# Information and Behavior: Evidence from Fertilizer Quantity Recommendations in Bangladesh*

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**Abstract**

We use a field experiment in Bangladesh to test if two types of variety-specific fertilizer recommendations—government provided, community-level recommendations and plot-specific recommendations based on individual soil tests—affect fertilizer use, yield, and profits. The treatments have a limited effect on quantity of most fertilizer types used by farmers. One exception is the case of TSP (phosphate fertilizer), which is recommended for all varieties but recommended quantities are significantly lower than the baseline average usage. A minority of treatment farmers over-react to the recommendations by stopping TSP use after the intervention. In the soil-testing treatment arm farmers also shift their seed choice to varieties for which their baseline fertilizer consumption aligns with the recommendation. Opting out of using TSP, an essential fertilizer, ultimately hurts productivity as farmers in the community-based recommendation arm experience a 4% yield reduction.

Keywords: Fertilizer Recommendations, Information Experiment, Farm Inputs, Bangladesh

JEL Codes: Q12, O13

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# 1 Introduction

Enhancing agricultural incomes in developing countries is paramount to economic advancement and development (Gollin, Parente & Rogerson, 2002).[1] In the post Green Revolution world, productivity gains are more likely to be achieved from increasing efficiency and reducing costs (Gollin, Morris & Byerlee, 2005). With this view, many governments and international organizations have focused on improving efficiency and sustainability of input usage, in line with the United Nations' Sustainable Development Goals. A global push for 'precision agriculture' assumes that increasing farmer control and accuracy of farming inputs and decisions can promote productivity and efficiency. One aspect of precision agriculture is use of fertilizers in accordance with plot- and crop-specific nutrient requirements. High resolution soil-testing allows for precise and individually targeted fertilizer recommendations.

In the context of Bangladesh, optimizing fertilizer use can be potentially cost saving as fertilizer subsidies have led to imbalanced, and at times, excess usage. Liquidity, behavioral, and information constraints prevent farmers from utilizing optimal fertilizer quantities (Duflo, Kremer & Robinson, 2011; Fishman, Gars, Kishore, Rothler & Ward, 2019). Incorrect usage can be costly to farmers and to the environment, and can affect long run fertilizer adoption (Duflo, Kremer & Robinson, 2008). Thus, increasing farmers' awareness about optimal usage may improve the profitability of fertilizers (Beaman, Karlan, Thuysbaert & Udry, 2013; Islam & Beg, 2021).

The government offers regional blanket recommendations to provide information about the fertilizer requirement of plants and to guide fertilizer usage of farmers.[2] However, the precision agriculture view and the extensively demonstrated role of farmer- and plot-specific heterogeneity in returns to inputs, particularly fertilizers, suggests that blanket recommendations may not lead to large gains for all farmers. Fertilizer recommendations can be more

[1] In 2014, rice yield in Bangladesh was 4.73 tons per hectare compared to 8.49 tons per hectare in the US (Ritchie, Rosado & Roser, 2022).

[2] The recommendations are at the union-council level. A union-council has nine wards on average. Typically one village constitutes one ward.

targeted and accurate if based on plot-specific soil nutrient needs (Corral, Giné, Mahajan & Seira, 2020; Harou, Madajewicz, Michelson, Palm, Amuri, Magomba, Semoka, Tschirhart & Weil, 2022).

In a novel experiment, we test the relative effectiveness of both types of fertilizer recommendations. We assign our sample of 970 rice farmers from 91 villages to one of three groups: two treatment groups and one control group (C). Farmers in the soil-test (ST) recommendation treatment group received information based on a soil-test of one of their randomly chosen plots.[3] Farmers in the union-council (UC) recommendation group received fertilizer recommendations for their union-council available through the UC office. The control group farmers received no recommendation. The fertilizer recommendations were provided on a paper recommendation card that followed the recommendation cards provided by the Soil Resource Development Institute (SRDI) for soil-test based fertilizer recommendations.[4] The recommendation card provided the recommended quantity in *grams per decimal* for each of the five common fertilizers.[5] Since recommended quantities also differ based on rice variety, we provide recommendations for the four main *Boro* varieties.[6] Each treatment farmer was told about the source of their respective recommendation and offered a brief training to explain the recommendation and it's use. Specifically, the trainers provided examples for a plot of a given area and variety, explaining how many kilograms and bags would be needed to meet the recommended amount. The trainers ensured that farmers understood what each card showed and could apply the quantities to their specific plots.

We collected baseline data in June 2015 at the end of the Boro 2015 season, after which we delivered the respective recommendation cards and training to treatment farmers. Endline

[3]Due to funding constraints, only one plot of the sample farmers was tested at the Soil Resource Development Institute (SRDI) lab. ST farmers were provided with the recommendation for their tested plot.

[4]The recommendation cards may also increase the salience of fertilizers or agricultural extension. The control group was provided with a card listing the contact of their local agricultural extension office, which was also listed on the recommendation cards for treatment farmers.

[5]One decimal is 1/100th of an acre.

[6]*Boro* is the dry season rice crop planted from December to early February and harvested between April and June.

data was collected after the Boro season of 2017.[7]

Our intervention intends to increase farmers' information of and access to soil-test based or community based recommendations. Information provision is useful in some cases and not in others, while access has been demonstrated as a considerable barrier in the adoption of improved farm practices. In our context, direct information and access are the relevant constraints to adoption of precise fertilizer recommendations for three reasons. First, despite the status quo availability and advertisement, take-up among farmers is low—only 7.3 percent of baseline farmers report using government recommendations to guide their fertilizer use, and only 11% have ever obtained a soil-test. To access union-council based recommendations farmers must approach the local agricultural extension agents and obtain a union-council recommendation card that allows them to determine the prescribed quantity based on variety planted and the depth of their plot. For soil-test based recommendations farmers must bear the monetary costs of lab soil testing. Second, the current modes of knowledge transmission are known to be affected by frictions. Niu & Ragasa (2018) validate the importance of information in agricultural systems, and note that information loss is most likely to occur at its transmission from the extension agent to the farmer in the knowledge transmission chain. Third, low levels of numeracy and education may further restrict farmers' ability to access and use recommendations.

Our intervention removes these knowledge and access barriers to fertilizer recommendations by offering simplified recommendations and delivering a brief training to farmers to assist their understanding of the recommendations. Our paper empirically tests the relative effect of information and availability of the two types of fertilizer recommendations on farmers' fertilizer usage. An additional motivation for our study is to understand the usefulness of such blanket advisories as community based fertilizer recommendations. There is little thorough evidence on the accuracy of blanket recommendations. They might be outdated or irrelevant for specific plots, given the changing nature of regional soil characteristics over

[7] The Boro season is the primary rice-planting season. The fertilizer recommendations provided to farmers are for various varieties of rice used in the Boro season.

time as well as the prevalence of substantial heterogeneity in soil characteristics within narrowly defined regions demonstrated in other contexts (Gollin & Udry, 2021; Suri, 2011). Indeed, low rates of subscription to union-council level recommendations may be due to beliefs about their efficacy (Bold, Kaizzi, Svensson & Yanagizawa-Drott, 2017; Michelson, Fairbairn, Ellison, Maertens & Manyong, 2018). A unique feature of our study is that we compile union-council recommendations, soil test results and soil test based recommendations for the same set of plots. We are thus able to compare both community level union-council recommendations and individual plot level soil test based recommendations.

We first compare the union-council based recommendations to the specific soil nutrient content and note that the aggregate recommendations are rarely suited to plot-specific requirements. We find that the union recommendations are only moderately correlated with the nutrient content of soil. Second, comparing the two types of recommendations, we note that on average union-council recommendations are lower than soil-test based recommendations. These comparisons suggest that blanket recommendation may not serve the needs of individual farmers or plots. Third, we compare the recommended quantities to actual baseline fertilizer usage by farmers in our sample. We match the recommended fertilizer quantity for the variety grown by each farmer at baseline with the reported usage of the same fertilizer. Conditional on the variety choices, farmers significantly over use TSP, i.e. baseline usage is higher than recommended quantities. Farmer usage is much higher relative to the union-council recommendations as they are significantly lower than soil-test based recommendations. For other commonly used fertilizers (Urea and MOP), there is both overuse and underuse by farmers.[8]

Our experimental results indicate that while the interventions have a limited effect on the specific quantity used for most fertilizers, for one of the fertilizer types some farmers stop using it altogether. At endline we find no significant effect on the quantity of fertilizer

[8] We compare both the actual usage and the UC based recommendations to the soil test results, assuming those provide a relatively accurate representation of the soil fertilizer needs. However, soil test results may suffer from measurement error.

used by treatment farmers and marginal effects on the application error as measured by the difference between the quantity used and quantity recommended. The lack of treatment effects on quantity of fertilizer usage is in line with Fishman et al. (2019) who find no effect on fertilizer of providing soil health cards to farmers in India. One exception in our case is Triple Super Phosphate (TSP)—based on both sets of recommendations, over 85% of farmers overuse TSP, applying 3-6 times more than the recommended amounts. Applied TSP falls for the ST and UC treatment groups, but this is predominantly driven by farmers stopping TSP application. Treatment farmers are 3-4% less likely to use TSP relative to control farmers, and the negative effect is larger and stronger for the UC recommendation treatment group. UC recommendations always prescribe a positive amount of TSP, which provides phosphorus, an integral nutrient for plant growth.[9] A small group of farmers thus respond to the recommendation of a lower quantity for TSP, but overcompensate for the over-usage by reacting at the extensive margin.[10]

The negative effect on TSP usage is about 1.6 times in the union-council recommendation group than in the soil-test group, consistent with the difference in TSP recommendation across the two groups. While recommended TSP is lower than farmers' baseline application, it is much more so for union-council based recommendations. In other words, UC recommendations prescribe significantly lower quantities of TSP than ST based recommendations. As such, we observe more farmers in the UC group stopping TSP use.

Abandoning TSP results in a significant drop in yield, particularly for UC group farmers, who lose 0.9 kg/decimal of yield, 24.6 Bangladeshi Taka per decimal (BDT/dec) in revenue and 23.5 BDT/dec in profit.[11] Farm expenditure is lower (insignificant) due to the treatments. In the ST treatment group, we do not observe a significant effect on yield, consistent

[9]ST recommendation is positive for 93% of the soil tested plots.

[10]This finding may be interpreted as an over-reaction to the treatment in combination with inattention to specific quantity information, which are behavioral features demonstrated in other contexts.Morrison & Taubinsky (2019) demonstrate the possibility of over-reaction to information; agents are more likely to exert costly mental effort and the degree of over-reaction is lower when stakes are high. Limited attention in take-up of farm technology is demonstrated in Hanna, Mullainathan & Schwartzstein (2014). These are plausible mechanisms consistent with our findings, but we are unable to test them directly.

[11]1 acre = 100 decimals (dec). $1 is approximately 85 Bangladeshi Taka.

with the smaller effect on TSP use in the ST group and further results presented below.

Our findings suggest that farmers notice the difference between fertilizer recommendation across seed varieties. High yielding varieties demand more TSP than other varieties; if farmers switched to high yielding varieties without changing TSP usage, they would make up the gap between usage and recommendation. We observe that ST farmers shift away from other varieties to high yielding varieties, plausibly because they learn that their baseline TSP application is more suited to those varieties. Thus, two effects seem to operate in explaining the yield response for ST farmers—increase in high yield variety and drop in TSP use—resulting in an overall zero effect of the soil-test based recommendation treatment on yield.[12]

The limited response of farmers' fertilizer application behavior to these recommendations may be due to low demand for these recommendations among farmers.[13] Limited understanding or attention may also play a role, whereby farmers' learning is limited by their ability to process the multitude of information provided to them in the form of the recommended quantities for 5 fertilizers and 4 possible rice varieties.[14] In contrast, a parallel experiment that offered farmers 'leaf color charts' to track nitrogen content of their soil accompanied by 'rule-of-thumb' instructions on urea application, and thus with substantially lower mental and attention demands on farmers, has a significant effect on the quantity of urea (nitrogen-fertilizer) applied (Islam & Beg, 2021). Lastly, low levels of schooling and numeracy may also limit farmers' ability to apply the recommendations to their personal farm and crop situations and thus lower the extent to which famers respond to recommendations.

Our study makes three key contributions. First, it demonstrates that farmers' fertilizer application practices differ from plot specific needs. Second, our unique data allows us to

[12]The variety discrimination of union-council based recommendations is not as high as in soil-test based recommendations, which may explain why the shift into high yield varieties is small and statistically insignificant for UC farmers.

[13]Fishman et al. (2019) also find no effect on fertilizer of providing soil health cards to farmers in India, especially for farmers who are confident in their fertilizer decisions.

[14]We note that our intervention is still highly policy relevant as our recommendation cards closely mimic the cards provided by the Department of Agriculture and Soil Research Development Institute (SRDI).

examine the accuracy of the government recommendations relative to the soil-test based, plot-specific nutrient requirement of plants. Harou et al. (2022) point out that the soil-testing based recommendations may supersede government blanket recommendations due to the potential inaccuracy of the latter when regional heterogeneity in soil characteristics is high. However, they do not explicitly compare the government and soil-test based recommendations. By demonstrating the gap in soil-test based and union recommendations, we support the argument that average soil conditions mask regional and farmer-specific heterogeneity, and returns from adoption of technologies and practices in agriculture are subject to these heterogeneities (Hussam, Rigol & Roth, 2018; Michler, Tjernström, Verkaart & Mausch, 2019; Suri, 2011). Last, we experimentally demonstrate the effectiveness of soil-testing and government provided community based recommendations in the same context, whereas previous studies have mostly focused on the fertilizer application behavior and yield in response to soil-test based recommendations (Fishman et al., 2019; Harou et al., 2022; Murphy, Roobroeck, Lee & Thies, 2020). In a related paper, Corral et al. (2020) provide both individualized and aggregated recommendations to farmers. However, the aggregate recommendation in their experiment was constructed by averaging the soil analyses for all farmers in a cluster, whereas ours are official union-level recommendations.

The paper builds on a large literature on the learning and information frictions in the adoption of updated agricultural practices. Various channels of information diffusion have been studied, with varying degrees of success, ranging from opportunities for 'learn by doing', or through agricultural extension workers, social networks, 'seed' or 'contact' farmers that are central in the rural networks, ICT-dependent methodologies and the interaction of more than one mode of dissemination.[15] Our intervention disseminates information about

[15] Conley & Udry (2010), Maertens (2017), Krishnan & Patnam (2014) and Fafchamps, Islam, Malek & Pakrashi (2019) examine social networks' role in technology diffusion, Aker (2011), Chua, Li, Rahman & Yang (2021), Fafchamps & Minten (2012) and Cole & Fernando (2021) examine mobile phones, while Beaman, BenYishay, Magruder & Mobarak (2021) and Kondylis, Mueller & Zhu (2017) test the effects of seed or contact farmers. Field days, or the interaction of 'seed farmers' and group meetings, is effective in disseminating information (Emerick & Dar, 2020) and so is the interaction of extension agents and connectivity (Gebresilasse, 2019), and of 'seed farmers' and incentives (BenYishay & Mobarak, 2019).

increasing efficiency through optimizing fertilizer quantities. By demonstrating that even the less accessible recommendations are not adopted extensively, we highlight the importance of targeted training, incentives, complimentary interventions, and network externalities in increasing the effectiveness of agricultural extension.

Our work also provides insights on farmer behavior in the usage of inputs in response to intricate information. While fertilizer is considered a divisible input as it can be used in smaller or larger quantities, our results are consistent with the plausibility of investment in fertilizer being lumpy or similar to indivisible inputs (David, 1966). Other work has also suggested that farmers may pay limited attention to fertilizer quantities when making their investment decisions, highlighting behavioral inconsistencies in generating meaningful gains from traditional, quantity recommendations and extension services (Duflo et al., 2011; Hanna et al., 2014).[16] In this case, information about 5 different fertilizers and four variety types may come with high costs of processing the information, limiting farmers from responding in the optimal way. In contrast, farmers (including those from this study) respond by changing fertilizer usage when offered 'rule of thumb' instructions to guide fertilizer application in Islam & Beg (2021). While our data does not allow us to test any of these mechanisms directly, we emphasize the need for future work in testing these plausible channels for explaining the limited effectiveness of quantity based fertilizer recommendations.

The findings of the paper taken together with the existing literature have a few implications. Aggregate, blanket recommendations may be oversimplified and far from plot specific needs. While access may be a constraint in the widespread adoption of recommendations, providing access may not be sufficient and complementary interventions might be necessary to achieve beneficial change in farmers' input usage in response to tailored recommendations.

[16] Drexler, Fischer & Schoar (2014) note that simplified, 'rule-of-thumb' financial training is more beneficial than standard training models, particularly for a population with lower skills. Similarly, Bennear, Tarozzi, Pfaff, Balasubramanya, Ahmed & Van Geen (2013) find that a simpler message (providing red versus green labels) about whether a well has dangerous levels of arsenic is more effective than providing more continuous information. Lipnowski, Mathevet & Wei (2020) note that information is optimal when the environment comprises one issue and with multiple issues attention costs can cause some information to be ignored and decisions to be imperfect. Mistakes or seemingly irrational behavior may arise in contexts with inattention in choice for health care plans, taxes, stock market investment. See Gabaix (2019) for a review.

Simplified rules of thumb are possibly more impactful as is shown in other contexts. Key policy insights that can be drawn from the findings include: first, farmers can benefit from improved fertilizer application advice as existing application practices are not always suited to plot nutrient needs. Second, any recommendation advice should be bundled with training and extension services to ensure farmers benefit as intended. Last, certain fertilizers (e.g. TSP) may be prone to overuse, as aspect agricultural policy can target through extension services or revising subsidy policies.

The paper is organized as follows. Section 2 provides the description of the recommendations, study design and data. We present the empirical strategy in Section 3. Section 4 discusses the results and Section 5 concludes.

# 2 Background, Study Design and Data Description

We first discuss the background of fertilizer subsidies and recommendations in Bangladesh in Section 2.1 and the study design in Section 2.2. We then present description of data, summary statistics, and baseline balance tests in Section 2.3.

## 2.1 Fertilizer Use, Subsidies and Recommendations

In the 1960s, the Bangladesh state authority (then East Pakistan) launched a 'Grow More Food' campaign to feed the country's increasing population. Farmers were supplied with chemical fertilizers and pesticides at a subsidized price. Urea, triple superphosphate (TSP), muriate of potash (MOP) are the most commonly used fertilizers. In 2013-14 urea was subsidized at 62%, and the subsidy on TSP and MOP was 50% (Huang, Gulati & Gregory, 2017). Approximately all farmers in our sample used Urea, TSP and MOP at baseline.[17] Most fertilizer is used during the dry or Boro season, the primary rice planting season that runs from approximately December to April.

[17]Usage rate is 100% for urea, 98% for TSP and 94% for MOP.

Despite high rates of adoption, farmers may not apply fertilizer efficiently. Fertilizers are typically sold in 50kg bags, and farmers tend to apply most fertilizer at the time of planting by broadcasting it by hand (Nash, Grewer, Bockel, Galford, Pirolli & White, 2016). These application methodologies are prone to wastage, in contrast with deep placement techniques that are encouraged to optimize usage. High subsidies and conventional application practices have raised concerns of fertilizer overuse. The Bangladesh Agricultural Research Council (BARC) thus promotes regional or plot-specific fertilizer recommendations aimed at regularizing farmers' fertilizer usage as well as preventing environmental spillovers.

Fertilizer recommendations prescribe optimal quantities of fertilizer to use depending on the growing season and crop variety. The recommendations can be tailored to farmers' individual plots in two ways. First, plot-specific soil-test based recommendations can be compiled based on the plots' soil nutrient profiles. Soil samples are tested at the laboratory of the Soil Resource Development Institute (SRDI) to determine the soil nutrient content for Nitrogen, Phosphorus, Potassium, Sulfur and Zinc. Five common fertilizers—urea, TSP, MOP, zinc, and gypsum—replenish each of these five nutrients in the soil. The 'fertilizer recommendation guide' issued by Bangladesh Agricultural Research Council (BARC) prescribes quantities of each type of fertilizer to be applied to plots based on the soil content of each of the nutrients, the variety grown, and the cropping season.

Second, union-council based fertilizer recommendations prescribe fertilizer quantities based on the geographic location and depth of the plot, and do not require plot specific soil tests. Union-council based recommendations offer a common recommendation for all plots with the same depth within a union-council.[18] The recommendations are determined based on nutrient needs reflected by soil samples through out the union-council. The content of specific nutrients may differ at different depths, which is accounted for by differing UC recommendations for various plot depths.

In order to compile the union level recommendations, soil samples are collected from the

[18] UC recommendations also depend on crop variety and cropping season.

union councils. SRDI (the institute that does laboratory testing for plot level soil sample) first identifies available soil types and land heights from existing aerial data in a subdistrict. They obtain one soil sample from every 200 hectares of land, ensuring that they have a representation of available soil types and land heights within each union. These soil samples are tested in the SRDI laboratory. These tests are used to generate average nutrient content for a union council and recommendations are constructed based on the averaged nutrient profile.

Once the average nutrient content for the union council is determined from the soil sampling and testing, the process for generating recommendations is identical to that for individual plot soil testing. The process does not take costs into account in determining the recommended fertilizer amounts. In both types of recommendation, SRDI uses the yield response data that BARC (Bangladesh Agriculture Research Council) produces to determine the recommended amount of fertilizer for each crop variety. SRDI has no input in generating the yield response data; they use what BARC provides as is.[19]

The union-council based recommendations may differ from the plot-specific, soil-test based ones as the union-council level soil samples may be outdated or may not represent the needs of specific plots due to heterogeneity in plot characteristics within a union-council. Both types of recommendations may also suffer from measurement error. Existing work indicates that measurement error in lab soil testing is possible at the field sampling, sample handling and transport, and laboratory analysis stages (van Leeuwen, Mulder, Batjes & Heuvelink, 2022).

[19]We provide a brief comparison of the cost associated with both types of recommendations. In each union, one soil sample is collected for approximately 200 hectares of arable land. Based on average arable land per union council, the sampling process for the UC recommendations thus collects roughly 10 samples per UC. Average land holding is 0.6 Ha, which implies that a UC has about 3300 holdings/plots. In other words, to generate the UC level recommendations, one soil sample is collected and tested for 330 plots. On the other hand, one sample needs to be collected and tested for each plot-level recommendation. Thus, for a particular plot, the costs of soil obtaining plot-specific soil test is more than 300 times the cost associated with union-level soil testing.

## 2.2 Study Design and Intervention Details

Our sample is based on a prior study of 2000 farmers from catchment villages of our NGO partner, Center for Development Innovation and Practices (CDIP).[20] We randomly selected 1000 farmers from the prior study sample, and attempted to collect soil samples for one plot of each farmer (also randomly selected). In some cases a soil sample could not be collected, for instance if the plot was under water, and our final sample consists of all farmers with least one successfully collected soil sample. The final randomization sample includes 970 farmers from 91 villages across 8 districts of Bangladesh, namely Brahmanbaria, Chandpur, Comilla, Gazipur, Lakhipur, Munshiganj, Naranganj, and Noakhali. We work in partnership with the Center for Development Innovation and Practices (CDIP) to distribute the two kinds of recommendations to farmers in our study.

In this sample, we stratified by district and farmer yield and randomly divided farmers in each stratum into three groups. The individual or soil-test (ST) treatment group were given recommendations on fertilizer quantity based on soil test results for their plot. The union-council (UC) based treatment group received recommendations already available through the union-council office. The control group (C) received no recommendation. Table A1 summarizes the description of the intervention by treatment group.

Both sets of recommendations were for five main fertilizer types—urea, TSP, MOP, zinc, and gypsum—and for four categories of rice varieties planted during the Boro season. We first compile plot specific, soil-test based recommendations for each fertilizer for the selected plot of all sample farmers. Soil-test based recommendations prescribe fertilizer quantity

[20]We have yield and fertilizer usage data of the 2000 households for 2012 from the previous study. Our original sample was from 105 villages under 20 CDIP branches spread across 21 sub-districts in the 8 districts of Brahmanbaria, Chandpur, Comilla, Gazipur, Lakhipur, Munshiganj, Naranganj, and Noakhali. CDIP selected 20 of their branch offices to participate in the study, and we selected approximately 100 farming households from the villages covered by each branch. Comparing our original sample to a nationally representative sample from the Household Income and Expenditure Survey (HIES 2010), we note that the average baseline rice yield in the study farmers is practically equal to that for an average farmer in Bangladesh (25.78 kilograms/decimal in the HIES and 26.22 kilograms/ decimal for sample farmers. 100 decimals = 1 acre). 62% of farmers in the HIES grow rice on 95 decimals per household on average (in the study sample, average area under rice cultivation is 66 decimals per household).

for each rice variety based on the nutrient content from the soil test results. Since we only have soil samples from one plot per farmer, we have variety-wise recommendations for all five fertilizers and Boro varieties for the tested plot. Second, we obtain union-council recommendations for the same fertilizers and rice varieties for all the union-councils in our sample. Union-council based recommendations prescribe fertilizer quantities for each rice variety for five possible plot depths. In other words, union-council recommendations depend on union-council where a plot is located, the plot-depth and the variety grown; plots of the same depth in the same union council have the same UC based recommendation for each variety. Soil-test based recommendations depend on the variety grown and the nutrient content of the specific plot.[21]

Figure 2 shows the format of the SRDI recommendation card that was used to inform the format of the recommendation card provided to treatment farmers in our intervention (Figure 3 shows a sample recommendation card used in our study for the ST farmers).[22] The recommendation cards (for both ST and UC recommendations) used in the intervention attempted to mimic the government provided recommendation card. For ST farmers, the card indicated the name of the plot whose soil test determined the recommended quantities. As farmers cultivate plots with varying depths, the union-council recommendation card had two sides with recommended quantities for two possible plot depths (based on farmers' baseline data). The two types of recommendation cards looked exactly the same showing recommended quantities for the five commonly used fertilizers and four main Boro varieties, with the exception of the inclusion of plot name (in the case of ST farmers) and information for two different depths (in the case of UC farmers).

We provided farmers with the recommendations and a brief training just before Boro season planting. Both ST and UC recommendations were delivered at the same time. Enumerators explained the recommendation to each farmer during this visit, including the fact

[21]Figure 1 shows the recommendations by rice variety (hybrid and other) and fertilizer type.

[22]The sample SRDI union-council level recommendation card shown includes information on the fertilizer application method and includes additional rows as it provides recommendations for eight fertilizer types (including variants of zinc and phosphorous type).

that recommendations vary by the variety of rice seed planted by the farmer. Farmers were also told that recommendations are listed as grams per decimal of area cultivated, and a simple illustration was used to demonstrate that the actual quantity they must use would depend on the total area of their plot. In the case of union-council recommendations, farmers were told that recommendations were based on the Department of Agricultural Extension recommendation and the depth of their plot. In the case of soil test recommendations, farmers were told that soil samples collected earlier were tested at a lab and recommendations are derived from their plots' specific nutrient content. There was no mention of timing or application frequency on the recommendation cards or during the training.[23]

## 2.3 Data Description and Balance

The baseline data was collected during June to August of 2015, just after the 2015 Boro season. Our baseline sample included 3,173 plots of 970 farmers. We solicited information about the crops grown, inputs used and output for each plot of the sample farmer. Based on farmer responses, we construct measures of plot-level fertilizer amount applied (in kilograms per decimal), yield or total rice output per unit area (in kilograms per decimal). We also measure expenditures on fertilizer, seeds, pesticides, irrigation and hired labor for each plot. To calculate plot-level profits, we take per decimal revenue (output times price of rice) less the total per decimal costs or expenditures. Table 1 reports descriptive statistics and balance tests for farmer level baseline characteristics. The farmers are on average 49 years old and have received 5 years of schooling. Farmers used urea in 98 percent of plots and TSP in 96 percent of plots. The average farmer level yield is 21 kilograms per decimal. Table A2 reports plot level baseline characteristics. Our sample is balanced at baseline in terms of farmer characteristics, farm inputs, output and fertilizer usage. We have 4 instances of

[23]Since all farmers were approached to collect soil samples, farmers in the UC treatment group may have assumed they were getting ST based recommendation cards. To avoid this, the trainers clearly explained that the recommendation cards included the union council level recommendations to ensure that farmers understood the intervention.

marginal imbalance across the 105 hypothesis tests in the tables.[24]

The soil test recommendation could only be provided to ST farmers for the plot where we were able to collect a soil sample. If a farmer had multiple plots, a soil sample was collected from a randomly selected plot where collection was possible, i.e the plot was not under water. Thus, even though on average plots of ST farmers are statistically indistinguishable from plots of other farmers, the treated plots of ST farmers (i.e. those with the soil test recommendation) may differ from their other plots. Since randomization was at the farmer level and the selection of soil-tested plots was same across farmers, the soil-tested plots would be balanced across the three treatment arms. Table A3 confirms this by comparing plot level characteristics across the three treatment groups only for plots that were tested.[25]

In early 2016 we collected soil samples for plots farmers intended to cultivate in the Boro 2016-2017 season (Boro season planting begins in December-February and harvest is between April and June). We obtained lab test results for the soil samples and compiled the soil-test based and union-council based recommendations. We returned to farmers in November 2016 (just before Boro planting) to deliver the recommendations cards and training. The endline data was collected after the Boro season of 2016-2017 in June-August of 2017. We tracked 923 households in the endline. As our recommendations are only for Boro rice, we restrict our endline sample to farmers who could be surveyed and had cultivated rice in the 2017 Boro season. This leaves us with 1,767 plots of 677 farmers. Table 2 column (1) reports attrition across the treatment arms, and confirms there is no differential attrition by treatment status. We additionally test if a farmer is not in the endline sample because he (i) Did not complete endline or (ii) Did not plant rice. Reassuringly, there is no differential attrition due to either reason. In Table A5 we test if there is selective attrition related to farmers baseline characteristics by interacting treatment with farmer characteristics. We find no evidence that attrited farmers differ in baseline characteristics across the treatment

[24]Since the study farmers were party of a prior study that distributed 'Leaf Color Charts' (LCC), we also test for balance in receiving the LCC treatment.

[25]We also show balance in baseline characteristics of the farmers included in the endline analysis (after attrition) in Table A4.

and control groups.

The randomization design allows us to make comparisons across all plots of farmers in the ST, UC, and C groups, and also across only soil-tested plots of the three groups. In some cases we test the treatment effect separately for the treated plots and untreated plots of ST farmers, but to account for pre-exiting differences in the the soil-tested and non-soil-tested plots we control for plot characteristics as well as an indicator for any plot with a soil test. The details on the empirical strategy follow in the next section.

# 3 Empirical Strategy

The randomization design allows us to obtain unbiased estimates of the effect of access to soil test based recommendations or union-council based recommendations relative to plots of the control group farmers.

We conduct the analysis at the plot level using the following simple difference equation:

$$Y_{p,i} = \beta_0 + \beta_1 ST_i + \beta_2 UC_i + X_i' \Psi + Z_{p,i}' \Phi + \kappa + \epsilon_{p,i} \tag{1}$$

Where, $Y_{p,i}$ is an outcome for plot p of farmer i at endline. $ST_i$ is an indicator for ST or soil-test treatment group, while $UC_i$ is an indicator for UC or union-council treatment group. $X_i$ are farmer level control variables, including the pre-treatment value of the outcome variable, total cultivated area, varieties planted, age, schooling, and non-agricultural income at baseline.[26] $Z_{p,i}$ are plot level control variables, including dummies for plot depth. We also include a fixed effect for whether a soil sample was obtained and tested from plot $p$. $\kappa$ refers to strata fixed effects. $\beta_1$ estimates the causal effect of receiving soil test based recommendation, while $\beta_2$ estimates the causal effect of receiving the union-council based recommendation. We cluster the standard errors at the farmer level.

We test the treatment effects on the following endline outcome variables:

[26]Farmers grow three main categories of rice varieties. For each farmer, we calculate the share of plots with each variety at baseline and include these shares as controls.

1. Extensive margin of each of the five fertilizers measured by an indicator for using the fertilizer at endline.
2. A measure of application error, measured by the absolute value of the difference between amount per decimal of the fertilizer used at endline and the recommended amount.
3. Per decimal yield, revenue, farm expenditure and profit.

Since some farmers change plots between baseline and endline, we aggregate baseline plot level inputs and output to the household level, when using them as controls. If the baseline value for a household is not available, we impute the value and include a dummy variable that indicates whether the observation is missing its baseline value.

Since the ST treatment is a plot-level recommendation, we additionally test if the ST effects are driven by plots for which the recommendation was available. In these specifications we measure the treatment effect on the soil tested plot and other plots of the same farmer by including separate indicators for those categories of plots.

# 4 Results and Discussion

We presents the results in this section. First, in Section 4.1 we document the two types of recommendations relative to each other and to baseline usage in the sample farmers. Second, we report the estimates of the treatment effects on fertilizer use in Section 4.2. We then present treatment effects for farm output, inputs and profit in Section 4.3. Section 4.4 presents heterogeneity analysis. We discuss the results in Section 4.5.

## 4.1 Soil Test and Union-Council Based Recommendations for Tested Plots

Our data allow a comparison of the union-council based recommendations with those based on the soil test results for the same plot. Specifically, for each plot with nutrient information (soil tested plots), we linked the prescribed quantity based on both types of recommendations for each fertilizer and seed variety. Table 3 shows the correlation of the recommendations with nutrient content, as well as the difference in the recommended quantities across the two sources. The correlations of soil-test based recommendations to the nutrient they replenish are all negative, as higher nutrient content implies lower fertilizer requirement. The coefficient ranges from -0.2 to -1.8, where a coefficient of -0.2 implies that a 1% higher nutrient content reduces the recommended amount by 0.2%.

The union-council based recommendations, on the other hand, do not correlate strongly with the nutrient content of the plots. The correlation between the union council and nutrient content is statistically zero for all fertilizers except zinc. This confirms that there is considerable heterogeneity across plots within a union-council, which are large geographical units, resulting in union-council recommendations being far from accurate for the specific needs of plots. The low correlation between union council and soil test based recommendations further confirms this—the correlation coefficient is high for urea, but 0.3 for TSP and 0.2 for gypsum.[27]

We next test if union-council recommendations are systematically above or below soil test recommendations; on average union council recommendations are lower than soil test based recommendations and the gap is the largest for TSP and gypsum where the soil test based recommendation is almost 3 times the union-council based recommendation. These comparisons are presented with the caveat that soil tests offer a measurement error prone representation of the true nutrient content of soil matter.

[27]The inconsistency between aggregated and individualized recommendations is also documented in Corral et al. (2020), who compare plot-specific soil characteristics to averaged values of the same soil features for plots within a geographical cluster.

We further examine how farmers' baseline usage differs with soil nutrient needs and recommended quantities. For this analysis, we match the recommended fertilizer quantity for the variety grown by each farmer at baseline with the reported usage of the same fertilizer. Figure 4 shows the distribution of the recommended quantities for different fertilizers as well as the baseline usage.[28] Conditional on the variety choices, farmers significantly over use TSP, and the usage-recommendation ratio is naturally higher in the case of the union-council recommendations as they are significantly lower than soil test based recommendations.[29] For other commonly used fertilizers (Urea and MOP), the gap is narrower and is also more fairly distributed around zero, implying that some farmers apply more than the recommended amount and others apply less. Seventeen percent of farmers use any zinc and 16% use gypsum at baseline, but when used, the applied quantities are typically higher than recommended amounts. The usage-recommendation ratios greater than 1 are consistent with the fact that farmers use traditional application practices applying by hand, implying that when they do apply they pay little attention to precise quantities and can tend to overuse. Overuse may also be a result of information constraints or risk aversion among farmers.[30]

## 4.2 Treatment Effects on Fertilizer Use

Tables 4 presents estimates of treatment effects on fertilizer use. First, as noted above, the use of urea and TSP is almost universal in the control group. Union-council recommendations are also always positive, i.e. urea and TSP is recommended for all rice types. However, the recommended TSP quantity is lower than the farmers reported usage in roughly 90% of the control plots. The treatment is thus expected to lower TSP usage. In the case of other fertilizers, there are cases of both over and underuse relative to the recommendations and the average treatment effect may be positive or negative depending on the recommendation. Zinc and gypsum are rarely used, but farmers using them tend to over apply. The treatment

[28] All quantities are expressed per decimal of area.

[29] Corral et al. (2020) also demonstrate higher usage of phosphate fertilizer, DAP (Diammonium Phosphate), relative to soil test based recommendations in Mexico.

[30] In Table A6 we show the share of farmers that overuse fertilizers relative to recommended quantities.

may thus cause a switch into using these fertilizer and/or a change in amount used depending on the recommendation.

Table 4 shows the extensive margin of usage for all five fertilizer types. Treatment farmers who received the soil-test based recommendation (ST) lower TSP usage by 2.8%. There is a stronger negative and significant effect on the extensive margin of TSP usage in response to the UC treatment (union-council based recommendations), where 4% of farmers stop using TSP. This is despite that UC recommendations always prescribe some TSP usage, though, the quantities are significantly lower than actual usage. There are no significant effects on any other fertilizer use. Appendix Table A7 shows the effects separately for ST farmers' plots that were tested and therefore the soil test based recommendations are specific to those plots. The extensive margin effect on TSP usage is negative for these as well as other plots of ST farmers implying that farmers' reaction to the recommendation is not localized to the tested plots. There are positive effects on Gypsum and Zinc usage specifically on the plots for which the soil test recommendations were offered, but these effects are not precisely estimated.

The negative effect on the TSP usage for ST farmers is smaller in magnitude, though not significantly so. This is consistent with the recommendations—while soil-test based recommendations for TSP are lower than baseline usage, they are not as low as union-council based recommendations.

Our treatment effects may be spurious as we test multiple hypotheses. To account for multiple hypotheses being tested, we adjust the $p$-values following Anderson (2008) and Benjamini & Hochberg (1995). The false discovery rate adjusted sharpened q-values, which confirm the validity of the treatment effects, are presented in Tables A8-A9. In the case of fertilizer usage, we test across 10 $p$-values. The treatment effects of union-council based recommendation on TSP use is robust to this conservative adjustment, but the ST effect on TSP usage does not survive the adjustment.

To investigate whether farmers move any closer to the recommendations, we test the endline application error with respect to both soil test and union council based recommendations. The application error is constructed for farmers who apply a non-zero amount of the respective fertilizer and is the absolute difference between endline usage and the recommended quantity for each fertilizer. We standardize the application error with respect to the control group mean and standard deviation. The first panel of Table 5 shows estimates from equation 1 where the difference of usage with respect to soil-test based recommendation is the outcome variable and Panel B shows the same estimates when the difference is with respect to union-council based recommendations.[31] Table 5 shows that ST farmers reduce their TSP application error by 0.2 SD. UC farmers also respond marginally, moving closer to the recommended quantities for Gypsum and Zinc. However, these intensive margin effects are not consistently observed for all fertilizers are not robust to correction for multiple hypotheses.[32] In Tables A13 and A14, we note that the farmers' average quantity used does not respond to treatment for any of the five fertilizers.

We further explore whether the drop in TSP usage is driven by the farmers who were using excessive TSP, or those who were using smaller quantities stop their usage when they realize recommendations are lower. We examine treatment effect on the likelihood of TSP usage non-parametrically as a function of baseline usage. In Figure 5, we plot on the y-axis residuals from a regression of an indicator for using any TSP at endline on farmer, plot and location controls. Percentile of residual baseline TSP usage (in kg/decimal) is plotted on the x-axis. We plot these separately for the control and the two treatment groups. The control group line (circular markers) shows that at endline TSP is used by almost all farmers in the control group regardless of baseline usage. In the treatment groups, the drop in endline TSP usage is driven by the farmers with relatively lower baseline usage, and not by farmers who were most excessively over-applying TSP at baseline. This evidence suggests that farmers

[31] Since we only have the ST recommendation for the soil-tested plots, Panel A includes only the soil -tested plots of the sample farmers.

[32] In Table A10 we show the outcome as absolute value of the application error (before standardization). Table A11 Panels A and B show the standardized application error without conditioning on usage. Table A12 replicates Panel B from Table 5 restricting the sample to soil-tested plots, and application error conditional on usage.

closer to the margin stop using TSP as result of the treatment.

In similar spirit, Figure 6 shows the distribution of total TSP used by farmers. The peaks at 50 and 100 is consistent with the fact that fertilizer is typically sold in 50 kg bags. There is a shift throughout the distribution of total TSP usage. In particular, farmers who would have used one bag or less appear to suspend usage as a result of the intervention.

Put together, we have suggestive evidence that farmers respond on the intensive margin and move closer to the recommended quantities in line with the recommendations. This effect is not consistently observed for all fertilizers, and in particular, is not robust to multiple hypotheses correction. We have strong evidence that some farmers react to the information that their TSP use is higher than recommended and respond by stopping TSP usage on their plots. This may count as an over-reaction on the part of the farmers but is possibly indicative of the lumpy nature of fertilizer usage and to the observation that farmers pay limited attention to precise quantities. These are plausible mechanisms consistent with our findings, but we are unable to test them directly. We next turn to farm output in response to the treatments.[33]

## 4.3 Treatment Effects on Farm Output, Inputs and Profit

Table 6 presents results for estimates of effects on yield, revenue, and profit. The ST treatment has no effect on any of these outcomes. UC treatment has a significant and negative effect on yield, revenue, and profit. The union-council based recommendation reduces per decimal yield by 0.9 kilogram relative to the control group at endline. This is a 4% reduction in yield, consistent with the drop in TSP demonstrated earlier. The reduction in yield translates in a reduction in revenue of 25 BDT per decimal. We find no significant effect on

[33] We can expect spillover effects of the intervention as farmers may share information. We test this by examining the fertilizer use of control farmers as a function of proximity to treatment farmers. Using information on farmers' locations we calculate the total number of treated farmers within 2km of each control farmer. We regress fertilizer use of control farmers on the number of ST and and UC farmers in a 2km radius to test if being proximate to treatment farmers has any effect. We don't find significant spillover effects of being proximate to treatment farmers. Having one more treatment farmer close to a control farmer reduces the likelihood of using TSP by 2 percentage points, but this effect is not statistically significant (Table A15).

the total cost;[34] this reduction in revenue, therefore, reduces per decimal profit by 9%.[35]

Thus UC farmers over-react to the union-council recommendations and erroneously stop using TSP, a vital fertilizer for crop growth, while showing no change in other fertilizer practices. Their yield and profits are significantly lower as a result of this mistake. On the other hand, ST farmers show a similar over-reaction to the soil-test based recommendations that is smaller in magnitude, but do not observe the same drop in yield. This seemingly contradictory finding could stem from a reallocation in other inputs that we explore further below.

We test the treatment effect on other inputs for treatment farmers. In particular, we note that recommendations may increase farmers awareness of seeds as the recommendations are listed by seed variety. The varieties are grouped by categories, which include hybrid seeds, other improved seeds, and locally improved varieties. The recommended quantities are markedly high for hybrid seeds (Figure 1). We test if farmers respond to the variety specific recommendations by shifting into hybrid varieties. Table 7 shows the treatment effects on an indicator for planting a hybrid variety at endline. Treatment farmers switch into these high yielding varieties, and this effect is large and significant for the ST group. ST farmers are 22% more likely to use hybrid seeds, specifically on plots where recommendations were provided. Moreover since the recommendations are specific to the Boro season, only varieties commonly used during the Boro season were included on the the recommendation card. The *Aman* (wet season) varieties were not shown as they are not recommended for use during the Boro season. About 5% of farmers incorrectly use the *Aman* variety in the Boro season, and the ST farmers are significantly less likely to do so. Thus ST farmers switch away from the incorrect variety and into higher yielding varieties.[36] These seed changes can offset the negative effect of yield noticed for UC farmers. In Section 4.5 we offer some discussion

[34]We later show that as expected expenditure on fertilizer is lower, but not significantly so. Expenditure on other inputs, specifically seeds, is marginally higher resulting in an overall null effect on total expenditure.

[35]These results are presented with the caveat that we cannot account for family labor in the calculation of profits. Profits are calculated using total farm revenue less total farm expenses as reported by the farmer.

[36]Using control farmers we can verify that the Boro yield depends on varieties, with the hybrid varieties correlated with significantly higher yield (Table A16)

around why the results differ for ST and UC treatment groups.

Table A17 shows expenditure on other inputs, including irrigation, labor, seeds, fertilizers, and total cost on all inputs. We do not observe any significant changes in specific quantities of inputs. We observe an insignificant increase in expenditure on seeds, consistent with the movement of some farmers into using hybrid varieties. Expenditure on fertilizer is lower (insignificant), which may be expected as the treatment leads to a significant drop in TSP usage.

For a final robustness check, we generate the exact $p$-values for our primary estimates of interest using randomization inference following Young (2019), which verify that our inferences based on the regression estimates are correct. The exact $p$-values, in addition to the coefficients and $p$-values from regression estimates, are presented in Tables A18-A20. For plot level effects on TSP usage, we find that the exact $p$-value of the ST arm is 0.066, while that of the UC arm is 0.004 (Table A18). The exact $p$-values for these two estimates suggest that our inference of the ST and UC arms having a significant negative impact on TSP usage is correct. For none of the other fertilizers we find an exact $p$-value that is lower than 0.1. Similarly, the exact $p$-value of the ST arm's effect on TSP application error (0.046) verifies that our finding that ST farmers reduce their TSP application error by 0.2 SD is correct (Table A19). Finally, we report the exact $p$-values of the intervention arms' effects on yield, revenue, and profit (Table A20). None of the statistically significant estimates we found from our preferred specification have an exact $p$-value that is higher than 0.05.

## 4.4 Heterogeniety

We stratified treatment by baseline yield, allowing us to test if treatment effects differ across baseline productivity of farmers. These heterogeneity tests also allow us to see what part of the farmers' productivity distribution may be negatively affected by these recommendations. The results presented in Appendix Table A21 show that farmers in the lowest yield tercile are significantly more likely to end TSP usage because of the intervention, and also significantly more likely to experience lower yield, revenue and profits. This could be consistent with lower liquidity among the lowest yield farmers, making them more likely to stop fertilizer purchases. These findings could also imply that the treatment effect on TSP use and productivity is more negative for farmers with lower literacy and numeracy farmers (who are more likely to also have lower yields). The UC treatment effect for farmers in the upper yield terciles is statistically indistinguishable from zero. In the case of ST, the heterogeneous effects by yield tercile are not as precisely estimated although the direction of effects is similar as the farmers in the lower and middle yield terciles at baseline are more likely to erroneously stop TSP usage and experience lower yield.[37] These findings suggest that changes to yield variance may be an important implication of increasing the availability of quantity recommendations among farmers.

## 4.5 Discussion of Findings

Our findings are consistent with Harou et al. (2022) who find limited adoption of tailored recommendations. Corral et al. (2020) suggest strong complementarity between recommendations and detailed extension services. They also find significantly higher adoption when farmers are offered an in-kind grant with the recommendations. In our treatments farmers did not receive any grants. While a one time training was offered when recommendation cards were delivered, our treatment did not include extensive extension advice. The overall limited effects on fertilizer quantities, and the negative effects on TSP use for some farmers thus suggest that complementary interventions might be necessary to achieve beneficial change in farmers' input usage in response to tailored recommendations. We note that the null effects on fertilizer usage are not simply due to lack of statistical power to detect effects.

[37] We also test heterogeneity of treatment effect by baseline schooling levels of the primary farmers among sample households. Farmers with below median levels of schooling are relatively more likely to end TSP use (Table A22). The fertilizer application error is also lower for farmers with higher schooling, and significantly so for TSP and Urea (results not presented). This heterogeneity analysis provides suggestive evidence that lower schooling farmers drive the negative effects of the intervention. Low levels of numeracy and literacy may be barriers to implementing fertilizer recommendations and that more intensive training or extension efforts may be required alongside recommendations.

We calculate the minimum detectable effect (MDE) sizes for different outcomes and fertilizer types. Based on ex-ante power calculations our study was powered to detect changes in quantity of fertilizer used (kg/dec) of 0.004-0.09 SD, depending on the fertilizer type. The MDE for application error (i.e. standardized absolute value of (Usage-Recommendation) ranges from 0.19 to 0.21 SD for the different fertilizer types.[38] The measured treatment effects on fertilizer application error are small and positive (opposite of the expected sign) in some cases, indicating a lack of consistent evidence that farmers adjust application in line with the recommended quantities.

While our measured treatment effects are very similar for fertilizer usage across the two treatment arms, we find slightly differential effects for seed choice. The average baseline TSP usage is closest to the soil test based TSP recommendations for hybrid varieties. Thus, in the ST group farmers can adjust seed choice without adjusting TSP quantity to be closer to the recommended amount.[39] We note this in Table 5 where the application error at endline (conditional on using any TSP) is significantly lower in the ST group, which is expected for farmers who switch to using the hybrid rice varieties.

Farmers appear to pay marginally more attention to ST based recommended quantities. We discuss possible explanations for the differential treatment effect on seed choice and yield across the two treatment arms. It is possible farmers may have different perceptions about soil testing based recommendations compared to UC recommendations. We have limited self reported knowledge and perceptions of farmers in the survey data. Based on available data on knowledge and perceptions, approximately 90% of control farmers report having some knowledge of soil testing, and 85% of these understand its purpose in providing nutrient profiles or recommendations. About 75% of farmers also perceive soil testing to be beneficial to the soil health or yield, and the primary reason for non-adoption is lack of

[38] Our original power calculation assumes an attrition rate of 15%. Accounting for a 30% attrition (closer to what we actually observe), the MDE for quantity used ranges from 0.005-0.10 SD and the MDE for application error is 0.16-0.25 SD for the different fertilizer types.

[39] If farmers switched to hybrid varieties they can close over two-thirds of the baseline usage-recommendation gap in the case of the ST recommendation.

access to a lab or cost of testing. On the other hand, while farmers also have knowledge about government prescribed union based recommendations and have greater access to them through agricultural extension agents, they do not subscribe to or pay attention to these guidelines widely. This is apparent from the anecdotes from agricultural extension officers and from our data where over 95% of farmers report that they don't know the per decimal quantity recommended by the government for the commonly used fertilizers, and only 7% percent of baseline farmers reported that government recommendations inform their fertilizer decision.

Another reason for why farmers' input usage is more likely to respond to soil test based recommendations may be the amount of information on the two types of recommendations. Plot based recommendation cards offer recommended quantities of five different fertilizers, for each of four different rice varieties. Union-council based recommendation cards present twice the information, as the quantities differ by plot depth. We present recommendations for two possible plot depths, based on the plot depths reported at baseline for all plots of the farmer. If limited attention impose costs on processing and learning from the information provided, these costs will be higher in the case of union based recommendations, affecting farmers decision making in response to the information about recommendations (Lipnowski et al., 2020; Wei, 2021). The attention costs may be higher for the poorest farmers, who may also be most constrained in terms of numeracy and literacy. The heterogeneity analysis supports this, as the negative treatment effects of the UC treatment are concentrated in the farmers with the lowest baseline yield.

# 5 Conclusion

A fertilizer recommendation intervention that increased farmers' access to soil-testing based and community based quantity recommendations has limited effects on quantity of fertilizer usage, despite simplifying commonly available recommendations and providing essential training on how to use them to guide usage. Farmers pay limited attention to the specific quantities and do not adjust fertilizer use on the intensive margin, while some farmers adjust on the extensive margin. In particular, treatment farmers stop using TSP, which is recommended in significantly smaller quantities than farmers' baseline usage. These negative effects on TSP usage results in lower yield for farmers.

Our findings have implications for the mode of information delivery to farmers. This over-reaction on the part of farmers suggests that farmers have limited understanding or low demand for recommendations. Nudges, training, network externalities or complimentary interventions play an important role in agricultural extension, and farmer's may be more likely to follow simple, 'rule-of-thumb' guidelines.

Our findings also highlight the relative low utility of community based agricultural advice in a context with heterogeneity in soil characteristics across regions. Community-based fertilizer recommendations, while theoretically more cost-effective relative to individual soil tests, might be provide broadly relevant advice that is not suited to farmers' individual plot needs.

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# Tables

Table 1: Summary Statistics and Balance Test for Farmer-level Baseline Characteristics

| Variable | (1) C Mean/SE | (2) ST Mean/SE | (3) UC Mean/SE | T-test p-value (1)-(2) | (1)-(3) | (2)-(3) |
|---|---|---|---|---|---|---|
| Age (in years) | 49.462 | 49.645 | 48.179 | 0.763 | 0.468 | 0.555 |
| | (0.728) | (0.766) | (0.756) | | | |
| Schooling (in years) | 5.061 | 5.671 | 5.429 | 0.169 | 0.372 | 0.999 |
| | (0.258) | (0.265) | (0.257) | | | |
| Log(Farmer's other income in BDT) | 10.442 | 10.467 | 10.630 | 0.890 | 0.052* | 0.033** |
| | (0.091) | (0.085) | (0.065) | | | |
| Received LCC treatment (=1) | 0.513 | 0.470 | 0.525 | 0.773 | 0.930 | 0.174 |
| | (0.033) | (0.033) | (0.034) | | | |
| Number of plots owned | 2.593 | 2.665 | 2.570 | 0.709 | 0.903 | 0.415 |
| | (0.082) | (0.094) | (0.087) | | | |
| Mean total plot area (decimal) | 84.613 | 80.997 | 81.493 | 0.150 | 0.846 | 0.942 |
| | (2.990) | (2.813) | (2.971) | | | |
| Mean total cultivated area (decimal) | 75.663 | 72.776 | 74.681 | 0.243 | 0.799 | 0.578 |
| | (3.050) | (2.857) | (2.995) | | | |
| Mean yield (kg/decimal) | 20.520 | 21.284 | 20.297 | 0.502 | 0.678 | 0.366 |
| | (0.586) | (0.476) | (0.571) | | | |
| Mean revenue (BDT/decimal) | 326.508 | 337.796 | 326.193 | 0.278 | 0.530 | 0.233 |
| | (7.287) | (6.196) | (6.765) | | | |
| Mean total cost (BDT/decimal) | 241.801 | 241.271 | 240.009 | 0.683 | 0.932 | 0.916 |
| | (5.009) | (4.129) | (4.433) | | | |
| Mean profit (BDT/decimal) | 84.707 | 96.525 | 86.184 | 0.160 | 0.550 | 0.219 |
| | (6.510) | (5.798) | (6.224) | | | |
| Fertilizer usage (used=1) | | | | | | |
| *Urea* | 0.978 | 0.994 | 0.997 | 0.151 | 0.037** | 0.901 |
| | (0.008) | (0.004) | (0.002) | | | |
| *TSP* | 0.964 | 0.967 | 0.965 | 0.796 | 0.838 | 0.915 |
| | (0.010) | (0.009) | (0.010) | | | |
| *MOP* | 0.896 | 0.884 | 0.886 | 0.864 | 0.492 | 0.970 |
| | (0.017) | (0.017) | (0.017) | | | |
| *Gypsum* | 0.162 | 0.153 | 0.144 | 0.615 | 0.767 | 0.773 |
| | (0.021) | (0.019) | (0.019) | | | |
| *Zinc* | 0.180 | 0.153 | 0.161 | 0.145 | 0.652 | 0.637 |
| | (0.022) | (0.020) | (0.020) | | | |
| Mean quantity of fertilizer used (kg/decimal) | | | | | | |
| *Urea* | 0.906 | 0.880 | 0.892 | 0.146 | 0.685 | 0.109 |
| | (0.024) | (0.019) | (0.019) | | | |
| *TSP* | 0.677 | 0.636 | 0.637 | 0.083* | 0.436 | 0.551 |
| | (0.023) | (0.021) | (0.019) | | | |
| *MOP* | 0.324 | 0.313 | 0.318 | 0.611 | 0.899 | 0.834 |
| | (0.013) | (0.010) | (0.011) | | | |
| *Gypsum* | 0.059 | 0.043 | 0.040 | 0.106 | 0.119 | 0.757 |
| | (0.009) | (0.006) | (0.006) | | | |
| *Zinc* | 0.010 | 0.008 | 0.009 | 0.132 | 0.390 | 0.220 |
| | (0.002) | (0.001) | (0.002) | | | |
| N | 312 | 335 | 323 | | | |

*Notes:*The value displayed for t-tests are $p$-values. Standard errors are clustered at farmer level. Strata fixed effects are included in all estimation regressions. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level. 100 decimal = 1 acre; 1 $US\$ \approx 85$ BDT

Table 2: Attrition

| | (1)<br>Atritted | (2)<br>Did not complete endline | (3)<br>Did not cultivate rice |
|---|---|---|---|
| ST | 0.043 | 0.047 | -0.004 |
| | (0.034) | (0.032) | (0.018) |
| UC | 0.035 | 0.011 | 0.024 |
| | (0.036) | (0.032) | (0.020) |
| Control mean | 0.276 | 0.202 | 0.074 |
| p value for ST=UC | 0.826 | 0.283 | 0.170 |
| N | 970 | 970 | 970 |

Heteroscedasticity-robust standard errors are in parenthesis. Includes strata fixed effects.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3: Relationship Between Nutrient, Fertilizer Recommendation, and Actual Usage

**Panel A**

| Nutrient | Fertilizer | Correlation with ST recommendation (1) | Correlation with UC recommendation (2) | Correlation between ST and UC recommendation (3) | Mean ST recommendation / UC recommendation (4) |
|---|---|---|---|---|---|
| N | Urea | -0.37 | 0.06 | 0.76 | 1.18 |
| P | TSP | -0.34 | 0.13 | 0.32 | 3.21 |
| K | MOP | -1.02 | 0.16 | 0.38 | 1.62 |
| S | Gypsum | -0.16 | 0.02 | 0.16 | 2.88 |
| Zn | Zinc | -1.85 | -1.52 | 0.26 | 1.24 |

**Panel B**

| Nutrient | Fertilizer | Correlation with actual usage (1) | Used at Baseline (%) (2) | Mean Baseline Usage / ST recommendation (3) | Mean Baseline Usage / UC recommendation (4) |
|---|---|---|---|---|---|
| N | Urea | 0.11 | 100 | 0.89 | 1.09 |
| P | TSP | -0.06 | 98 | 3.55 | 6.89 |
| K | MOP | 0.02 | 95 | 1.18 | 1.62 |
| S | Gypsum | -0.03 | 16 | 0.96 | 1.95 |
| Zn | Zinc | -0.04 | 17 | 3.65 | 4 |

*Notes:* The Table uses data from soil test results of all tested plots. ST indicates soil-test based recommendations and UC indicates union council recommendations. The elasticities in Panel A Columns (1)-(2) show the coefficient when the natural log of each nutrient content is regressed on logged recommendation. Column 3 in Panel A shows the correlation between ST recommendation and UC recommendation. Panel A Column (4) is showing the plot-level ratio of ST recommendation and UC recommendation. The correlations in Panel B Columns (1) show the coefficient when the natural log of each nutrient content is regressed on logged actual usage. Column 2 in Panel B shows the share of plots in which the fertilizer has been used at baseline. Columns (3) and (4) of Panel B show the ratio of plot level fertilizer application (conditional on any usage) and, respectively, ST and UC recommendations.

Table 4: Plot-level Effects on Fertilizer Usage (Full Sample ITT Estimate)

| | Fertilizer used in endline=1 | | | | |
|---|---|---|---|---|---|
| | (1) Urea | (2) TSP | (3) MOP | (4) Gypsum | (5) Zinc |
| ST | -0.003 | -0.027* | -0.013 | -0.004 | 0.006 |
| | (0.003) | (0.014) | (0.019) | (0.032) | (0.030) |
| UC | 0.001 | -0.043** | -0.021 | -0.024 | 0.039 |
| | (0.003) | (0.017) | (0.019) | (0.032) | (0.030) |
| Control group endline mean | 1.00 | 0.98 | 0.96 | 0.20 | 0.24 |
| $p$-value for equality across arms | 0.21 | 0.37 | 0.67 | 0.53 | 0.29 |
| N | 1,764 | 1,764 | 1,764 | 1,760 | 1,758 |

*Notes:* Dependent variable is an indicator variable for whether the specific fertilizer was used on the plot at endline. ST indicates the farmers in the soil-test based recommendation treatment group and UC indicates farmers in the union council recommendation treatment group. All regressions include strata and union fixed effects, the share of plots on which the farmer applied the fertilizer at baseline, farmer's age, years of education, total plot area, log of nonagricultural income in BDT and the share of plots with different rice varieties at baseline, and a dummy variable to indicate whether the plot was soil-tested. Plot level controls include plot depth.
Standard errors, clustered at the farmer level, are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5: Endline Fertilizer Application Error

| Panel A | Standardized absolute value of (Usage-ST recommendation) | | | | |
|---|---|---|---|---|---|
| | (1) Urea | (2) TSP | (3) MOP | (4) Gypsum | (5) Zinc |
| ST | 0.146 | -0.219* | -0.072 | -0.212 | 0.269 |
| | (0.128) | (0.121) | (0.120) | (0.227) | (0.687) |
| Control group endline mean | 0.00 | 0.01 | -0.02 | -0.04 | 1.31 |
| N | 489 | 473 | 468 | 71 | 87 |
| **Panel B** | **Standardized absolute value of (Usage-UC recommendation)** | | | | |
| | (1) Urea | (2) TSP | (3) MOP | (4) Gypsum | (5) Zinc |
| UC | 0.031 | -0.042 | 0.036 | -0.143** | -0.278* |
| | (0.071) | (0.075) | (0.072) | (0.068) | (0.150) |
| Control group endline mean | -0.00 | 0.02 | -0.04 | -0.10 | 1.30 |
| N | 1,740 | 1,682 | 1,667 | 339 | 400 |

*Notes:* Dependent variable is the standard deviation of the difference between plot level per decimal fertilizer usage at endline and the recommended amount, conditional on any usage. The recommended amount is based on the ST recommendation in Panel A and and on the UC recommendation in Panel B. Panel A includes only soil-tested plots. ST indicates the farmers in the soil-test based recommendation treatment group and UC indicates farmers in the union council recommendation treatment group. All regressions include strata and union fixed effects, the average per decimal fertilizer usage by the farmer at baseline, farmer's age, years of education, total plot area, log of nonagricultural income in BDT and the share of plots with different rice varieties at baseline, and a dummy variable to indicate whether the plot was soil-tested. Plot level controls include plot depth.

Standard errors, clustered at the farmer level, are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6: Effects on Plot-level Outcomes (Full Sample ITT Estimate)

| | (1) Yield (kg/dec.) | (2) Revenue (BDT/dec.) | (3) Profit (BDT/dec.) |
|---|---|---|---|
| ST | 0.248 | 4.195 | 6.481 |
| | (0.363) | (8.631) | (10.578) |
| UC | -0.899** | -24.561*** | -23.458** |
| | (0.392) | (8.675) | (10.976) |
| Control group endline mean | 21.47 | 467.14 | 247.22 |
| $p$-value for equality across arms | 0.01 | 0.00 | 0.01 |
| N | 1,764 | 1,764 | 1,764 |

*Notes:* Dependent variable is plot level per decimal yield, revenue and profit, respectively. Profit is the difference between revenue and total cost. Total cost includes costs of the following: labor, fertilizer, pesticides, equipment rental, vitamins, transportation, seed, fuel, composts, irrigation, and weed killer/herbicides. ST indicates the farmers in the soil-test based recommendation treatment group and UC indicates farmers in the union council recommendation treatment group. All regressions include strata and union fixed effects, farmer level average of the dependent variable at baseline, farmer's age, years of education, total plot area, log of nonagricultural income in BDT and the share of plots with different rice varieties at baseline, and a dummy variable to indicate whether the plot was soil-tested. Plot level controls include plot depth.
Standard errors, clustered at the farmer level, are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
100 decimal = 1 acre; 1 $US\$ \approx 85$ BDT

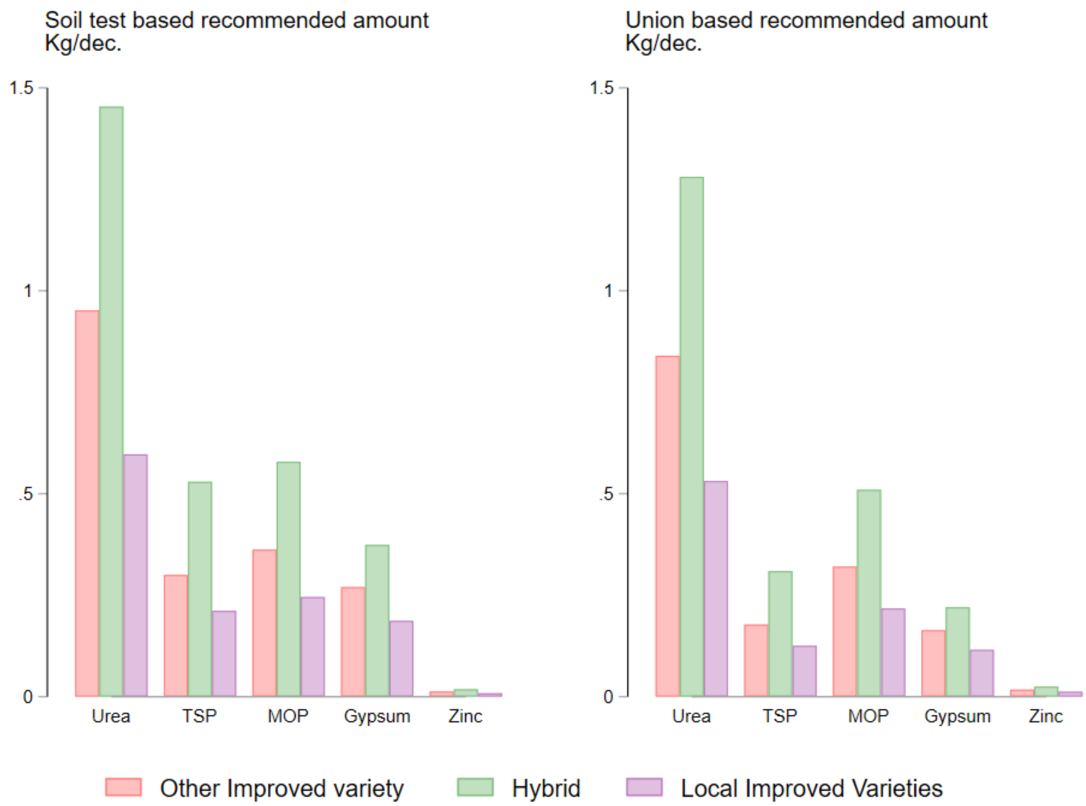
Table 7: Plot-level Rice Variety in the Endline

| | (1) Hybrid Varieties | (2) Other Improved Varieties | (3) Local Varieties | (4) Aman Season Varieties |
|---|---|---|---|---|
| ST | 0.052* | -0.051 | 0.028 | -0.031** |
| | (0.031) | (0.034) | (0.021) | (0.013) |
| UC | 0.012 | -0.023 | 0.029 | -0.013 |
| | (0.029) | (0.036) | (0.021) | (0.011) |
| Control group endline mean | 0.23 | 0.64 | 0.07 | 0.05 |
| $p$-value for T1=T2 | 0.23 | 0.46 | 0.95 | 0.13 |
| N | 1,764 | 1,764 | 1,764 | 1,764 |

*Notes:* The dependent variable is an indicator for whether the specific variety of rice was used on the plot at endline. ST indicates the farmers in the soil-test based recommendation treatment group and UC indicates farmers in the union council recommendation treatment group. All regressions include strata and union fixed effects, farmer's age, years of education, total plot area, log of nonagricultural income in BDT and the share of plots with different rice varieties at baseline, and a dummy variable to indicate whether the plot was soil-tested. Plot level controls include plot depth.
Standard errors, clustered at the farmer level, are reported in parentheses.
$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

# Figures

Figure 1: Variety-wise Recommendations




*Notes:* The figure shows the average variety-wise quantities from union and soil test-based recommendations.

Figure 2: Sample Government Union Recommendation Card

**Fertilizer Recommendation Card**

District: Comilla, Upazilla: Chouddagram, Union: Ujirpur, Plot type: Plot depth medium high, Soil type: Polo

Farmer: N/A, Village: N/A

Crop: Aman (BR 25, Bridhan 33, Nridhan 39, and Binashail)

| Serial | Nutrient | Fertilizer | Results (for 1 decimal) | Application Technique |
|---|---|---|---|---|
| 1 | Nitrogen | Urea (if TSP is used) | 619 gram | Spread the fertilizer 1st installment: 10-15 days after rowing seedlings. 2nd installment: after *Kushi* grows, 3rd installment: 5-7 days before *Kaich Thor* grows |
| 2 | Nitrogen | Urea (if DAP is used) | 604 gram | Spread the fertilizer 1st installment: 10-15 days after rowing seedlings. 2nd installment: after *Kushi* grows, 3rd installment: 5-7 days before *Kaich Thor* grows |
| 3 | Phosphorus | TSP | 40 gram | During preparing the plot |
| 4 | Phosphorus | DAP | 40 gram | During preparing the plot |
| 5 | Potassium | MOP | 138 gram | During preparing the plot |
| 6 | Sulpher | Gypsum | 180 gram | During preparing the plot |
| 7 | Zinc | Zinc Sulphate (Hepta) | Not required | |
| 8 | Zinc | Zinc Sulphate (Mono) | Not required | |
| 9 | Boron | Boric Acid | Not required | |
| 10 | Boron | Solubor | Not required | |
| 11 | Organic matter | Manure/Compost | As needed | During preparing the plot |

Source: Respective Upazilla Guidebook

*Notes:* The figure shows a translated version of the sample recommendation card provided by the government.

Figure 3: Sample Recommendation Card Used for the Intervention

Group 2 farmers                                                    Id: N

Village Information

| | | | |
|---|---|---|---|
| Village | **Tajer Vomra** | Union | **7th Laksam East** |
| **Contact:**<br>For any education, health, solar power, microfinance, and agriculture related question, please contact the following CDIP branch. | | | |
| CDIP Branch Name | **Laksam** | CDIP Branch Phone No. | **XXX-XXXXXXXX** |
| CDPI Branch Address | **Center for Development Innovation and Practices (CDIP)**<br>**Village: Nashratpur**<br><br>**Post Office: Laksam, District: Comilla** | | |

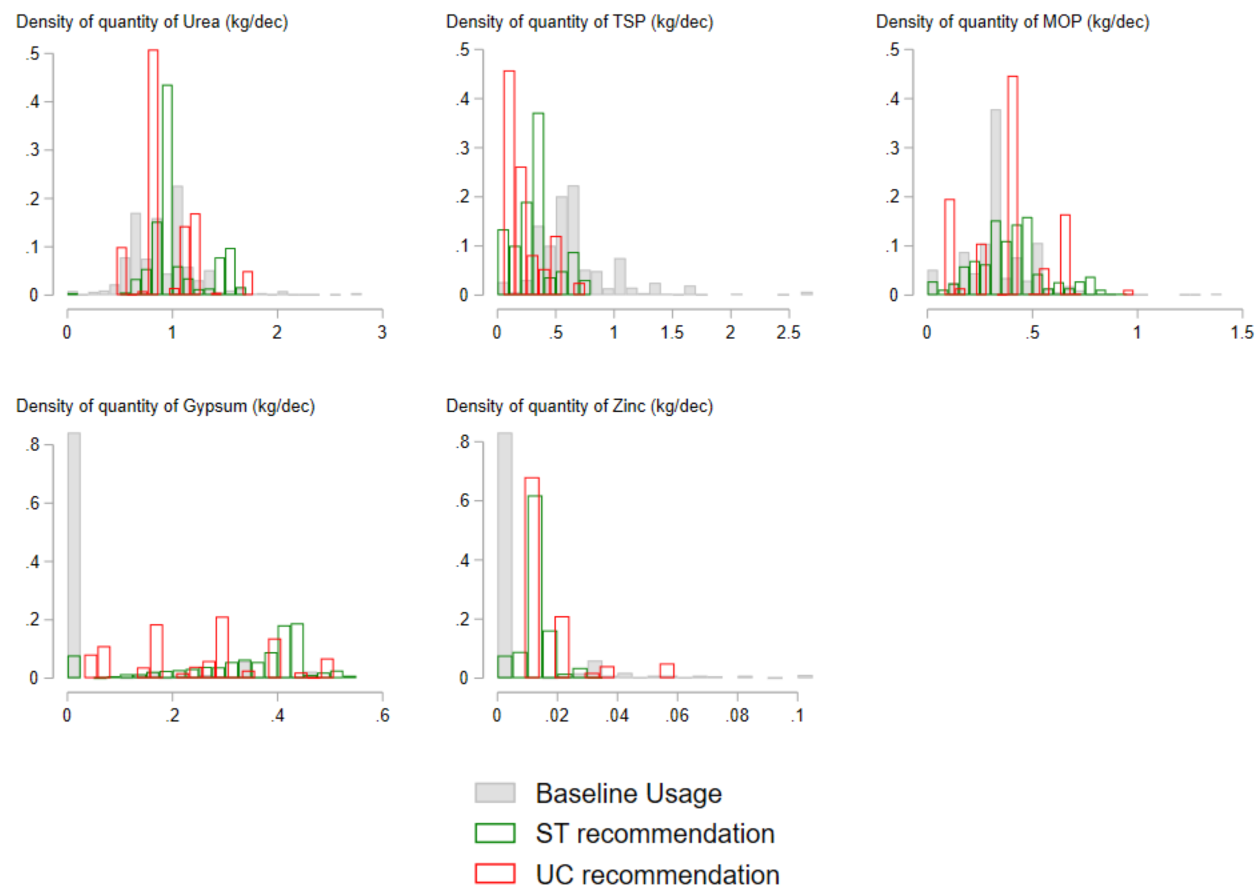
Farmer/Plot Information

| | | | |
|---|---|---|---|
| Farmer Id | **N** | | |
| Name of farmer and father | **A** | | |
| Plot Name | **C** | Plot Code | **B** |

| | | Boro Raice Variety | | | |
|---|---|---|---|---|---|
| **Name of Fertilizer** | | BR 1, BR 2, BR 7, BR 15, Bridhan 28, Bridhan 35, Bridhan 36 | BR 3, BR 8, BR 9, BR 14, BR 16, R 17, BR 18, BR 19, Binadhan 4 | Bridhan 29, Binadhan 6, Hybrid | Local Improved Variety |
| 1 | Urea (gram/decimal) | 892 | 1146 | 1427 | 586 |
| 2 | MOP (gram/decimal) | 368 | 460 | 607 | 257 |
| 3 | TSP (gram/decimal) | 74 | 104 | 149 | 59 |
| 4 | Gypsum (gram/decimal) | 393 | 314 | 471 | 236 |
| 5 | Zinc (gram/decimal) | 13 | 15 | 20 | 9 |

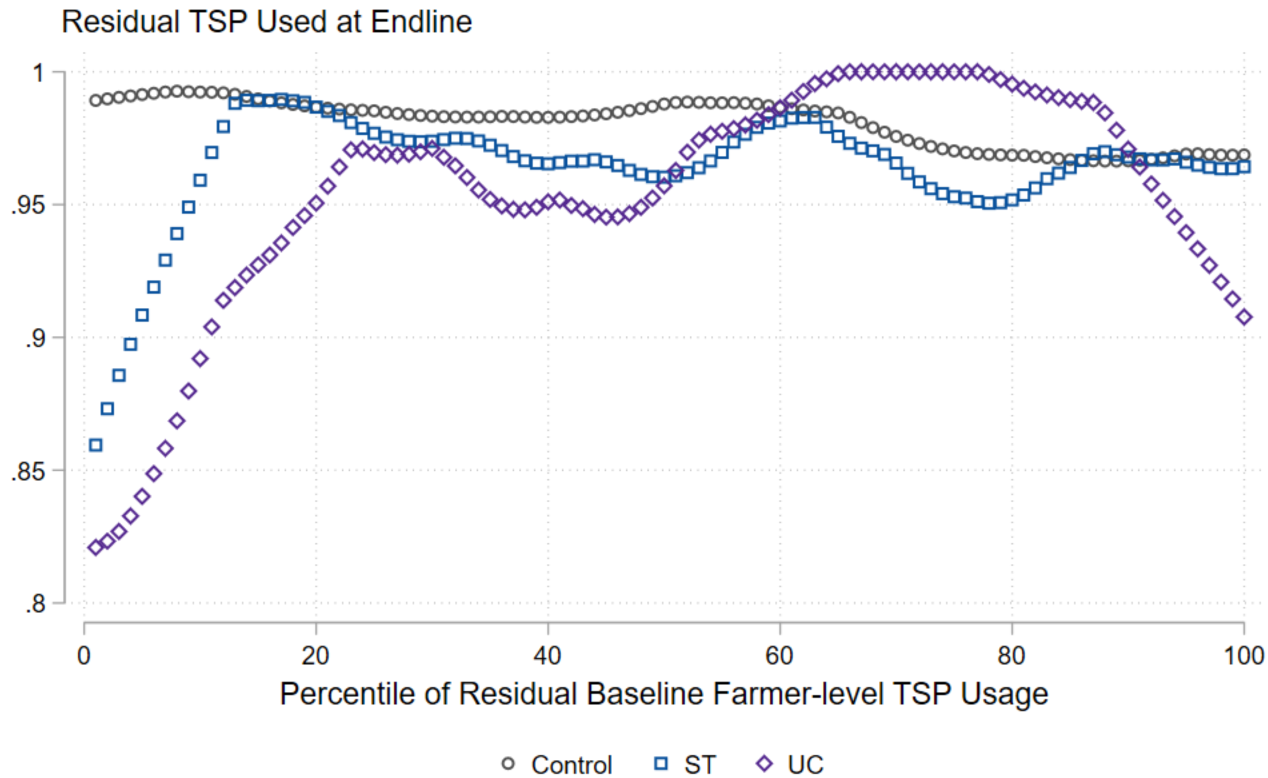
*Notes:* The figure shows a translated version the sample recommendation card delivered to ST farmers.

Figure 4: Baseline Usage, ST Recommendation, and UC Recommendation



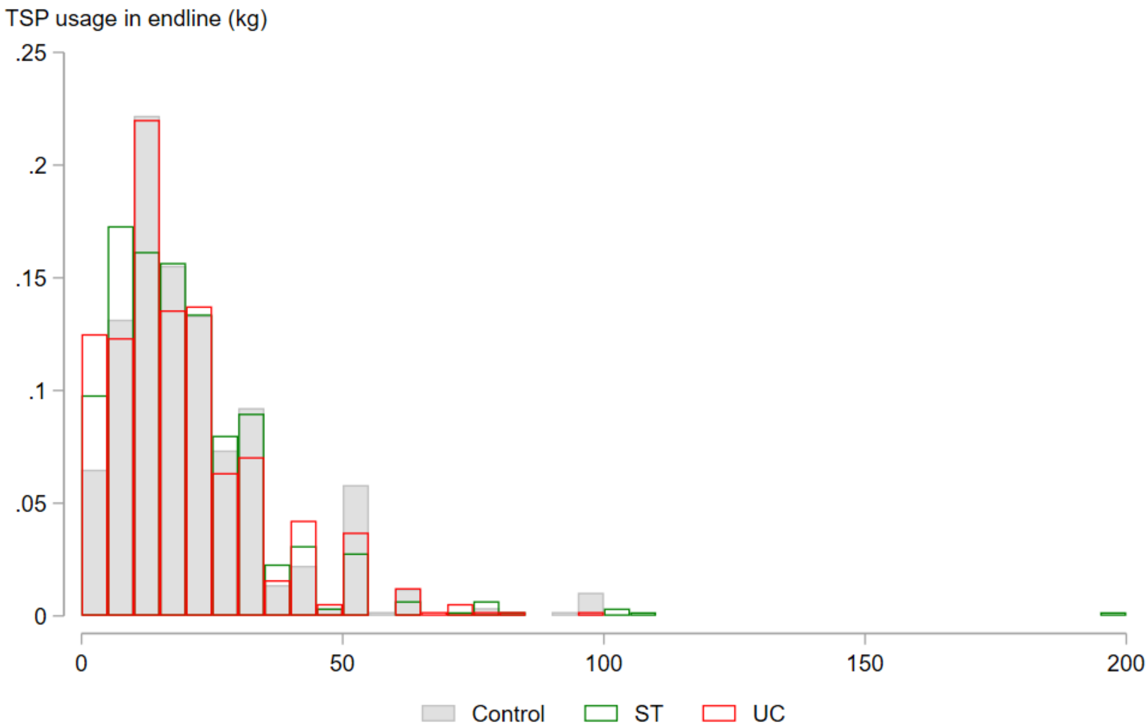

*Notes:* The figure shows the distribution of the plot-level baseline usage, ST recommendation, and UC recommendation (including plots where the usage or recommendation is zero).

Figure 5: Non-parametric Treatment Effects by Percentile of Baseline TSP Usage




*Notes:* The figure shows residual TSP used as a function of percentile of residual baseline per decimal TSP usage for the control and treatment groups. These treatment and control lines are estimated using local linear regressions. The x-axis is the percentile of the residual of a regression of the baseline farmer-level TSP usage on baseline farmer- and plot-level characteristics including union and strata fixed effects. The y-axis is the residual of a regression of an indicator variable whether the farmer used TSP at endline on baseline farmer- and plot-level characteristics including union and strata fixed effects

Figure 6: Total TSP Usage by Treatment Arm




*Notes:* The figure shows the distribution of total TSP used by a farmer at endline for control and treatment groups.

# Appendix A

parentheses

Table A1: Description of Treatment Arms

| Treatment/ Control | Description of treatment | Number of farmers in baseline |
|---|---|---|
| C | No recommendation received. | 312 |
| ST | Individual recommendation. Based on soil test results | 335 |
| UC | Union based recommendation. Varies by plotdepth | 323 |

Table A2: Summary Statistics and Balance Test for Plot-level Baseline Input and Output by Treatment Arm

| Variable | (1) C Mean/SE | (2) ST Mean/SE | (3) UC Mean/SE | t-test p-value (1)-(2) | (1)-(3) | (2)-(3) |
|---|---|---|---|---|---|---|
| Yield (kg/decimal) | 21.537 | 21.921 | 21.195 | 0.424 | 0.889 | 0.395 |
| | (0.342) | (0.342) | (0.538) | | | |
| Revenue (BDT/decimal) | 339.114 | 341.346 | 335.832 | 0.713 | 0.834 | 0.425 |
| | (6.172) | (6.072) | (7.707) | | | |
| Total cost (BDT/decimal) | 261.099 | 260.723 | 259.904 | 0.526 | 0.808 | 0.576 |
| | (4.663) | (4.254) | (4.400) | | | |
| Profit (BDT/decimal) | 78.015 | 80.623 | 75.927 | 0.471 | 0.737 | 0.324 |
| | (6.565) | (6.396) | (7.595) | | | |
| Fertilizer usage (used=1) | | | | | | |
| *Urea* | 0.997 | 1.000 | 1.000 | 0.128 | 0.126 | N/A |
| | (0.002) | (0.000) | (0.000) | | | |
| *TSP* | 0.978 | 0.980 | 0.978 | 0.909 | 0.786 | 0.821 |
| | (0.010) | (0.009) | (0.008) | | | |
| *MOP* | 0.955 | 0.933 | 0.946 | 0.396 | 0.831 | 0.309 |
| | (0.012) | (0.016) | (0.013) | | | |
| *Gypsum* | 0.200 | 0.192 | 0.167 | 0.608 | 0.560 | 0.982 |
| | (0.027) | (0.025) | (0.024) | | | |
| *Zinc* | 0.198 | 0.171 | 0.176 | 0.135 | 0.703 | 0.461 |
| | (0.027) | (0.023) | (0.023) | | | |
| Quantity of fertilizer used (kg/decimal) | | | | | | |
| *Urea* | 0.920 | 0.905 | 0.925 | 0.226 | 0.356 | 0.111 |
| | (0.023) | (0.019) | (0.021) | | | |
| *TSP* | 0.626 | 0.611 | 0.632 | 0.262 | 0.827 | 0.497 |
| | (0.020) | (0.019) | (0.021) | | | |
| *MOP* | 0.330 | 0.327 | 0.336 | 0.708 | 0.507 | 0.445 |
| | (0.009) | (0.011) | (0.011) | | | |
| *Gypsum* | 0.063 | 0.048 | 0.042 | 0.206 | 0.101 | 0.902 |
| | (0.009) | (0.006) | (0.006) | | | |
| *Zinc* | 0.009 | 0.008 | 0.009 | 0.215 | 0.369 | 0.185 |
| | (0.001) | (0.001) | (0.001) | | | |
| N | 705 | 793 | 743 | | | |
| No. of farmers | 312 | 335 | 323 | | | |

*Notes:* The value displayed for t-tests are $p$-values. Standard errors are clustered at farmer level. Strata fixed effects are included in all estimation regressions. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level. 100 decimal = 1 acre; 1 $US\$ \approx 85$ BDT

Table A3: Summary Statistics and Balance Test for Plot-level Baseline Input and Output by Treatment for Soil Test Plots

| Variable | (1) C Mean/SE | (2) ST Mean/SE | (3) UC Mean/SE | t-test p-value (1)-(2) | (1)-(3) | (2)-(3) |
|---|---|---|---|---|---|---|
| Yield (kg/decimal) | 21.406 | 21.822 | 21.605 | 0.529 | 0.598 | 0.722 |
| | (0.387) | (0.326) | (0.337) | | | |
| Revenue (BDT/decimal) | 336.412 | 339.870 | 334.340 | 0.623 | 0.976 | 0.418 |
| | (6.673) | (5.884) | (6.556) | | | |
| Total cost (BDT/decimal) | 261.815 | 262.111 | 261.004 | 0.500 | 0.712 | 0.556 |
| | (5.082) | (4.812) | (4.931) | | | |
| Profit (BDT/decimal) | 74.597 | 77.759 | 73.337 | 0.409 | 0.851 | 0.328 |
| | (7.223) | (6.600) | (7.493) | | | |
| Fertilizer usage (used=1) | | | | | | |
| *Urea* | 1.000 | 1.000 | 1.000 | N/A | N/A | N/A |
| | (0.000) | (0.000) | (0.000) | | | |
| *TSP* | 0.987 | 0.980 | 0.971 | 0.532 | 0.449 | 0.910 |
| | (0.007) | (0.014) | (0.012) | | | |
| *MOP* | 0.965 | 0.942 | 0.955 | 0.159 | 0.734 | 0.292 |
| | (0.012) | (0.018) | (0.014) | | | |
| *Gypsum* | 0.169 | 0.171 | 0.163 | 0.932 | 0.960 | 0.805 |
| | (0.025) | (0.028) | (0.025) | | | |
| *Zinc* | 0.195 | 0.180 | 0.171 | 0.499 | 0.624 | 0.791 |
| | (0.028) | (0.029) | (0.025) | | | |
| Quantity of fertilizer used (kg/decimal) | | | | | | |
| *Urea* | 0.924 | 0.864 | 0.900 | 0.052* | 0.646 | 0.168 |
| | (0.027) | (0.019) | (0.023) | | | |
| *TSP* | 0.649 | 0.618 | 0.613 | 0.181 | 0.355 | 0.678 |
| | (0.025) | (0.025) | (0.022) | | | |
| *MOP* | 0.326 | 0.318 | 0.341 | 0.397 | 0.118 | 0.019** |
| | (0.010) | (0.011) | (0.011) | | | |
| *Gypsum* | 0.052 | 0.049 | 0.045 | 0.954 | 0.698 | 0.985 |
| | (0.008) | (0.009) | (0.007) | | | |
| *Zinc* | 0.009 | 0.008 | 0.009 | 0.464 | 0.238 | 0.373 |
| | (0.001) | (0.001) | (0.001) | | | |
| N | 231 | 294 | 245 | | | |
| No. of farmers | 206 | 229 | 212 | | | |

*Notes*: The value displayed for t-tests are $p$-values. Standard errors are clustered at farmer level. Strata fixed effects are included in all estimation regressions. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level. 100 decimal = 1 acre; 1 $US\$ \approx 85$ BDT

Table A4: Summary Statistics and Balance Test for Farmer-level Baseline Characteristics (Analysis Sample))

| Variable | (1)<br>C<br>Mean/SE | (2)<br>ST<br>Mean/SE | (3)<br>UC<br>Mean/SE | T-test<br>*p*-value<br>(1)-(2) | <br><br>(1)-(3) | <br><br>(2)-(3) |
|---|---|---|---|---|---|---|
| Age (in years) | 49.719 | 49.352 | 48.572 | 0.453 | 0.569 | 0.901 |
| | (0.837) | (0.867) | (0.889) | | | |
| Schooling (in years) | 4.905 | 5.639 | 5.264 | 0.416 | 0.622 | 0.721 |
| | (0.291) | (0.312) | (0.307) | | | |
| Log(Farmer's other income in BDT) | 10.435 | 10.470 | 10.585 | 0.975 | 0.092* | 0.152 |
| | (0.111) | (0.096) | (0.066) | | | |
| Received LCC treatment (=1) | 0.513 | 0.470 | 0.525 | 0.686 | 0.984 | 0.135 |
| | (0.033) | (0.033) | (0.034) | | | |
| Number of plots owned | 2.593 | 2.665 | 2.570 | 0.814 | 0.964 | 0.506 |
| | (0.082) | (0.094) | (0.087) | | | |
| Mean total plot area (decimal) | 82.876 | 81.722 | 78.913 | 0.532 | 0.609 | 0.352 |
| | (3.233) | (3.442) | (3.308) | | | |
| Mean total cultivated area (decimal) | 77.009 | 76.748 | 74.271 | 0.775 | 0.593 | 0.405 |
| | (3.315) | (3.474) | (3.349) | | | |
| Mean yield (kg/decimal) | 21.824 | 21.508 | 21.089 | 0.727 | 0.775 | 0.876 |
| | (0.639) | (0.395) | (0.493) | | | |
| Mean revenue (BDT/decimal) | 341.812 | 342.305 | 333.806 | 0.719 | 0.528 | 0.504 |
| | (7.664) | (5.970) | (6.565) | | | |
| Mean total cost (BDT/decimal) | 250.701 | 247.033 | 246.280 | 0.464 | 0.809 | 0.734 |
| | (4.816) | (4.408) | (4.447) | | | |
| Mean profit (BDT/decimal) | 91.110 | 95.272 | 87.526 | 0.418 | 0.655 | 0.404 |
| | (7.646) | (6.080) | (6.392) | | | |
| Plot depth at endline | | | | | | |
| *High* | 0.120 | 0.082 | 0.077 | 0.052* | 0.093* | 0.895 |
| | (0.020) | (0.017) | (0.016) | | | |
| *Medium high* | 0.413 | 0.443 | 0.438 | 0.553 | 0.196 | 0.397 |
| | (0.030) | (0.030) | (0.030) | | | |
| *Medium low* | 0.311 | 0.315 | 0.340 | 0.774 | 0.684 | 0.670 |
| | (0.028) | (0.028) | (0.029) | | | |
| *Low* | 0.126 | 0.137 | 0.120 | 0.922 | 0.494 | 0.074* |
| | (0.021) | (0.021) | (0.020) | | | |
| *Very low* | 0.031 | 0.024 | 0.025 | 0.358 | 0.690 | 0.763 |
| | (0.009) | (0.009) | (0.009) | | | |
| Fertilizer usage (used=1) | | | | | | |
| *Urea* | 0.997 | 0.997 | 1.000 | 0.908 | 0.212 | 0.332 |
| | (0.003) | (0.003) | (0.000) | | | |
| *TSP* | 0.967 | 0.975 | 0.972 | 0.587 | 0.737 | 0.970 |
| | (0.011) | (0.009) | (0.010) | | | |
| *MOP* | 0.926 | 0.908 | 0.929 | 0.744 | 0.796 | 0.818 |
| | (0.016) | (0.018) | (0.016) | | | |
| *Gypsum* | 0.162 | 0.166 | 0.157 | 0.711 | 0.912 | 0.846 |
| | (0.024) | (0.024) | (0.025) | | | |
| *Zinc* | 0.186 | 0.161 | 0.178 | 0.194 | 0.782 | 0.725 |
| | (0.025) | (0.024) | (0.025) | | | |
| Mean quantity of fertilizer used (kg/decimal) | | | | | | |
| *Urea* | 0.929 | 0.892 | 0.912 | 0.020** | 0.902 | 0.106 |
| | (0.024) | (0.019) | (0.020) | | | |
| *TSP* | 0.637 | 0.608 | 0.615 | 0.208 | 0.795 | 0.431 |
| | (0.022) | (0.020) | (0.021) | | | |
| *MOP* | 0.338 | 0.333 | 0.332 | 0.894 | 0.927 | 0.749 |
| | (0.014) | (0.012) | (0.011) | | | |
| *Gypsum* | 0.058 | 0.044 | 0.040 | 0.454 | 0.141 | 0.634 |
| | (0.010) | (0.007) | (0.007) | | | |
| *Zinc* | 0.009 | 0.008 | 0.010 | 0.228 | 0.384 | 0.187 |
| | (0.001) | (0.001) | (0.002) | | | |
| N | 226 | 230 | 221 | | | |

*Notes:*The value displayed for t-tests are *p*-values. Standard errors are clustered at farmer level. Strata fixed effects are included in all estimation regressions. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level. 100 decimal = 1 acre; 1 $US\$ \approx 85$ BDT

Table A5: Attrition Heterogeneity

| | (1) Atritted | (2) Atritted | (3) Atritted |
|---|---|---|---|
| ST | 0.022 | 0.023 | 0.039 |
| | (0.023) | (0.023) | (0.030) |
| UC | 0.034 | 0.028 | 0.052 |
| | (0.024) | (0.024) | (0.032) |
| ST × Baseline TSP Usage | 0.031 | | |
| | (0.101) | | |
| UC × Baseline TSP Usage | -0.045 | | |
| | (0.106) | | |
| ST × Baseline Yield | | 0.008 | |
| | | (0.005) | |
| UC × Baseline Yield | | -0.001 | |
| | | (0.004) | |
| ST × Above median schooling=1 | | | -0.052 |
| | | | (0.047) |
| UC × Above median schooling=1 | | | -0.056 |
| | | | (0.049) |
| Control mean | 0.276 | 0.276 | 0.276 |
| N | 970 | 970 | 970 |

*Notes:*Each regression includes respective interacted variable and strata fixed effects. Heteroscedasticity-robust standard errors are in parentheses. In columns 1 and 2, demeaned TSP usage and yield are included, respectively. * $p < 0.10$, ** $p < 0.05$, ***

Table A6: Share of Farmers Overusing Fertilizer Relative to Recommendations

| Nutrient | Fertilizer | Share of plots where Usage > ST Recommendation | Share of plots where Usage > UC Recommendation |
|---|---|---|---|
| N | Urea | 0.35 | 0.49 |
| P | TSP | 0.85 | 0.90 |
| K | MOP | 0.42 | 0.44 |
| S | Gypsum | 0.42 | 0.67 |
| Zn | Zinc | 1.00 | 0.98 |

*Notes:* The table shows farmers that apply fertilizer quantities above the recommended amount as a share of all farmers using that fertilizer.

Table A7: Plot-level Effects on Fertilizer Usage (Full Sample ITT Estimate)

| | Fertilizer used in endline=1 | | | | |
|---|---|---|---|---|---|
| | (1) Urea | (2) TSP | (3) MOP | (4) Gypsum | (5) Zinc |
| ST × Plot Soil Tested | 0.001 | -0.026 | -0.030 | 0.008 | 0.053 |
| | (0.003) | (0.020) | (0.027) | (0.036) | (0.036) |
| ST × Plot Soil Not Tested | -0.004 | -0.027* | -0.006 | -0.009 | -0.013 |
| | (0.004) | (0.014) | (0.019) | (0.034) | (0.032) |
| UC | 0.001 | -0.043** | -0.021 | -0.024 | 0.040 |
| | (0.003) | (0.017) | (0.019) | (0.032) | (0.030) |
| Control group endline mean | 1.00 | 0.98 | 0.96 | 0.20 | 0.24 |
| $p$-value for equality across arms | 0.45 | 0.67 | 0.53 | 0.64 | 0.07 |
| N | 1,764 | 1,764 | 1,764 | 1,760 | 1,758 |

*Notes:* Dependent variable is an indicator for whether the specific fertilizer was used on the plot at endline. ST indicates the farmers in the soil-test based recommendation treatment group and UC indicates farmers in the union council recommendation treatment group. All regressions include strata and union fixed effects, the share of plots at which the farmer applied the fertilizer in the baseline, farmer's age, years of education, total plot area, log of nonagricultural income in BDT and the share of plots with different rice varieties at baseline, and a dummy variable to indicate whether the plot was soil-tested.. Plot level controls include plot depth.
Standard errors, clustered at the farmer level, are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A8: Multiple Hypothesis Testing Adjustment

| Outcome | Effect | *p*-value | FDR Adjusted *p*-value |
|---|---|---|---|
| | ST | | |
| Fertilizer usage (used=1) | | | |
| *Urea* | -0.003 | 0.331 | 0.661 |
| *TSP* | -0.027* | 0.053 | 0.171 |
| *MOP* | -0.013 | 0.496 | 0.721 |
| *Gypsum* | -0.004 | 0.902 | 0.902 |
| *Zinc* | 0.006 | 0.847 | 0.902 |
| Yield (kg/dec.) | 0.248 | 0.495 | 0.721 |
| Revenue (BDT/dec.) | 4.195 | 0.627 | 0.772 |
| Profit (BDT/dec.) | 6.481 | 0.540 | 0.721 |
| | UC | | |
| Fertilizer usage (used=1) | | | |
| *Urea* | 0.001 | 0.689 | 0.787 |
| *TSP* | -0.043** | 0.011 | 0.088 |
| *MOP* | -0.021 | 0.285 | 0.653 |
| *Gypsum* | -0.024 | 0.453 | 0.721 |
| *Zinc* | 0.039 | 0.191 | 0.511 |
| Yield (kg/dec.) | -0.899** | 0.022 | 0.118 |
| Revenue (BDT/dec.) | -24.561*** | 0.005 | 0.077 |
| Profit (BDT/dec.) | -23.458** | 0.033 | 0.132 |

*Notes*: Notes: Adjusted sharpened q-values calculated for all outcomes using the method suggested by Anderson (2008) based on Benjamini & Hochberg (1995).
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A9: Multiple Hypothesis Testing Adjustment for Effects on Fertilizer Application Error

| Outcome | Effect | p-value | FDR Adjusted $p$-value |
|---|---|---|---|
| | | ST | |
| Standardized absolute value of (Usage-ST recommendation) | | | |
| *Urea* | 0.146 | 0.253 | 0.633 |
| *TSP* | -0.219* | 0.071 | 0.238 |
| *MOP* | -0.072 | 0.548 | 0.699 |
| *Gypsum* | -0.212 | 0.358 | 0.699 |
| *Zinc* | 0.269 | 0.698 | 0.699 |
| | | UC | |
| Standardized absolute value of (Usage-UC recommendation) | | | |
| *Urea* | 0.031 | 0.667 | 0.699 |
| *TSP* | -0.042 | 0.577 | 0.699 |
| *MOP* | 0.036 | 0.616 | 0.699 |
| *Gypsum* | -0.143** | 0.039 | 0.238 |
| *Zinc* | -0.278* | 0.064 | 0.238 |

*Notes*: Notes: Adjusted sharpened q-values calculated for all outcomes using the method suggested by Anderson (2008) based on Benjamini & Hochberg (1995).
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A10: Endline Fertilizer Application Error

| | Absolute value of (Usage-ST recommendation) | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| | Urea | TSP | MOP | Gypsum | Zinc |
| ST | 0.043 | -0.078* | -0.012 | -0.033 | 0.010 |
| | (0.038) | (0.043) | (0.019) | (0.035) | (0.025) |
| Control group endline mean | 0.35 | 0.46 | 0.19 | 0.27 | 0.07 |
| N | 489 | 473 | 468 | 71 | 87 |
| | Absolute value of (Usage-UC recommendation) | | | | |
| | (1) | (2) | (3) | (4) | (5) |
| | Urea | TSP | MOP | Gypsum | Zinc |
| UC | 0.010 | -0.016 | 0.005 | -0.022** | -0.012* |
| | (0.023) | (0.029) | (0.011) | (0.011) | (0.007) |
| Control group endline mean | 0.40 | 0.53 | 0.19 | 0.13 | 0.08 |
| N | 1,740 | 1,682 | 1,667 | 339 | 400 |

*Notes:* Dependent variable is the absolute difference between plot level per decimal fertilizer usage at endline and the recommended amount, conditional on any usage. Panel A includes only soil-tested plots. ST indicates the farmers in the soil-test based recommendation treatment group and UC indicates farmers in the union council recommendation treatment group. All regressions include strata and union fixed effects, the average per decimal fertilizer usage by the farmer at baseline, farmer's age, years of education, total plot area, log of nonagricultural income in BDT and the share of plots with different rice varieties at baseline, and a dummy variable to indicate whether plot was soil-tested. Plot level controls include plot depth.
Standard errors, clustered at the farmer level, are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A11: Endline Fertilizer Application Error

| Panel A | Standardized absolute value of (Usage-ST recommendation) | | | | |
|---|---|---|---|---|---|
| | (1) Urea | (2) TSP | (3) MOP | (4) Gypsum | (5) Zinc |
| ST | 0.146 | -0.209* | 0.010 | 0.164 | 0.062 |
| | (0.128) | (0.119) | (0.121) | (0.110) | (0.100) |
| Control group endline mean | 0.00 | -0.00 | -0.00 | 0.00 | -0.00 |
| N | 489 | 489 | 489 | 487 | 489 |
| **Panel B** | **Standardized absolute value of (Usage-UC recommendation)** | | | | |
| | (1) Urea | (2) TSP | (3) MOP | (4) Gypsum | (5) Zinc |
| UC | 0.034 | -0.090 | 0.040 | -0.013 | -0.046 |
| | (0.071) | (0.077) | (0.074) | (0.021) | (0.062) |
| Control group endline mean | -0.00 | 0.00 | -0.00 | 0.00 | 0.00 |
| N | 1,745 | 1,745 | 1,745 | 1,741 | 1,745 |

*Notes:* Dependent variable is the standard deviation of the difference between plot level per decimal fertilizer usage at endline and the recommended amount, unconditional on usage. The recommended amount is based on the ST recommendation in Panel A and on the UC recommendation in Panel B. Panel A includes only soil-tested plots. ST indicates the farmers in the soil-test based recommendation treatment group and UC indicates farmers in the union council recommendation treatment group All regressions include strata and union fixed effects, the average per decimal fertilizer usage by the farmer at baseline, farmer's age, years of education, total plot area, log of nonagricultural income in BDT and the share of plots with different rice varieties at baseline, and a dummy variable to indicate whether plot was soil-tested. Plot level controls include plot depth.
Standard errors, clustered at the farmer level, are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A12: Endline Fertilizer Application Error

| | Standardized absolute value of (Usage-ST recommendation) | | | | |
|---|---|---|---|---|---|
| | (1) Urea | (2) TSP | (3) MOP | (4) Gypsum | (5) Zinc |
| | Standardized absolute value of (Usage-UC recommendation) | | | | |
| | (1) Urea | (2) TSP | (3) MOP | (4) Gypsum | (5) Zinc |
| UC | 0.085 | -0.165 | -0.063 | -0.005 | -0.157 |
| | (0.109) | (0.116) | (0.110) | (0.139) | (0.421) |
| Control group endline mean | -0.16 | 0.13 | 0.00 | -0.08 | 1.26 |
| N | 489 | 473 | 468 | 71 | 87 |

*Notes:* Dependent variable is the standard deviation of the difference between plot level per decimal fertilizer usage at endline and the recommended amount, unconditional on usage. The recommended amount is based on UC recommendation. The table replicates Panel B of Table 5 but includes only soil-tested plots. ST indicates the farmers in the soil-test based recommendation treatment group and UC indicates farmers in the union council recommendation treatment group All regressions include strata and union fixed effects, the average per decimal fertilizer usage by the farmer at baseline, farmer's age, years of education, total plot area, log of nonagricultural income in BDT and the share of plots with different rice varieties at baseline, and a dummy variable to indicate whether plot was soil-tested. Plot level controls include plot depth. Standard errors, clustered at the farmer level, are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A13: Plot-level Effects on Fertilizer Usage (Conditional on Using the Fertilizer, Full Sample ITT)

| | Quantity of fertilizer used (kg/dec.) | | | | |
|---|---|---|---|---|---|
| | (1) Urea | (2) TSP | (3) MOP | (4) Gypsum | (5) Zinc |
| ST | -0.029 | -0.007 | -0.002 | 0.006 | -0.008 |
| | (0.028) | (0.027) | (0.014) | (0.007) | (0.005) |
| UC | -0.010 | -0.020 | -0.011 | 0.002 | -0.012* |
| | (0.028) | (0.029) | (0.015) | (0.007) | (0.007) |
| Control group endline mean | 0.90 | 0.71 | 0.36 | 0.03 | 0.09 |
| $p$-value for equality across arms | 0.50 | 0.65 | 0.50 | 0.52 | 0.65 |
| N | 1,759 | 1,701 | 1,684 | 341 | 406 |

*Notes:* Dependent variable is plot level per decimal fertilizer usage at endline. ST indicates the farmers in the soil-test based recommendation treatment group and UC indicates farmers in the union council recommendation treatment group. All regressions include strata and union fixed effects, the average per decimal fertilizer usage by the farmer at baseline, farmer's age, years of education, total plot area, log of nonagricultural income in BDT and the share of plots with different rice varieties at baseline, and a dummy variable to indicate whether plot was soil-tested. Plot level controls include plot depth.
Standard errors, clustered at the farmer level, are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
100 decimal = 1 acre

Table A14: Plot-level Effects on Fertilizer Usage by Soil Test Status (Conditional on Using the Fertilizer, Full Sample ITT)

| | Quantity of fertilizer used (kg/dec.) | | | | |
|---|---|---|---|---|---|
| | (1)<br>Urea | (2)<br>TSP | (3)<br>MOP | (4)<br>Gypsum | (5)<br>Zinc |
| ST × Plot Soil Tested | -0.008 | -0.045 | -0.005 | 0.009 | -0.013 |
| | (0.036) | (0.035) | (0.017) | (0.009) | (0.008) |
| ST × Plot Soil Not Tested | -0.038 | 0.009 | -0.000 | 0.005 | -0.007 |
| | (0.029) | (0.028) | (0.014) | (0.007) | (0.005) |
| UC | -0.010 | -0.020 | -0.012 | 0.002 | -0.012* |
| | (0.028) | (0.029) | (0.015) | (0.007) | (0.007) |
| Control group endline mean | 0.90 | 0.71 | 0.36 | 0.03 | 0.09 |
| $p$-value for equality across arms | 0.47 | 0.16 | 0.77 | 0.66 | 0.55 |
| N | 1,759 | 1,701 | 1,684 | 341 | 406 |

*Notes:* Dependent variable is plot level per decimal fertilizer usage at endline. ST indicates the farmers in the soil-test based recommendation treatment group and UC indicates farmers in the union council recommendation treatment group. All regressions include strata and union fixed effects, the average per decimal fertilizer usage by the farmer at baseline, farmer's age, years of education, total plot area, log of nonagricultural income in BDT and the share of plots with different rice varieties at baseline, and a dummy variable to indicate whether plot was soil-tested. Plot level controls include plot depth.
Standard errors, clustered at the farmer level, are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
100 decimal = 1 acre

Table A15: Plot level spillover effects on fertilizer usage (Restricted to control farmers only)

| | Fertilizer used in endline=1 | | | | |
|---|---|---|---|---|---|
| | (1) Urea | (2) TSP | (3) MOP | (4) Gypsum | (5) Zinc |
| Number of ST farmers in 2km radius | 0.001 | -0.024 | 0.016 | 0.048 | -0.003 |
| | (0.002) | (0.017) | (0.015) | (0.042) | (0.039) |
| Number of UC farmers in 2km radius | -0.003 | -0.017 | 0.029 | 0.098** | 0.005 |
| | (0.004) | (0.011) | (0.023) | (0.050) | (0.044) |
| Control group endline mean | 1.00 | 0.98 | 0.96 | 0.20 | 0.24 |
| N | 583 | 583 | 583 | 583 | 583 |

*Notes:* The sample is restricted to control farmers. Dependent variable is an indicator variable for whether the specific fertilizer was used on the plot at endline. ST indicates the farmers in the soil-test based recommendation treatment group and UC indicates farmers in the union council recommendation treatment group. All regressions include strata and union fixed effects, total number of study farmers in the 2km radius, the share of plots on which the farmer applied the fertilizer at baseline, farmer's age, years of education, total plot area, log of nonagricultural income in BDT and the share of plots with different rice varieties at baseline, and a dummy variable to indicate whether plot was soil-tested. Plot level controls include plot depth.
Standard errors, clustered at the farmer level, are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A16: Plot-level Yield by Rice Variety (Only for Control Group Farmers)

| | (1)<br>Yield (kg/dec) |
|---|---|
| Hybrid | 2.445*** |
| | (0.626) |
| Other varieties mean | 20.75 |
| N | 583 |

*Notes:* All regressions include strata, union, and plot-depth fixed effects. Standard errors, clustered at the farmer level, are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

## Table A17: Effects on Plot-level Components of Cost

| | (1) Labor (BDT/dec.) | (2) Fertilizer (BDT/dec.) | (3) Pesticide (BDT/dec.) | (4) Equipment Rent (BDT/dec.) | (5) Vitamins (BDT/dec.) | (6) Transportation (BDT/dec.) | (7) Seeds (BDT/dec.) | (8) Fuel (BDT/dec.) | (9) Compost (BDT/dec.) | (10) Irrigation (BDT/dec.) | (11) Weedkiller (BDT/dec.) | (12) Total Cost (BDT/dec.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ST | -0.598 | -1.523 | -0.047 | -0.861 | -0.081 | 0.119 | 0.601 | 0.124 | -0.012 | 0.003 | -0.002 | -2.244 |
| | (5.919) | (1.343) | (0.722) | (1.331) | (1.013) | (0.373) | (0.378) | (0.095) | (0.104) | (0.002) | (0.001) | (6.756) |
| UC | 2.310 | -1.852 | -0.526 | 0.261 | -1.459 | -0.089 | 0.343 | 0.159 | -0.125 | 0.004 | -0.004*** | -0.824 |
| | (5.914) | (1.359) | (0.776) | (1.331) | (0.920) | (0.394) | (0.266) | (0.101) | (0.119) | (0.003) | (0.002) | (6.810) |
| Control group endline mean | 148.04 | 47.00 | 6.51 | 6.19 | 5.46 | 2.87 | 2.20 | 1.54 | 0.17 | 0.05 | 0.02 | 219.92 |
| p value for equality across arms | 0.65 | 0.80 | 0.55 | 0.40 | 0.22 | 0.59 | 0.41 | 0.74 | 0.45 | 0.93 | 0.15 | 0.85 |
| N | 1,764 | 1,764 | 1,764 | 1,764 | 1,764 | 1,764 | 1,764 | 1,764 | 321 | 1,764 | 1,764 | 1,764 |

*Notes:* Dependent variable is plot level per decimal cost for the respective items. ST indicates the farmers in the soil-test based recommendation treatment group and UC indicates farmers in the union council recommendation treatment group. All regressions include strata and union fixed effects, farmer level average of per decimal cost across plots at baseline, farmer's age, years of education, total plot area, log of nonagricultural income in BDT and the share of plots with different rice varieties at baseline, and a dummy variable to indicate whether plot was soil-tested. Plot level controls include plot depth. Standard errors, clustered at the farmer level, are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

100 decimal = 1 acre; 1 $US\$ \approx 85$ BDT

Table A18: Randomization Inference Based $p$-values for Plot-level Effects on Fertilizer Usage (Full Sample ITT Estimate)

| | Fertilizer used in endline=1 | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| | Urea | TSP | MOP | Gypsum | Zinc |
| ST | -0.003 | -0.027* | -0.013 | -0.004 | 0.006 |
| | (0.330) | (0.053) | (0.496) | (0.902) | (0.846) |
| | [0.450] | [0.066] | [0.551] | [0.914] | [0.842] |
| UC | 0.001 | -0.043** | -0.021 | -0.024 | 0.039 |
| | (0.689) | (0.011) | (0.285) | (0.453) | (0.191) |
| | [0.670] | [0.004] | [0.337] | [0.517] | [0.273] |
| Control group endline mean | 1.00 | 0.98 | 0.96 | 0.20 | 0.24 |
| $p$-value for equality across arms | 0.21 | 0.37 | 0.67 | 0.53 | 0.29 |
| N | 1,764 | 1,764 | 1,764 | 1,760 | 1,758 |

*Notes*: $p$-values from regression estimates are in parentheses and randomization inference based $p$-values are in square braces. Standard errors are clustered at the farmer level. Dependent variable is an indicator variable of whether the farmer used a fertilizer on a certain plot in the endline. ST indicates the farmers in the soil-test based recommendation treatment group and UC indicates farmers in the union council recommendation treatment group. All regressions include strata and union fixed effects, the share of plots at which the farmer applied the fertilizer at baseline, farmer's age, years of education, total plot area, log of nonagricultural income in BDT and the share of plots with different rice varieties at baseline, and a dummy variable to indicate whether plot was soil-tested. Plot level controls include plot depth.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A19: Randomization Inference Based $p$-values for Endline Fertilizer Application Error

| | Standardized absolute value of (Usage-ST recommendation) | | | | |
|---|---|---|---|---|---|
| | (1) Urea | (2) TSP | (3) MOP | (4) Gypsum | (5) Zinc |
| ST | 0.146 | -0.219* | -0.072 | -0.212 | 0.269 |
| | (0.253) | (0.071) | (0.548) | (0.358) | (0.698) |
| | [0.251] | [0.046] | [0.589] | [0.421] | [0.627] |
| Control group endline mean | 0.00 | 0.01 | -0.02 | -0.04 | 1.31 |
| N | 489 | 473 | 468 | 71 | 87 |
| | Standardized absolute value of (Usage-UC recommendation) | | | | |
| | (1) Urea | (2) TSP | (3) MOP | (4) Gypsum | (5) Zinc |
| UC | 0.031 | -0.042 | 0.036 | -0.143** | -0.278* |
| | (0.667) | (0.577) | (0.616) | (0.039) | (0.064) |
| | [0.502] | [0.575] | [0.613] | [0.961] | [0.131] |
| Control group endline mean | -0.00 | 0.02 | -0.04 | -0.10 | 1.30 |
| N | 1,740 | 1,682 | 1,667 | 339 | 400 |

*Notes*: $p$-values from regression estimates are in parentheses and randomization inference based $p$-values are in square braces. Standard errors are clustered at the farmer level. Dependent variable is the standard deviation of the difference between plot level per decimal fertilizer usage at endline and the recommended amount. ST indicates the farmers in the soil-test based recommendation treatment group and UC indicates farmers in the union council recommendation treatment group All regressions include strata and union fixed effects, the average per decimal fertilizer usage by the farmer at baseline, farmer's age, years of education, total plot area, log of nonagricultural income in BDT and the share of plots with different rice varieties at baseline, and a dummy variable to indicate whether plot was soil-tested. Plot level controls include plot depth.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A20: Randomization Inference Based $p$-values for Effects on Plot-level Outcomes (Full Sample ITT Estimate)

| | (1) Yield (kg/dec.) | (2) Revenue (BDT/dec.) | (3) Profit (BDT/dec.) |
|---|---|---|---|
| ST | 0.248 | 4.195 | 6.481 |
| | (0.495) | (0.627) | (0.540) |
| | [0.523] | [0.674] | [0.573] |
| UC | -0.899** | -24.561*** | -23.458** |
| | (0.022) | (0.005) | (0.033) |
| | [0.029] | [0.008] | [0.033] |
| Control group endline mean | 21.47 | 467.14 | 247.22 |
| $p$-value for equality across arms | 0.01 | 0.00 | 0.01 |
| N | 1,764 | 1,764 | 1,764 |

*Notes*: $p$-values from regression estimates are in parentheses and randomization inference based $p$-values are in square braces. Standard errors are clustered at the farmer level. Dependent variable is plot level per decimal yield, revenue and profit, respectively. ST indicates the farmers in the soil-test based recommendation treatment group and UC indicates farmers in the union council recommendation treatment group. All regressions include strata and union fixed effects, farmer level average of the dependent variable at baseline, farmer's age, years of education, total plot area, log of nonagricultural income in BDT and the share of plots with different rice varieties at baseline, and a dummy variable to indicate whether plot was soil-tested. Plot level controls include plot depth.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A21: Heterogeneity by Mean Yield (Full Sample ITT Estimate)

| | (1) TSP Used | (2) Yield (kg/dec.) | (3) Revenue (BDT/dec.) | (4) Profit (BDT/dec.) |
|---|---|---|---|---|
| ST × Yield Tercile 1 | -0.032 | -0.908 | -31.212** | -28.111 |
| | (0.024) | (0.676) | (14.841) | (18.303) |
| ST × Yield Tercile 2 | -0.056** | 0.727 | 13.425 | 13.468 |
| | (0.023) | (0.640) | (14.754) | (17.123) |
| ST × Yield Tercile 3 | 0.008 | 0.647 | 23.326 | 27.189 |
| | (0.024) | (0.605) | (15.152) | (18.545) |
| UC × Yield Tercile 1 | -0.101*** | -1.621** | -39.422*** | -33.547* |
| | (0.035) | (0.675) | (14.725) | (18.056) |
| UC × Yield Tercile 2 | -0.027 | -0.899 | -21.400 | -23.791 |
| | (0.024) | (0.669) | (15.215) | (18.643) |
| UC × Yield Tercile 3 | -0.005 | -0.249 | -15.890 | -15.337 |
| | (0.027) | (0.685) | (15.526) | (19.555) |
| Control group endline mean | 0.98 | 21.47 | 467.14 | 247.22 |
| ST: Tercile 1 = Tercile 2 = Tercile 3 ($p$-values) | 0.18 | 0.14 | 0.02 | 0.08 |
| UC: Tercile 1 = Tercile 2 = Tercile 3 ($p$-values) | 0.09 | 0.35 | 0.50 | 0.78 |
| N | 1,764 | 1,764 | 1,764 | 1,764 |

*Notes:* Dependent variables are indicators for TSP use, plot level per decimal yield, revenue and profit, respectively. ST indicates the farmers in the soil-test based recommendation treatment group and UC indicates farmers in the union council recommendation treatment group. All regressions include strata and union fixed effects, indicator variables for baseline yield tercile, farmer level average of the dependent variable at baseline, farmer's age, years of education, total plot area, log of nonagricultural income in BDT and the share of plots with different rice varieties at baseline, and a dummy variable to indicate whether plot was soil-tested. Plot level controls include plot depth.

Standard errors, clustered at the farmer level, are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

100 decimal = 1 acre; 1 $US\$ \approx 85$ BDT

Table A22: Heterogeneity by Schooling in Plot-level Effects on TSP Usage and Yield (Full Sample ITT Estimate)

| | (1)<br>TSP used in endline | (2)<br>Yield (kg/dec.) |
|---|---|---|
| ST | -0.050** | -0.180 |
| | (0.024) | (0.518) |
| ST × Above median schooling | 0.051** | 1.046 |
| | (0.025) | (0.756) |
| UC | -0.050 | -0.867* |
| | (0.031) | (0.503) |
| UC × Above median schooling | 0.019 | -0.155 |
| | (0.035) | (0.817) |
| Control group endline mean | 0.98 | 21.47 |
| ST:$p$-value for overall effect | 0.97 | 0.11 |
| UC:$p$-value for overall effect | 0.05 | 0.12 |
| N | 1,764 | 1,764 |

*Notes:* All regressions include strata and union fixed effects, an indicator variable for above median schooling, farmer's age, years of education, total plot area, log of nonagricultural income in BDT and the share of plots with different rice varieties at baseline, and a dummy variable to indicate whether plot was soil-tested. Plot level controls include plot depth. In addition, column 1 includes the share of plots on which the farmer applied the fertilizer at baseline, and column 2 includes farmer level average yield across plots at baseline. Plot level controls include plot depth.
Standard errors, clustered at the farmer level, are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

# Appendix B

Figure B1: Sample Government Union Recommendation Card

## সার সুপারিশ কার্ড

**জেলা:** কুমিল্লা, **উপজেলা:** চৌদ্দগ্রাম, **ইউনিয়ন:** উজিরপুর, **ভূমি শ্রেণী:** উঁচু জমি (মাঝারি উঁচু জমি), **মাটির ধরন:** পলি মাটি
**কৃষক:** প্রযোজ্য নয়, **গ্রাম:** প্রযোজ্য নয়
**ফসল:** রোপা আমন (বি আর-২৫, ব্রিধান-৩৩, ব্রিধান-৩৯ এবং বিনাশাইল)

| ক্রমিক | পুষ্টি উপাদান | সার | ফলাফল(১ শতাংশ'র জন্য) | সার প্রয়োগ পদ্ধতি |
|---|---|---|---|---|
| 1 | নাইট্রোজেন | ইউরিয়া (যদি টিএসপি ব্যবহার করা হয়) | ৬১৯ গ্রাম | ১ম কিস্তি- চারা রোপনের ১০-১৫ দিন পর, ২য় কিস্তি- কুশি গজানোর সময় এবং ৩য় কিস্তি- কাইচ থোড় আসার ৫-৭ দিন পূর্বে ছিটিয়ে দিতে হবে। |
| 2 | নাইট্রোজেন | ইউরিয়া (যদি ডিএপি ব্যবহার করা হয়) | ৬০৪ গ্রাম | ১ম কিস্তি- চারা রোপনের ১০-১৫ দিন পর, ২য় কিস্তি- কুশি গজানোর সময় এবং ৩য় কিস্তি- কাইচ থোড় আসার ৫-৭ দিন পূর্বে ছিটিয়ে দিতে হবে। |
| 3 | ফসফরাস | টিএসপি | ৪০ গ্রাম | জমি তৈরির সময় এক সাথে প্রয়োগ করতে হবে |
| 4 | ফসফরাস | ডিএপি | ৪০ গ্রাম | জমি তৈরির সময় এক সাথে প্রয়োগ করতে হবে |
| 5 | পটাশিয়াম | এমওপি | ১৩৮ গ্রাম | জমি তৈরির সময় এক সাথে প্রয়োগ করতে হবে |
| 6 | গন্ধক | জিপসাম | ১৮০ গ্রাম | জমি তৈরির সময় এক সাথে প্রয়োগ করতে হবে |
| 7 | দস্তা | জিংক সালফেট (হেপ্টা) | প্রয়োজন নেই | |
| 8 | দস্তা | জিংক সালফেট(মনো) | প্রয়োজন নেই | |
| 9 | বোরণ | বরিক এসিড | প্রয়োজন নেই | |
| 10 | বোরণ | সলুবর | প্রয়োজন নেই | |
| 11 | জৈব পদার্থ | গোবর/কম্পোষ্ট | প্রয়োজন মত | জমি তৈরির সময় এক সাথে প্রয়োগ করতে হবে |

উৎসঃ সংশ্লিষ্ট উপজেলা নির্দেশিকা

*Notes:* The figure shows the sample recommendation card provided by the government. The names of district, sub-district, and union, plot depth, soil type, and crop variety are printed at the top of the card. The chart contains columns indicating nutrient name, fertilizer name, per decimal recommended amount of fertilizer, and application technique. The card contains information for 11 type of fertilizers.

Figure B2: Sample Recommendation Card Used for the Intervention

**গ্রুপ -২ এর কৃষকদের জন্য** Id: N

**গ্রামের তথ্য**

| | | | |
|---|---|---|---|
| গ্রাম | **তাজের ভোমা** | ইউনিয়ন | **৭ নং লাক্সাম পূর্ব** |
| **যোগাযোগ:**<br>আপনি শিক্ষা, স্বাস্থ্য, সৌর বিদ্যুৎ, ক্ষুদ্রঋণ এবং কৃষি বিষয়ক যে কোন পরামর্শের জন্য নীচে সিদিপ শাখা অফিসের ঠিকানায় যোগাযোগ করতে পারেন | | | |
| সিদিপ ব্রাঞ্চ এর নাম | লাক্সাম | সিদিপ ব্রাঞ্চ এর নাম্বার | XXX-XXXXXXXX |
| সিদিপ ব্রাঞ্চ এর ঠিকানা | **সেন্টার ফর ডেভেলপমেন্ট ইনোভেশন এন্ড প্র্যাকটিসেস (সিদিপ)**<br>**গ্রামঃ নশরতপুর**<br>**পোঃ লাক্সাম, জেলাঃ কুমিল্লা** | | |

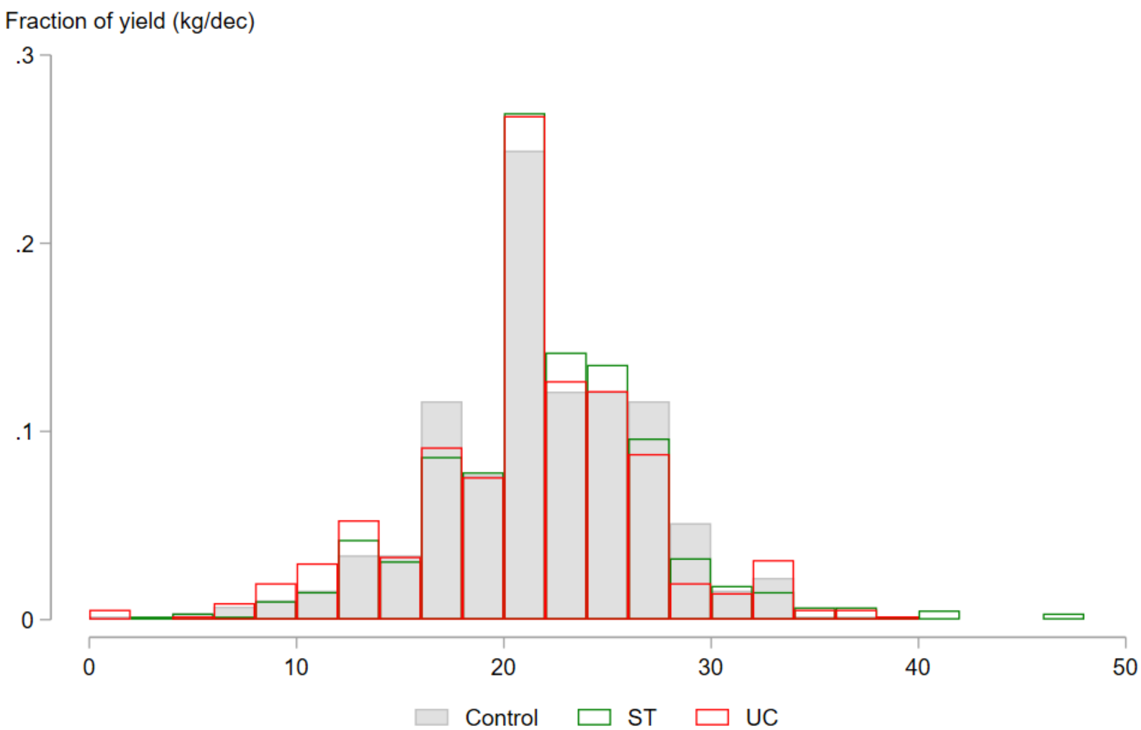
**কৃষক/ প্লট এর তথ্য**

| | | | |
|---|---|---|---|
| কৃষক আইডি | N | | |
| কৃষক এবং কৃষকের পিতার নাম | A | | |
| প্লটের নাম | C | প্লট কোড | B |

| | | বোর ধানের জাত | | | |
|---|---|---|---|---|---|
| | **সারের নাম** | বি আর ১, বি আর ২, বি আর ৭, বি আর ১৫, ব্রিধান ২৮ ব্রিধান ৩৫ ব্রিধান ৩৫ | বি আর ৩, বি আর ৮, বি আর ৯, বি আর ১৪, বি আর ১৬, বি আর ১৭ বি আর ১৮, বি আর ১৯ বিনাধান ৪ | ব্রিধান ২৯ বিনাধান ৬ হাইব্রিড | স্থানীয় উন্নত জাত |
| 1. | ইউরিয়া (গ্রাম/শতক) | **৮৯২** | **১১৪৬** | **১৪২৭** | **৫৮৬** |
| 2. | এমওপি (গ্রাম/শতক) | **৩৬৮** | **৪৬০** | **৬০৭** | **২৫৭** |
| 3. | টিএসপি (গ্রাম/শতক) | **৭৪** | **১০৪** | **১৪৯** | **৫৯** |
| 4. | জিপসাম (গ্রাম/শতক) | **৩৯৩** | **৩১৪** | **৪৭১** | **২৩৬** |
| 5. | জিঙ্ক (গ্রাম/শতক) | **১৩** | **১৫** | **২০** | **৯** |

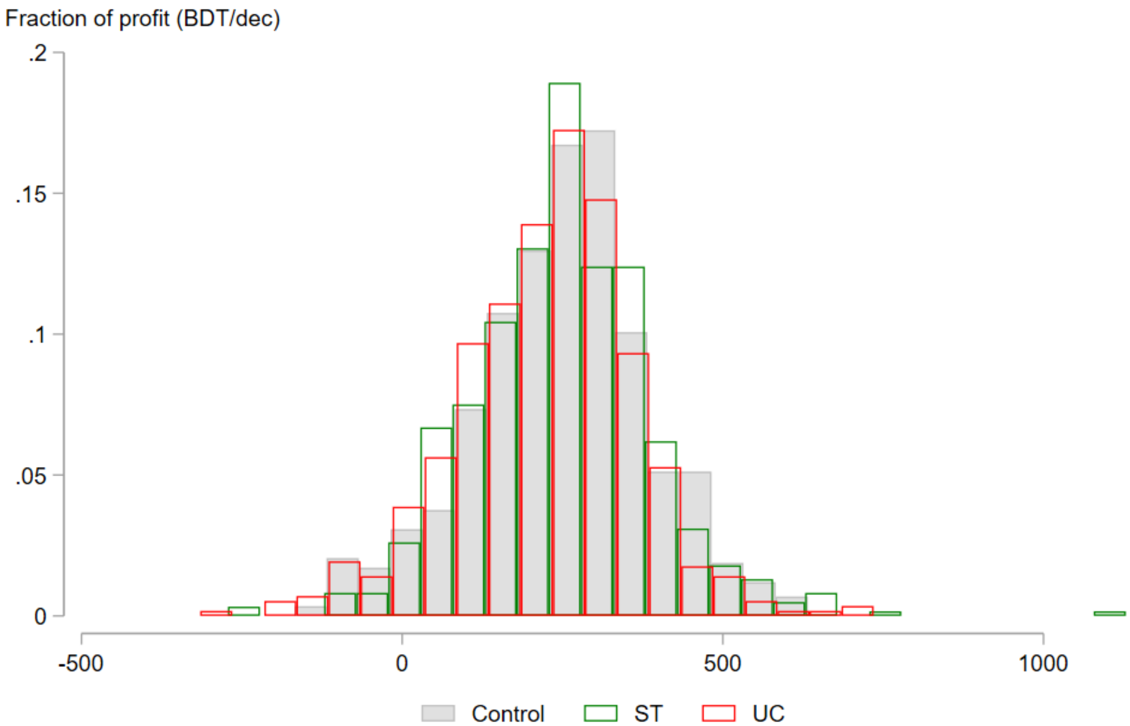
*Notes:* The figure shows the sample recommendation card delivered to ST farmers. It contains farmer name and farmer id, plot name and plot code, village and union name, CDIP branch name, address and phone number. The table at bottom is recommendation chart that includes recommended quantity of five types of fertilizer for four rice varieties. Fertilizer names are in rows while varieties are in columns. Cards for UC farmers had two tables for two possible plot depths

Figure B3: Distribution of Yield at Endline




*Notes:* The figure shows the distribution of endline yield (kg/decimal) for control and treatment groups.

Figure B4: Distribution of Profit at Endline




*Notes:* The figure shows the distribution of endline profit (BDT/decimal) for control and treatment groups.