)	-0.16	9.13	-0.19 (0.14)	-41.37	-0.70
	(0.12)	(28.13)		(31.24	(0.37)
Urea use in the last season (0/1)	0.24				
	(0.23)				
Urea quantity in the last season (kg/ha)		0.52			
		(0.13)			
Nitrogen use in the last season (0/1)			0.08		0.03
			(0.14)		(0.13)
Nitrogen[*1] quantity in the last season (kg/ha)				0.88	
				(0.38)*	
Plot size is over 0.05ha (0/1)	0.02	32.32	-0.06	-11.64	-0.36
	(0.25)	(26.76)	(0.23)	(13.33)	(0.40)
plot size over 0.05ha x treatment (High EE)	-0.04	-3.42	<|0.01|	-1.18	0.24
	(0.17)	(13.28)	(0.17)	(6.16)	(0.33)
plot size over 0.05ha x treatment (Low EE)	0.01	-26.88	0.06	31.96	0.66
	(0.16)	(29.43)	(0.17)	(28.56)	(0.44)
Household level variables	Yes	Yes	Yes	Yes	Yes
Village dummy	Yes	Yes	Yes	Yes	Yes
Constant	-0.13	-158.30	0.24	-134.10	-0.51
	(1.52)	(143.84)	(1.38)	(135.97)	(0.96)
Adj.R-Square	0.163	0.507	0.109	0.604	0.414
Observations	70	67	70	67	67

Notes)

*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. Since no or a little planting rice can be considered as a decision of not using urea provided from us in the target plot, these 3 observations were included in (1) and (3). However, since the rest the outcome variables should be considered as decisions related to rice cultivation, these 3 observations were excluded.

Robust standard errors clustered at EA level before wild bootstrapping are in parentheses. ***, ** and * indicate p<0.01, p<0.05 and p<0.1 obtained by wild bootstrapping.