Can a Rule-of-Thumb Tool Improve Fertilizer Management? Experimental Evidence from Bangladesh*

Mahnaz Islam
Harvard University

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Abstract

This paper demonstrates high returns to a simple rule-of-thumb tool to help farmers manage use of fertilizers, suggesting considerable scope for productivity gains through better management of inputs. The green revolution led to significant improvements in rice yields in South Asia, through the adoption of high-yielding varieties and the increase of inputs including fertilizers. Although adoption of fertilizers has been high, farmers may still fail to use it efficiently. In a field experiment in Bangladesh, I provide treatment farmers with a simple rule-of-thumb tool (leaf color chart) to improve the timing of fertilizer applications for urea, a popular nitrogen fertilizer. I find that treatment group farmers reduce urea use by 8% and yields increase by 7% on average, suggesting there is significant scope to improve urea management. Results show that farmers apply urea too early in the season, during a period when it is likely to be wasted, and that farmers at all levels of urea use can save urea without sacrificing yields. Farmers who performed better at baseline have the largest gains from treatment. Cost-effectiveness estimates suggest that each $1 spent on this intervention produces a return of $9 through a combination of savings of urea and higher revenue.

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1 Introduction

Since the green revolution in the 1970s, farmers in South Asia have achieved considerable improvements in rice yields by adopting high-yielding varieties, expanding irrigation and increasing their use of inputs, including fertilizers. However, productivity improvements in agriculture appear to have slowed, raising concerns that the gains from such changes have been nearly exhausted (Mottaleb et al 2014; Pingali et al 1997; Pingali et al 2001). As improvements in agricultural productivity raise living standards and reduce poverty, it is important to understand whether there is scope for further improvements by changing the management of existing technology and inputs. The literature on technology adoption suggests that farmers may fail to adopt optimal practices, for a variety of reasons including information and resource constraints or behavioral factors such as limited attention (Hanna et al 2014; Jack 2013; Marenya & Barrett 2007). If such barriers have prevented farmers from fully exploiting the potential gains from green revolution technologies, it may be possible to improve yields by addressing these barriers. Using data from a field experiment in Bangladesh, this paper explores how farmers manage the use of urea, a nitrogen fertilizer that has been widely-used since the green revolution. I provide farmers with a simple rule-of-thumb tool that reduces the decision costs involved in optimally using the fertilizer. The results indicate that access to the tool helps farmers reduce wastage of urea and improve yields.

In Bangladesh, agricultural lands are intensively cultivated and there is high levels of use of chemical fertilizers. Among the various fertilizers, the use of urea is most widespread. Urea, a source of nitrogen that is needed for plant growth, is used almost universally by rice farmers and it takes a share of over 65% of total fertilizers used in the country (Jahiruddin et al 2009; Kafiluddin et al 2008). Despite significant experience in using the fertilizer, farmers may fail to use urea efficiently. For any agricultural input, farmers have to learn about the right quantity, the correct timing and the proper method of application and the optimal application may also depend on other inputs, plot quality and environmental conditions. For urea in particular, the timing of the applications is very important in addition to quantity, which makes it easier to make mistakes. Unlike other fertilizers, urea needs to be applied several times during a season as it does not remain in the soil long due to it volatility. The timing of each of the applications is important as urea applied at the wrong time can have little or no effect on yields. Returns to urea are high when the crop can immediately take-up a lot of nitrogen so that wastage is reduced. This is when there is shortage of nitrogen in the crop as can be identified from light green leaves. Crops that have sufficient nitrogen have dark green leaves. A leaf color chart (LCC) is a simple tool that indicates whether urea is needed by the crop. It is a plastic, ruler-shaped strip containing four panels that range in color from yellowish green to dark green, which can be used to determine if the crop has sufficient nitrogen, by matching the leaf color to the chart. By using an LCC farmers can identify precisely when the crop needs nitrogen and time urea applications accordingly. Thus, it can help improve decisions on both quantity and timing.

Through a randomized control trial, I provided farmers in the treatment group with an LCC as well as basic training on how to use the chart. Treatment farmers were invited to attend a training session in their village at the beginning of the *Boro* (dry) season of 2013, followed by a short informal refresher training a few weeks later.[1] During the training sessions, treatment farmers were instructed to compare the color of the rice crop leaves with the LCC before applying urea and encouraged to apply the fertilizer only when the crop was deficient in nitrogen. The intervention, particularly the refresher training sessions, focused on rule-of-thumb training that provided very simple rules on when to check leaf colors and when to apply the fertilizer.[2] The training may also address constraints such as lack of information on timing and help farmers pay attention to the importance of leaf colors.

Prior to the intervention, I conducted a baseline survey that collected data on urea used and yields obtained in the *Boro* season of 2012. I conducted a detailed endline survey at the end of the season after the intervention, to determine any changes in urea use and yields caused by access to LCCs. During the 2013 season, several short midline surveys were also conducted to explore time use by farmers.[3] Data were also collected on the dates of urea applications and quantities applied on each date to understand any changes in the timing

[1] Field staff were instructed to time the refresher training session to the period when most farmers start applying urea.

[2] There is evidence in the literature that rule-of-thumb training can be much more effective than a more-complex training program (Drexler et al 2012).

[3] Some midline surveys were conducted on a sub-sample of farmers.

of fertilizer use.

The LCC farmers save urea and improve yields on average, suggesting that productivity gains can be obtained with just improvements to management of urea. For the analysis, I estimate the effect of gaining access to an LCC on urea application patterns, total urea use and yields. I first identify specific changes in farmer behavior in applying urea. I observe that on average farmers in the treatment group are more likely to delay the first application of urea until 21 days after planting instead of applying earlier in the season when returns to this fertilizer are low.[4] Treatment farmers reduce quantity of urea applied in the low-return period by 0.031 kilograms per decimal per application, although there is no significant difference in the quantity of urea applied in the high-return period. I find some evidence that farmers apply urea more frequently in the high-return period, although the coefficient is small and significant only at the 10% level. Treatment farmers are also marginally more likely to visit their fields more often.

I estimate that farmers in the treatment group reduce overall urea use by 0.079 kilograms per decimal, which is a decrease of about 8% compared to baseline levels and that they improve yields by about 1.76 kilograms per decimal, which is approximately an increase of 6.8%.[5] These results establish that substantial inefficiencies exist in the way farmers typically apply urea fertilizer; despite using more urea on average, they obtain lower yields. The results suggest that standard notions of underuse and overuse of fertilizers need to be redefined, as quantity is not the only dimension of fertilizer use that predicts yields but timing also needs to be considered. The savings in urea for the treatment group, is likely to be caused by a reduction in urea application in the unproductive period. Within the correct urea application period, I find no significant difference in the quantity of urea applied between the two groups, which implies that treatment farmers may improve the timing of urea application within the this period and increase the quantities of nitrogen that the crops can effectively absorb, which in turn generates the increase in yield. Although it is not possible to observe this directly with the available data, the findings that treatment farmers may apply urea more frequently in the high-return period and that they visit their

[4] Extension workers recommend that urea should be applied 3 times during the period between 21 days after planting date until a month before harvest.

[5] 1 acre = 100 decimals

fields more often, together provide suggestive evidence that this is the case.

The results show substantial average gains by farmers, however, it is important to understand what happens to farmers at various points across the distributions of urea and yield. There is substantial variation in quantities of urea used by farmers at baseline so the treatment effects may vary by baseline behavior. Estimates from quantile regressions show farmers at all levels of the distribution reduce urea without sacrificing yields. The results for farmers at the lowest quantiles of urea use, suggest that savings of urea are possible without harming yields even when very little urea is used. The treatment coefficients on yields are not precise for the quantile regressions. However, the highest quantiles have the largest coefficients suggesting that treatment effects are largest for farmers who had higher yields at baseline. I also conduct a cost-effectiveness analysis, and find that the intervention is highly cost-effective and every $1 spent on the intervention generated a return of $9 for the mean farmer through a combined effect of savings in urea and higher revenue.

An LCC is an effective tool as it provides simple rules and gives understandable signals on whether or not leaves are healthy in terms of nitrogen sufficiency. The intervention provided information and directed attention to the importance of leaf colors for urea application. The availability of signals may also make it less risky for farmers to experiment and modify urea applications. The intervention also provided simple rules on when to apply urea. All of these factors can improve management of urea. The findings also show that in Bangladesh and in countries using similar technologies, such as India, there is still significant scope for productivity gains by improving management of inputs within existing technology and resources.

The paper is organized as follows. Section 2 provides background on the cultivation of rice in Bangladesh, discusses the challenges of using urea efficiently and how leaf color charts can help. Section 3 describes the the experimental design, data and the empirical strategy. Section 4 presents the results, including changes in urea application patterns and treatment effects on urea use and yields. Section 5 presents results from quantile regressions and examines whether there is any evidence for heterogenous treatment effects by time preferences and cognition of the primary farmer and baseline level of household income. Section 5 discusses cost-effectiveness of the intervention and Section 6 concludes.

2 Context

2.1 Rice Farming and Urea Use in Bangladesh

In Bangladesh, agriculture remains one of the most important sectors, characterized by a large number of small farmers. The agricultural sector contributes 21% to the GDP and employs about 50% of the labor force (BBS 2009). Rice is the staple food of the population of about 160 million and provides over 70% of direct calorie intake in the country (Alam, et al 2011). About 13 million agricultural households are involved in rice cultivation. Since the green revolution, use of high yielding varieties of rice have become widespread particularly in the *Boro* (dry) season. Rice crop yield has grown from 0.76 tons per acre in 1970 to 1.9 tons per acre in 2012. The increase occurred mainly due to the use of high-yielding varieties that require higher levels of fertilizers and a considerable increase in irrigation (Alam et al 2011; Anam 2014; BBS 2012).

The use of urea fertilizers has been common since the green revolution. Traditionally, urea has been heavily subsidized. The price of urea in the country is fixed by the government and is general much lower than world prices, although the price was increased in 2011. Although urea (nitrogen) fertilizers have been used most widely, use of non-urea fertilizers also increased after subsidies were introduced in 2004. In 2008, urea had a share of over 65% of all fertilizers used in the country. Overall, the use of fertilizers have increased by 400 percent in the last 30 years (Alam et al 2011; Anam 2014; BBS 2012; Kafiluddin et al 2008).

Although the increase in yields have been high, a rapidly growing population puts pressure to continue to improve yields as self-sufficiency in rice production is a politically important goal. Despite the large gains in productivity and intensive use of inputs, a gap remains between potential yield and actual yield achieved by farmers, known as the yield gap (Alam 2010; Begum et al 2010; Ganesh-Kumar et al 2012).[6] A high yield gap implies that there is still scope for improvement through better input management. A persistent yield gap suggests that despite decades of experience, there are shortcomings in learning by

[6] Potential yield is defined as the yield obtained in demonstration/test plots by agricultural specialists using existing technology.

farmers and potential mistakes in management of inputs that persist.

2.2 Importance of Timing for Urea

Urea is particularly challenging to use in comparison to other fertilizers, as the timing of the applications matter and can be difficult for farmers to learn. Farmers apply all non-urea fertilizers once just before planting, although some farmers also apply urea once at that time.[7][8] Typically, urea is applied in two or three separate applications, starting a few weeks after planting and ending at the start of the flowering stage, about a month before harvest (approximately over a period of 40 days). A stylized timeline is shown in Appendix Figure A1. If some non-urea fertilizers in the field are unused by the crop, it is retained by the soil and improves the quantity of nutrients available for crops in the next season. In contrast, much of the urea applied can be wasted as it is volatile and can leave the soil fairly quickly (Chowdhury & Kennedy 2004, 2005; Koenig et al 2007).[9]

Due to this potential for quick loss, urea is typically applied in several applications instead of once, as described above, but it may not be sufficient to minimize wastage. Depending on the rate of loss, if urea is applied at a time when the crop does not require much nitrogen, it will not contribute towards yield. Similarly, if farmers fail to apply urea at the time when the crop in deficient in nitrogen, they will obtain lower yield. Therefore, farmers need to account for differences in urea needs across plots and seasons and time the application of urea well, then they will use urea very inefficiently and obtain sub-optimal yield even if they are using high levels of the fertilizer. Overall, returns to urea are likely to be higher if it is applied when leaves have insufficient nitrogen and returns to urea may be very low if it is applied when the crop has sufficient nitrogen.

[7] Planting refers to transplanting the seedling from a nursery to the main plot.

[8] In focus group discussions, most farmers stated that urea should be applied two to three weeks after planting, although some farmers mentioned that they apply urea at planting for a feeling of safety to protect against yield loss.

[9] After a urea application, the nitrogen introduced in the soil constantly cycles among its various forms, including ammonia, nitrate and ammonium, and much of the nitrogen can be lost from conversion of ammonia and nitrate to nitrogen gas, as well leaching downwards and run-off away from the roots. The rate of loss depends on soil pH, temperature, moisture and other soil properties and there vary across plots and over seasons.

2.3 Leaf Color Charts

The Leaf Color Chart (LCC) is a simple tool that allows farmers to understand whether urea is needed by the crop at any point in time during the urea application period. It is a plastic, ruler-shaped strip containing four panels that range in color from yellowish green (nitrogen deficient) to dark green (nitrogen sufficient). As discussed above, rice farmers usually apply urea in several split applications during a season. With an LCC, before any application, farmers can compare the color of the paddy leaf to the chart to determine if nitrogen is needed. This allows for efficient urea application that is timed to a period when uptake by crops will be high (Alam et al 2005; Buresh, 2010; Witt et al, 2005). The instructions that accompany an LCC also tell farmers to first check 21 days after planting to determine if they should start applying urea, as the first three weeks are considered a period of higher wastage.[10]

The literature on LCCs in agricultural journals usually finds an increase in returns either through substantial reduction in use of nitrogen fertilizers without any reduction in yields, or through substantial reduction in nitrogen fertilizers as well as improvements in yields (Alam et al., 2006; Alam et al., 2005; Balasubramanian et al., 2000; Islam et al., 2007; Singh et al., 2002). However, many of the studies are from demonstration plots which were closely supervised by agricultural workers. If farmers are given LCCs and basic training, it is not clear if they would choose to adopt and use LCCs and also whether they would be able to use them effectively. LCCs will only change urea use or yields if farmers are unable to learn how to time urea application well on their own, which they may have learned to do through experience.

[10] Conversations with agriculture specialists in Bangladesh revealed that although the crop may respond to any urea applied early in the season, the returns are lower in that period, which is why they recommend starting urea application three weeks after planting. The first urea application is timed with early tillering (seminal roots and upto five leaves develop), which is usually around 21 days during the *Boro* season due to colder temperatures (Alam 2005).

3 Experimental Design, Data & Empirical Strategy

3.1 Study Area

I conducted this study in partnership with the Center for Development Innovation and Practices (CDIP), a non-government organization in Bangladesh.[11] The study was implemented in 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. A map of Bangladesh identifying the districts is shown in the Appendix in Figure A3. Appendix Table A1 presents some summary statistics for the districts. Among the districts, Narayanganj is less agricultural as it is close to the capital, Dhaka, and has a higher concentration of industries. However, the villages from Narayanganj included in this study have a high prevalence of agricultural activity. All locations are rural without the presence of a major market.

3.2 Data & Intervention

I conducted a baseline survey in September-October 2012, for 1440 farmers. I collected data at the plot level on all crops grown in the past year by season. The survey focused on the *Boro* season of 2012, and included information for the season on all prices and all inputs including fertilizers. A short survey was conducted with an additional 603 farmers in December 2012.[12] CDIP staff conducted the baseline surveys in their program locations, after I provided training.

Treatment farmers were invited to attend a training session in their village in January 2013. The training session was organized by local CDIP staff and led by an extension worker or agriculture officer invited from the Department of Agricultural Extension (DAE). During the session, each farmer received a leaf color chart and instructions on how to use the chart. CDIP staff conducted home visits for farmers who did not attend the training, to provide the LCC and instructions. The training sessions were generally held just before or

[11] CDIP is primarily a micro-finance institution that also has education programs.

[12] Due to delays in receiving funding for the project, I could not be conduct the longer baseline survey for all farmers, since the intervention had to be completed by January 2013. New farmers were added to the study by including additional CDIP branches and following the same guidelines in selecting farmers.

around the time of planting. CDIP staff also conducted a more informal refresher training (individually with farmers or in small groups) a few weeks after the main training (before the time urea is generally applied). Figure A2 in the Appendix shows a timeline for the study.

CDIP staff conducted four short midline surveys electronically on about 67% of the sample.[13] These surveys focused on time use by farmers. A midline survey focusing on the timing of urea applications was conducted on all farmers. An endline survey was conducted for all farmers after harvest from June to August 2013. I implemented the endline survey through an independent survey company, that had not been involved in the interventions or previous data collection to reduce the probability of bias. The survey was similar to the long-form baseline survey, and collected detailed plot-level information for all farmers in the study. We were able to track 97.5% of the households and about 75.7% were still involved in rice cultivation.[14]

3.3 Randomization

CDIP selected 20 of their branch offices to participate in the study and and I selected approximately 100 farmers from villages covered by each branch. Within each branch, approximately, one-third of the sample was drawn from CDIP micro-finance clients and the remaining two-thirds were drawn from farmers residing in villages with a CDIP school. Further details on sampling are discussed in the Appendix.

I randomly assigned farmers into either a treatment or a control group, from a list of participants that included basic information about the farmer and the household.[15] To assign the farmers, I stratified the sample by CDIP branch and by type of sub-sample (CDIP microfinance clients and farmers from villages with CDIP schools) in the branch, and then randomized at the individual level.[16] Since I randomized at the individual level, each village in the study has both treatment and control group farmers, although the proportion varies.

[13] Sample size was limited by funding constraints. I selected the locations randomly after excluding some areas with expected staff shortages in that time period.

[14] Overall, 91.3% were still involved in agriculture.

[15] Random assignment was conducted after the baseline survey was completed, but not before all the baseline data had been entered.

[16] The choice of stratification was determined by preferences stated by CDIP to have an equal number of treatment and control group farmers in each branch, and in each type of sample within the branch.

This design increased statistical power compared to the alternative of randomizing at the village level, and as I discuss in section 4.1, cross-overs do not appear to be a concern in this setting.

Table 1 shows summary statistics and checks for balance across the treatment and control groups at baseline. Columns (1) and (2) show summary statistics for the control and treatment groups. On average, farmers in the control group are 45 years old, have 5.9 years of schooling, cultivate rice on 2.37 plots in the *Boro* season, and have a monthly non-agricultural household income of Tk 10,330 (USD 132). The average plot area is 29 decimals, and 1.01 kilograms of urea are applied per decimal and yield of 26.22 kilograms per decimal are obtained. Column (3) shows estimates from regressions of each baseline variable on a treatment dummy and strata fixed effects. There are no significant differences between the two groups for average age, years of schooling, number of plots farmed, non-agricultural income of the household, total plot area cultivated, urea use, yield, revenue or costs. A joint test reveals that the coefficients are not jointly significant.

Since some of the midline surveys were conducted on a sub-sample and there was also some attrition at endline, I also conduct randomization checks for the midline and endline samples as shown in Appendix Table A3.[17] There are no differences at baseline for the midline sample. For the endline sample (farmers remaining in rice cultivation), revenue and costs are marginally lower (significant at 10% level) but the estimates have similar magnitudes as estimates for the baseline sample. The coefficients are not jointly significant. Treatment farmers were invited to the training in January around the time of planting and did not know about their treatment status before then. Farmers make decisions on rice cultivation before planting, as seedlings are grown separately prior to that date so they can be transplanted to the plots at planting. Therefore, decisions on whether to cultivate rice or what varieties to cultivate will not be related to treatment.

[17] I selected the locations for the midline surveys randomly after excluding some areas with expected staff shortages in that time period.

3.4 Empirical Stratgey

I estimate the intent-to-treat effect of getting access to an LCC. I estimate a simple difference specification (Equation 1) for outcomes for which data are not available at baseline. This specification is used to estimate changes in urea application patterns using data in the midline surveys.

$$y_{ph} = \alpha_0 + \alpha_1 Treatment_h + \rho X_h + \delta Z_{ph} + \gamma_s + \epsilon_{ph} \tag{1}$$

y_{ph} is a urea application pattern in plot p by household h. $Treatment_h$ takes a value of 1 for household in the treatment group and is 0 otherwise and X_{ht} includes controls for household and individual specific characteristics including age and years of education completed by the farmer interviewed (primary farmer in household), total plot area cultivated by household, non-agricultural household income. Z_{ht} includes plot level variables such as variety of rice. γ_s controls for strata fixed effects and ϵ_{pht} is the error term. Standard errors are clustered at the household level. The coefficient α_1 estimates the difference between the treatment and control groups during the season.

For outcomes such as urea use and yields, for which data are available at baseline and endline, I estimate treatment effects using a difference-in-difference estimator (Equation 2).

$$\begin{aligned} y_{pht} &= \beta_0 + \beta_1 Treatment_h + \beta_2 Post_t + \beta_3 Treatment_h * Post_{ht} \\ &\quad + \rho X_{ht} + \delta Z_{pht} + \gamma_s + \epsilon_{pht} \end{aligned} \tag{2}$$

y_{pht} the outcome in plot p for household h at time t. $Post_t$ is 1 for the observations from the endline survey and 0 if it is from the baseline. Other variables are the same as above. Standard errors are clustered at the household level. Since assignment to receive an LCC was random, β_3 estimates the causal effect of gaining access to an LCC.

4 Results

In this section I present the main findings of this study. I first show estimates of take-up of leaf color charts in section 4.1. In section 4.2, I describe the observed behavior of farmers in applying urea, in the absence of leaf color charts, and discuss expected changes due to the intervention, followed by section 4.3, where I estimate whether we observe any of these changes after treatment. In section 4.4, I present the treatment effects on urea and yields as well as treatment effects on revenue, costs and profits for a sub-sample.

4.1 Take-up

Table 2 shows several estimates for the take-up of leaf color charts. During the endline survey, farmers were asked whether they received an LCC, whether they attended the main training, whether they used the LCC during the season and were also asked to show their LCC (if they said they had received one). The estimates in the table show that the treatment group farmers were much more likely to receive the LCC, attend training, use the LCC and could show the LCC to enumerators. Estimates with and without controls for individual and household characteristics are similar. The probability of stating that they received an LCC is 68.4 percentage points higher for the treatment groups farmers compared to the control group farmers. About 75% of the treatment group state they received a LCC. 7.8% of the control group also state they received an LCC, most likely through government extension workers.[18] The primary farmer in the household is the person interviewed at the endline survey and only 59% attended the DAE training session. Qualitative interviews with some of the farmers later on, revealed that in many of these cases, the primary farmer was away from the village or working in an additional occupation during the training and a family member attended instead as his representative, as CDIP records indicate almost full attendance, however, the representative often failed to explain how the LCC works to the farmer. 56% of the treatment farmers stated they used the LCC compared to 5.5% of the control group farmers. Therefore, there were some cross-overs but it was very limited.

[18] Although CDIP staff were instructed not to allow anyone other than farmers who were invited to attend the training, in a few cases other farmers came. I find from CDIP records and qualitative work that the control group farmers who have an LCC, usually received it from the DAE representative outside the training or in a few cases if they attended the training.

4.2 LCC Instructions & Expected Changes

Figure 1 shows four histograms that illustrate how farmers in the control group apply urea. The first chart shows the distribution of the number of days between planting and first urea application. About 13% of farmers apply urea at planting or before planting. Most farmers apply urea 15 days after planting, and less than 20% wait until 21 days. Therefore, most farmers apply urea early, in a period where returns may be lower. Most farmers apply urea twice and almost 40% apply urea three times as traditionally recommended. The third chart shows the distribution of urea per application and the average is 0.52 kilograms per decimal. The tail of this distribution are driven by farmers who apply only once. The last histogram shows the distribution of the number of days between flowering and last urea application. The last application can be timed close to flowering and the large duration in driven by people applying fewer than three times. There are no returns to urea after flowering (where the variable is negative), and very few farmers make the mistake of applying urea then.

In this study, I provided farmers in treatment group with an LCC and provided instructions on how to use the charts. Farmers were told to focus on a few simple instructions and a translated version of the handout is shown in Appendix Table A2.[19] Farmers were told to start checking leaf colors in their field with the LCC 21 days after planting to determine if they need to apply urea, which is a later starting date compared to what we observe above. After applying urea on any date, farmers were instructed to check back in 10 days, to determine whether additional urea is needed. If the chart indicated that urea was not needed, farmers were told to check again in 5 days. During each application, they were advised to apply 9 kilograms of urea per 33 decimals of land (0.27 kg/decimal), which is lower than the mean application. The Bangladesh Rice Research Institute estimates that with an LCC most farmers will apply urea four times instead of recommended number of three applications.[20] Farmers were also instructed to stop at flowering, which the data suggest that most farmers already do.

Based on these instructions, there are several possible changes in behavior compared to

[19]These were distributed during the refresher training sessions based on instruction developed by the Bangladesh Rice Research Institute (http://knowledgebank-brri.org/how-to-use-lcc.php), but simplified further.

[20]As stated in an instruction manual available at http://knowledgebank-brri.org/how-to-use-lcc.php.

prevalent practices. Farmers may delay urea application until 21 days after planting, apply urea more frequently and apply smaller quantities of urea per application. Farmers may improve timing of application (within the correct application period) so that they apply when leaves are light and delay application when leaves are dark. The instructions do not directly tell farmers to apply less urea overall or have more applications, but rather allow the leaf colors to indicate if they should apply at any point in time. In addition to estimating overall treatment effects on urea use and yields, I explore if there is any evidence for the first three changes in the next section. It is not possible to directly test the last change in behavior, as we do not know when farmers check leaf colors.

4.3 Timing of Urea Applications

In this section, I identify changes in behavior by farmers in the timing of urea applications as discussed above. Specifically I test whether (i) farmers delay urea application until 21 days after planting, (ii) apply urea more frequently and (iii) if they apply smaller quantities of urea per application. In the last round of the midline survey, timed around the end of the urea application period, I collected data at the plot level for all farmers on urea application dates and quantities applied on each date. I use this data to estimate the changes discussed above. I also estimate whether farmers spend more time in their fields, as LCCs may encourage farmers to check leaf colors frequently.

Table 3 shows estimates of Equation 1 for several outcomes from the midline data with and without individual and household level controls. The dependent variable in column (1) is a dummy variable that takes on a value of 1 if the first urea application in a plot took place on or after 21 days after planting. Panel B presents the results without controls and shows that farmers in the treatment group are much more likely to have waited until 21 days to start urea application compared to the control group. About 11.9% of farmers in the control group wait 21 days, and this increases by 4 percentage points in the treatment group (significant at 1% level). The dependent variable in column (2) is a dummy variable that takes on a value of 1 if the last urea application took place after flowering, the time when farmers should stop applying urea. Farmers in the treatment group are much less likely to apply urea at this period (decline of 0.9 percentage points), although these results come from a very small number of farmers who make this mistake. The mean interval between urea applications overall declines by 0.55 days (significant at 10% level), which is likely due to the delay in start time.

Columns (4), (5) and (6) show estimates for differences in frequency of urea applications between the treatment and control groups. The dependent variable in column (4) is the total number of times urea is applied while this variables is split up into the number of applications at the period of high-returns and low-returns respectively.[21] There is no significant difference in the frequency of urea applications overall, but the coefficient in positive and significant at the 10% level in the high-return period. The coefficient on treatment for the number of applications at the low-return period is negative but not significant. Columns (7), (8) and (9) show treatment effects on average quantity of urea in each application overall, in the high-return and low-returns periods. The coefficients in columns for urea per application overall and urea per application in the high-return period are negative but not significant. There is a decline in urea per application of 0.03 kilograms per decimal in the low-return period, which is significant at the 1% level. This is a 6% decrease compared to the control group. The results are consistent without controls (Panel A).

Overall, these results show strong evidence that treatment farmers on average delay the starting date of urea applications to a more productive period and reduces urea used in the low-returns period. There is weaker evidence that suggests that the intervention increases the frequency of urea applications in the high-return period. Changes in the overall timeline of urea application (intervals measured in days) are shown in Appendix Table A4.

In the second and fourth rounds of the midline surveys, a sub-sample of farmers were asked about time spent on various agricultural activities in the last seven days. The results are shown in Table 4. I compute Tobit estimates since the variables are highly censored at zero, but report OLS estimates in Appendix Table A5. The dependent variable in column (1) is the number of days in the last week, the farmer visited his fields. The other dependent variables are total number of minutes spent in the last seven days on fertilizer application, weeding, applying pesticides and other other activities in the field. Most of the coefficients

[21] High-return period in the interval from day 21 after planting until the flowering date, and the low-return period is any time before or after that period.

are positive but not precise, partly due to insufficient statistical power because these data are from a smaller sample, however, it shows that treatment farmers visit their plots 0.13 times more often (significant at the 10% level).

4.4 Treatment Effects on Urea Use and Yield

Table 5 shows the ITT effects of gaining an LCC through the intervention on urea used and yield attained by farmers. Columns 1 and 4, shows the treatment effects without any controls. Controls for age and years of education of the farmer, non-agricultural family income, total area cultivated by the farmer, the variety of rice cultivated on the plot and strata, are included in the rest of the regressions. Household fixed effects are also included in columns 3 and 6. The unit of observation is a plot and all regressions are clustered at the household level.

I find that, on average, urea use declines while yield increases for the treatment group relative to the control due to the intervention, and that these results are robust across the three specifications discussed above. Column (2), shows that having access to leaf color charts result in a decrease in urea use of 0.079 kilograms per decimal (significant at the 5% level). The coefficient is not significantly different without other control variables (Column (1)) or when household fixed effects are included (Column (3)). This is equivalent to an 8% decrease in urea use on average. Average area cultivated by farmers is about 66 decimals, so farmers in the treatment group save about 5.2 kilograms of urea on average, which is a savings of Taka 104 (USD 1.33). Column (5), shows that getting access to LCCs lead to an increase in yields of 1.757 kilograms per decimal (statistically significant at the 5% level), which is an increase of 6.8% from the mean baseline yield. The mean price of rice is Tk 15 per kilogram, so for average plot holding of 66 decimals, there is a gain of Tk 1739 in revenue (USD 22.3). The effect is not precise with household fixed effects.[22]

I also estimate the effects on total revenue, costs and profits for the farmers, to understand further the magnitude of the returns. As discussed in the section above above, price

[22] Estimates from an alternative specification using logs of urea per decimals and logs of yield per decimal is shown in Table A6. The results are consistent overall, however the estimates for effect of urea have a larger magnitude while that for yield have a smaller magnitude and lose precision. Based on these estimates, urea use decreases by 12% (significant at 1% level) while yields increases at 3.8% but is not significant.

data of inputs and details on quantities used for non-fertilizer inputs are only available at the baseline for the "long survey" sample of farmers so I estimate two sets of regressions. Columns (1) to (3) of Table 6 shows the difference-in-difference estimates for revenue, total cost and profits for farmers for the "long survey" sample. The difference between the treatment and control groups at endline are estimated for all farmers in the study and columns (4) to (6) shows the estimates for revenue, costs and profits.

Panel B shows estimates after controlling for individual, household characteristics and rice variety. For the sample for whom price data are available, revenue increases by Tk 34.4 per decimal (signicant at 5% level), total cost is higher by Tk 20 per decimal for the treatment group but it is not significant. Profits are higher by Tk 14 per decimal and is also not statistically significant. Using endline data for all farmers in the sample, revenue is higher by Tk 10 per decimal for the treatment group (signicant at 5% level), total cost are positive but not statistically significant.[23] The results in Panel A (without controls) are similar.

Overall, the treatment effects are substantial, particularly in savings of urea. Back of the envelop calculations discussed above show large quantities of savings of urea and higher revenue. This implies inefficiencies exists in the way urea is applied by the average farmer. With better information or signals, that farmers obtain due to this intervention, they are now able to both save urea and benefit from higher yields. The results on changes in timing of urea applications in the previous section suggest that the reduction in urea use observed overall comes from a reduction in urea used during the low-returns period.

The change in start date is not sufficient to explain an increase in yield, as applying urea before the third week will not harm the crop. However, an increase in yield can be explained if farmers improve timing of urea application within the period of high returns. There is some evidence that the treatment group farmers visit their fields more often and apply urea more frequently in the high-returns period, although the coefficients are small as discussed

[23]There are some concerns about the quality of the price data in the baseline and endline surveys, and some of the variables are much more noisy compared to other measures that were collected. To address this concern, I collected price data retrospectively at the village level (from local fertilizer stores) in March 2014. Table A7 estimates the same regressions using price data collected from the villages. The results are consistent and of similar magnitude as the first set of estimates although profits for the long survey sample are no longer significant.

in the previous section. These results provide suggestive evidence that treatment farmers may learn to improve the timing of urea use and spend more time on fertilizer application to ensure that returns to urea are higher.

5 Who Benefits from the Intervention?

In this section I discuss who benefits from the intervention. I estimate quantile regressions of urea and yield to identify any changes in these distributions due to treatment in section 5.1. I also investigate whether there is any evidence for heterogeneous treatment effects by time preferences, cognition or income in section 5.2.

5.1 Estimates from Quantile Regressions

As an LCC will encourage farmers who underuse to use more urea and farmers who overuse to use less urea, we may expect non-linear responses. To explore how the distributions of urea use and yield change with access to LCCs, I estimate quantile regressions for both. I control for individual, household and plot characteristics and strata fixed effects and cluster errors at the household level. Figure 2 shows the results of the quantile regressions, and reports coefficients at 0.1 quantile intervals from 0.1 quantile to 0.9 quantile. The figure shows that the full distribution of urea use shifts downwards for the treatment group. We cannot rule out that the coefficients are significantly different from one another. There is no significant change in the distribution of yield, however, the largest increase occurs at the highest end of the distribution. These results suggest that there is potential to save urea without sacrificing yields at all levels of the distribution. It also shows that the largest treatment effects come from farmers with the highest yields at baseline.

5.2 Treatment Effects by Patience, Cognition & Income

Treatment effects for households in the study may vary by characteristics of the primary farmer who makes agricultural decisions or by characteristics of the household. Since the timing of urea applications are important and as the LCC encourages farmers to check their fields regularly, the treatment effects may vary by time preferences or the level of patience of the primary farmer. An LCC is an easy-to-use tool and instructions to use the LCC in this intervention were simplified as much as possible, however, the ability to use the tool correctly may still depend on the cognitive abilities of the primary farmer. Finally, treatment effects may vary by the level of baseline household income if poverty acts as a constraint on whether farmers choose to take-up this tool.

At the endline survey, farmers were asked a series of standard questions to determine their time preferences. For the first set of questions, farmers were asked to choose between (hypothetically) receiving 1000 takas today or one month later, if they stated they would prefer to receive the money today they were asked what they would prefer in a choice between 1000 takas today or 1100 takas one month later. The stakes were increased incrementally and based on these questions I create a variable that measures where farmers switch from stating a preference for today to stating a preference for a larger amount tomorrow, which I use as a proxy for patience. I use a second set of similar questions with higher stakes (starting at 100,000 takas) to compute an additional measure of time preference. At the endline survey, farmers were given a short math quiz and a Raven's test, and scores were computed for each based on the number of correct answers.[24] I use both as measures of cognition. Ideally, these data would have been collected at baseline. However, time preferences or cognition are unlikely to change due to treatment, therefore, I use the endline measures to estimate whether treatment effects differ by measured levels of patience or cognition. I also estimate whether treatment effects vary by baseline levels of non-agricultural household income. To do so, I estimate Equation 3 for each of these measures.

$$
\begin{aligned}
y_{pht} &= \beta_0 + \beta_1 Treatment_h + \beta_2 Post_t + \beta_3 Treatment_h * Post_{ht} + \beta_4 C_h \\
&\quad + \beta_5 C_h * Treatment_h + \beta_5 C_h * Post_h + \beta_6 C_h * Treatment * Post_h \\
&\quad + \rho X_{ht} + \delta Z_{pht} + \gamma_s + \epsilon_{pht} \qquad (3)
\end{aligned}
$$

C_h is an individual or household characteristic, such as time preference and cognition

[24] 15 puzzles were chosen from the standard Raven's progressive matrices after piloting in a similar location outside the study area to ensure sufficient variation in responses.

of primary farmer or non-agricultural household income. All other variables are the same as before. Table 7 shows estimates of β_6 that tests whether treatment effects differ by time preferences, cognition or income. The sample sizes are smaller since these measures were collected at endline and the response rate was lower compared to the other modules in the survey. Overall, I find no differences in treatment effects on urea or yield for any of these measures suggesting that treatment effects are the same across the distribution of farmers for these characteristics. The coefficient showing treatment effect on yield by the low-stakes time preference variable is marginally significant at the 10% level in Panel A, but becomes imprecise when I include controls for age, schooling and total plot area cultivated. The treatment effects for urea do not vary by the level of patience using either measure and there are no differential effects on yields using the second measure for time preferences. There is no heterogeneity in treatment effects by cognition using either math scores or Raven's scores, suggesting that the tool was easy enough for everyone to use.[25] Treatment effects do not differ by baseline non-agricultural income, which suggest that for the farmers in this study resource constraints did not hinder the ability to take up and use the chart. This is not surprising, as the LCC was provided free of charge and did not require any significant investments later on.

6 Cost-Effectiveness of Intervention

Table 8 shows a cost-benefit analysis of the intervention and an estimate of the cost-effectiveness. Each LCC costs US $1.3 including shipping from Philippines and indirect fees. The expenses for the intervention included honorariums for DAE trainers, refreshments during training sessions, transportation costs and direct expenses incurred by CDIP workers to arrange the local training sessions and printing expenses for training materials. After including these expenses, the total cost per LCC is approximately $2.60.

To estimate benefits, I use treatment effects on urea and yield to compute back-of-the-envelope estimates of urea saved and yield gained for the mean farmer. On average farmers, cultivate rice on 66 decimals of land. Using the official price of urea and the average

[25] I also find no difference in treatment effects by years of schooling using a similar specification (results not presented).

reported price of rice at the endline survey, I estimate that farmers save \$1.34 on average from reducing urea use. This amount is larger than the cost of one LCC. I also estimate that the average farmer gains \$22.34 additional returns from higher yields. Combining both, the total benefit is \$23.68. Overall, the cost-effectiveness of the intervention is 9.10, i.e. every \$1 spent on the intervention generated a return of \$9.10. The cost-effectiveness is much higher when we consider the fact that the costs are a one-time expense, however, the LCC is durable and can be used by the farmer for many years. Moreover, these estimates show returns during the *Boro* season, but the LCC can also be used during the *Aman* season, although returns may be lower as average yields are lower in *Aman* compared to *Boro* season.

I use estimates for treatment effects on yields rather than treatment effects on revenue and profits, since I do not have data on revenue for all farmers, and costs and profits are imprecisely estimated. The cost-effectiveness estimate will be higher (11.6) if I use the estimated treatment effect on revenue. Profits are positive but not statistically significant. Based on this result, if we assume that returns were zero and that the only treatment effect came from savings in urea of \$1.34, even in that extreme scenario the program is cost-effective if the LCC is used in two seasons.

7 Conclusion

This paper explores whether there is potential for productivity gains through better management of chemical fertilizers. While it is challenging to learn how to reduce wastage of urea, farmers can learn to do so by paying attention to the timing of urea fertilizers and getting cues from the color of the rice leaves to determine whether the crop is getting sufficient nitrogen. In this study, through a field experiment, I provide rice farmers in the treatment group with an LCC, a simple tool applying rule-of-thumb learning, that helps with the management of urea fertilizers. I find that farmers save urea by 8% on average when they gain access to a leaf color chart, and in addition they benefit from an increase in yield of 7%, which suggest a failure to learn how to effectively apply urea without help from the chart, although farmers in the country have had decades of experience in using urea. In particular I find that farmers make the error of applying urea too early in the season, when the returns are lower and they are likely to correct this error once they have access to an LCC. I also find that there is scope to save urea by farmers at all levels of the distribution and that the largest gains in yield come from farmers who were performing relatively better at baseline. I also find that an LCC is very cost-effective and each $1 spent in the intervention led to a return of $9 for the mean farmer.

An LCC may be effective in improving urea management due to several features, most important of which is the ability to produce clear signals on nitrogen sufficiency and provide simple rules to follow, which reduce the complexity of learning the urea application process. A leaf color chart reduces both the cost and the risk associated with experimenting with urea and also focuses attention on a key dimension of input. The literature on learning presents several reasons why farmers fail to adopt improved agricultural practices. Lack of information, poverty and resource constraints, and risk preferences can all lead to poor adoption or sub-optimal use of inputs (Jack 2014; Marenya & Barrett 2007; Liu 2013). Leaf color charts can help farmers in the presence of many of these barriers. The LCC intervention provides basic information on timing and the significance of leaf colors and when they use an LCC the farmers get understandable signals in real time on how they are performing. Farmers now know that if leaves are dark, it means that the crop is healthy and has sufficient nitrogen. If they make a change in how they apply urea, the LCC shows them clearly whether the crop is being harmed, instead of having to wait until harvest, so farmers may be more willing to experiment.

The literature shows that behavioral constraints may limit how much farmers learn from experiments. Since there are many input dimensions, farmers with limited attention may fail to notice important aspects of the production process (Hanna et al 2014). If farmers fail to notice leaf colors or understand the relationship between urea applications and leaf colors, then an LCC focuses their attention to this important dimension of the cultivation cycle. Alternatively, an LCC may be effective due to its application of rule-of-thumb learning. The literature demonstrates the potential effectiveness of using simple rules to promote learning. Drexler et al (2012) conduct a field experiment with micro-entrepreneurs to promote financial literacy, and find that a simplified rule-of-thumb training is much more effective than a more-complex training program.

This paper's key contribution to the literature lies in demonstrating that measures of overuse or underuse of chemical fertilizers is insufficient in understanding whether farmers use fertilizers efficiently. Returns to fertilizers also vary by timing and attention should be paid to this dimension. The findings in this paper have several implications for policy. There is significant scope to improve productivity by improving the management of urea. This result holds even for farmers who perform well at baseline. LCCs are very cost-effective, and therefore disseminating LCCs to farmers in the region can lead to large gains. Policymakers and researchers should also explore other inputs that have the potential to be mismanaged. Although considerable resources are devoted towards agriculture extension, it is often reported to be insufficient. In this study, I utilized the existing network of a micro-finance organization without significant experience in agriculture to distribute the LCCs. Although extension workers were invited to conduct the primary training, CDIP workers were effective in reaching farmers and providing training that emphasized the simplicity of the rules. Therefore, for rule-thumb technology, there is significant scope to speed up awareness and dissemination by making use of other networks to complement traditional agriculture extension.

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Figures

Figure 1: Urea Application Patterns for Control Group

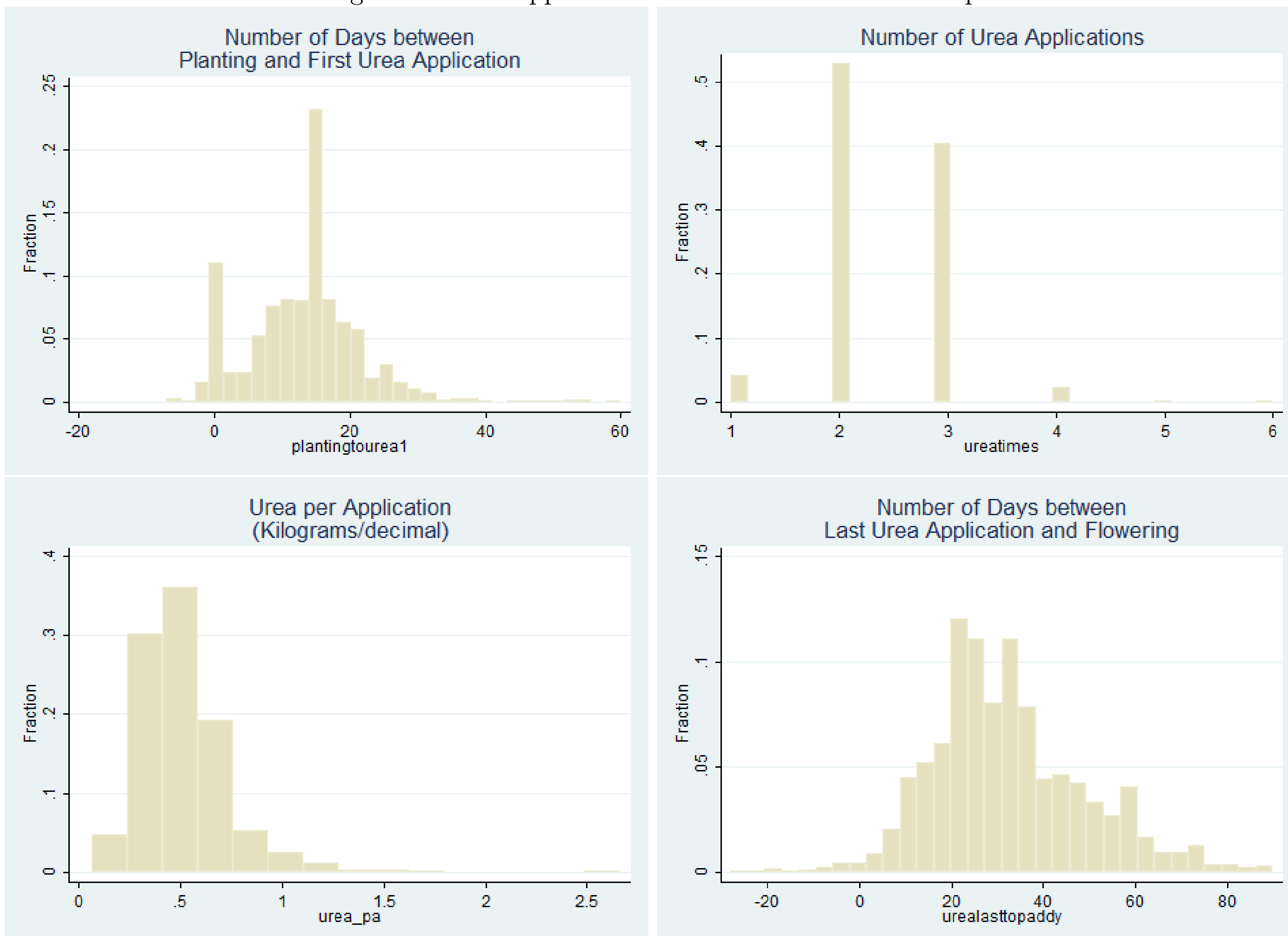
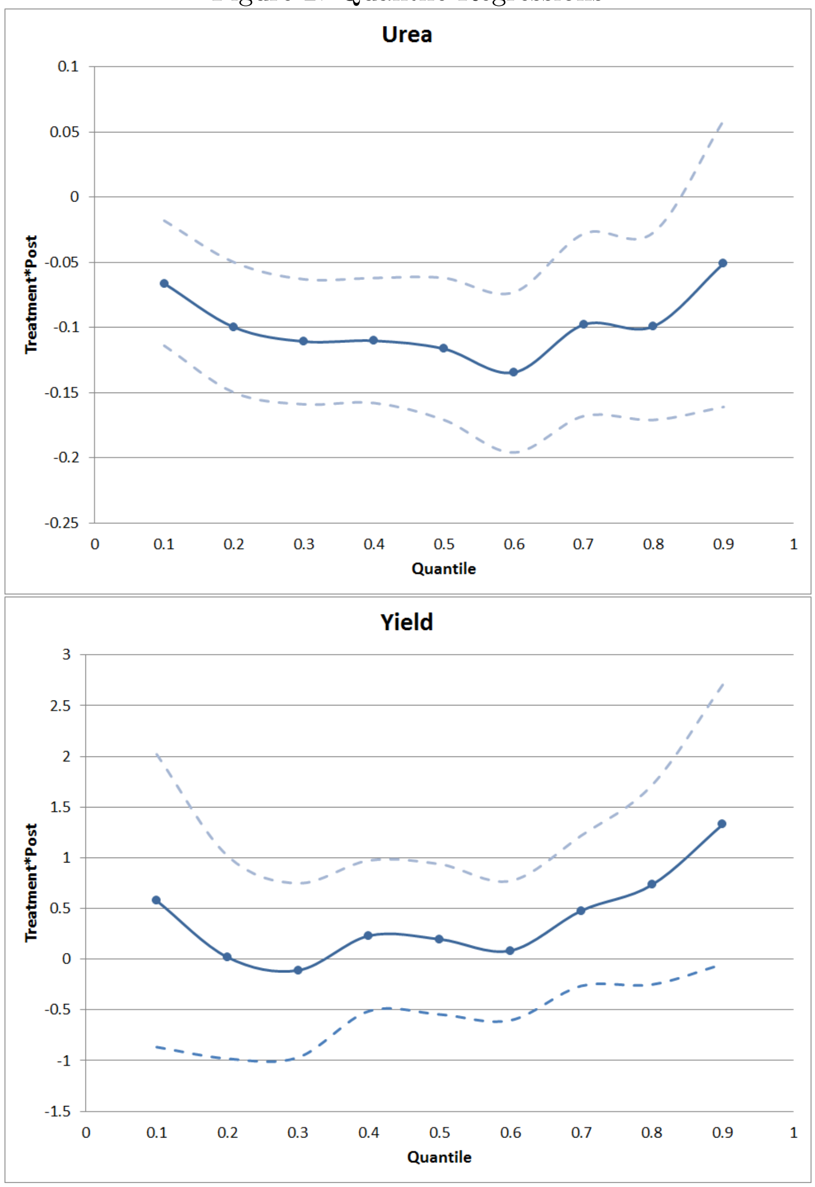


Figure 2: Quantile Regressions



Notes: The figures report estimates from quantile regressions of urea use and yield on $Treatment_h * Post_t$. The regressions also included covariates for $Treatment_h$, $Post_t$, controls for age, schooling, income and total plot area, rice variety and strata fixed effects. Standard errors are clustered at the household level. The quantiles are from 0.1-quantile to 0.9-quantile at 0.1-quantile intervals. 95% confidence intervals are shown. The dotted line shows the estimate of the corresponding OLS coefficient.

Tables

Table 1:
Baseline Characteristics

	(1)	(2)	(3)
	Summary Statistics		Randomization Checks
	Control Group	Treatment Group	Treatment
Farmer & Household Characteristics:			
Age (years)	45.02	45.78	0.663
	(12.73)	(12.40)	(0.546)
	[994]	[1001]	[1995]
Schooling (years)	5.86	5.72	-0.136
	(4.38)	(4.28)	(0.189)
	[948]	[970]	[1918]
Number of Plots	2.37	2.36	-0.015
	(1.18)	(1.18)	(0.046)
	[1008]	[1017]	[2025]
Non-agricultural income (Tk)	10329.70	9657.928	-674.164
	(10759.79)	(10392.05)	(455.634)
	[936]	[940]	[1876]
Total Plot Area (decimals)	65.30	67.09	1.215
	(43.42)	(43.62)	(1.763)
	[1008]	[1017]	[2025]
Number of Household Assets	4.28	4.34	0.042
	(2.23)	(2.17)	(0.106)
	[708]	[714]	[1422]
Plot Level Variables):			
Plot Area (decimals)	28.87	30.18	1.125
	(20.72)	(22.97)	(0.740)
	[2252]	[2260]	[4512]
Urea (kg/decimal)	1.01	1.01	-0.001
	(0.69)	(0.62)	(0.025)
	[2253]	[2263]	[4516]
Yield (kg/decimal)	26.22	25.25	-1.093
	(19.71)	(15.81)	(0.764)
	[2253]	[2263]	[4516]
Revenue (kg/decimal)	361.86	342.71	-21.641
	(278.02)	(205.08)	(13.198)
	[1682]	[1702]	[3384]
Total Cost (Tk/decimal)	245.92	233.87	-14.236
	(230.93)	(159.76)	(8.884)
	[1684]	[1704]	[3388]
Profit (Tk/decimal)	115.99	109.03	-7.455
	(292.69)	(209.38)	(12.658)
	[1682]	[1702]	[3384]
Joint Test (chi-squared)			2.51
p-value			(0.1130)

Notes: For columns (1) & (2), standard deviations are shown in parentheses and sample sizes are shown in square brackets. Column (3) reports the coefficients for regressions of each dependent variable on $Treatment$ and strata fixed effects. Robust standard errors for regressions with individual/household level variables and standard errors clustered at household level for regressions with plot level variables are shown in parentheses. Sample sizes are shown in square brackets. The joint test used a chi-squared test to estimate whether the coefficients are jointly significant.
*** p<0.01, ** p<0.05, * p<0.1.

Table 2:
Take-up & Stated use of LCCs

	(1) Received LCC	(2) Attended Training	(3) Used LCC	(4) Could Show LCC
Panel A: Without Controls				
Treatment	0.684***	0.531***	0.491***	0.581***
	(0.018)	(0.020)	(0.020)	(0.019)
Mean of Control Group	0.0788	0.0604	0.0604	0.0723
Observations	1,526	1,526	1,526	1,526
Panel B: Including Controls				
Treatment	0.682***	0.529***	0.489***	0.579***
	(0.018)	(0.020)	(0.020)	(0.019)
Age (years)	0.000	0.001	0.001	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Schooling (years)	-0.006***	-0.006**	-0.005**	-0.004*
	(0.002)	(0.003)	(0.003)	(0.003)
Total plot area	0.000	0.000	0.001**	0.000*
	(0.000)	(0.000)	(0.000)	(0.000)
Income (Non-agri)	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Mean of Control Group	0.0788	0.0604	0.0604	0.0723
Observations	1,526	1,526	1,526	1,526

Notes: The dependent variables are dummy variables that respectively take on values of 1 if farmers state receiving a leaf color chart, attending the training, using the chart and if they can show the chart to the enumerator, and 0 otherwise. Robust standard errors are shown in parentheses. All regressions include strata fixed effects
*** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 3:
Changes in Behavior in Using Urea

	Overall Change			Change in Frequency			Change in Quantity		
	(1) Applied First Urea After 21 days	(2) Applied Urea After Flowering	(3) Mean Interval between Applications (days)	(4) # Times Urea Applied	(5) # Times Urea Applied High-return Period	(6) # Times Urea Applied Low-return Period	(7) Urea per application (kg/decimal)	(8) Urea/app. High-return Period (kg/decimal)	(9) Urea/app. Low-Return Period (kg/decimal)
Panel A: Without Controls									
Treatment	0.042***	-0.009***	-0.541*	0.020	0.050*	-0.030	-0.011	-0.007	-0.031***
	(0.014)	(0.004)	(0.293)	(0.028)	(0.029)	(0.026)	(0.009)	(0.014)	(0.012)
Control Group Mean	0.119	0.0132	20.75	2.419	1.250	1.169	0.508	0.423	0.496
Observations	3,541	3,541	3,107	3,541	3,541	3,541	3,541	3,541	3,541
Panel A: Including Controls									
Treatment	0.040***	-0.009***	-0.551*	0.020	0.047*	-0.027	-0.011	-0.007	-0.030***
	(0.014)	(0.003)	(0.295)	(0.028)	(0.029)	(0.026)	(0.009)	(0.015)	(0.012)
Control Group Mean	0.119	0.0132	20.75	2.419	1.250	1.169	0.508	0.423	0.496
Observations	3,541	3,541	3,107	3,541	3,541	3,541	3,541	3,541	3,541

Notes: This table shows changes in urea application patterns overall, as well as within periods of high-returns and low-returns to urea. The high-return period is defined as 21 days after planting until 60 days after planting (expected time of flowering). The low return period is defined as any application within 21 days after planting or after 60 days of planting. Control variables include age, schooling, income, total plot area and baseline urea.
Standard errors, shown in parentheses, are clustered at household level. All regressions include strata fixed effects.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 4:
Tobit Estimates of Time Use by Farmers (7 day recall)

	(1) #Times in Field	(2) Fertilizer Application (minutes)	(3) Weeding (minutes)	(4) Pesticide Application (minutes)	(5) Other Activities (minutes)
Panel A: Without any Controls					
Treatment	0.154*	7.629	13.948	10.038	6.407
	(0.081)	(10.285)	(18.962)	(14.952)	(9.340)
Control Group Mean	2.700	50.31	57.35	4.471	38.85
Observations	2,066	2,066	2,066	2,066	2,066
Panel B: Including all controls					
Treatment	0.134*	7.949	10.047	9.245	2.200
	(0.079)	(10.186)	(18.639)	(14.903)	(9.130)
Control Group Mean	2.700	50.31	57.35	4.471	38.85
Observations	2,066	2,066	2,066	2,066	2,066

Notes: This table shows Tobit estimates of treatment effects on on time use by farmers using data from Rounds 2 and 4 of the midline surveys. The dependent variables in Columns (2) to (5) are total time spent in minutes in the last seven days on different agricultural activities. Control variables in Panel B include age, schooling, total plot area cultivated and non-agricultural income.
Standard errors clustered at the household level are shown in parentheses. All regressions control for survey round and strata FE.
*** p<0.01, ** p<0.05, * p<0.1.

Table 5:
Full Sample: Treatment Effects on Urea & Yield

Urea & Yield in Kilograms per Decimal

	Urea			Yield		
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*Post	-0.074**	-0.079**	-0.089**	1.823**	1.757**	1.352
	(0.035)	(0.034)	(0.041)	(0.867)	(0.849)	(0.941)
Treatment	-0.001	0.001		-1.103	-1.035	
	(0.025)	(0.025)		(0.772)	(0.759)	
Post	0.059**	0.084***	0.088***	-3.416***	-3.238***	-2.932***
	(0.026)	(0.026)	(0.031)	(0.677)	(0.697)	(0.787)
Controls	No	Yes	Yes	No	Yes	Yes
Household FE	No	No	Yes	No	No	Yes
Mean at Baseline	1.011	1.011	1.011	25.73	25.73	25.73
Observations	8,144	8,144	8,144	8,144	8,144	8,144

Notes: This table shows treatment effects on urea use and yield. Control variables include age, schooling, total plot area cultivated, income, rice variety.
Standard errors clustered at the household level are shown in parentheses. All regressions include strata fixed effects.
100 decimals = 1 acre
*** p<0.01, ** p<0.05, * p<0.1.

Table 6:
Revenue, Cost & Profits

All dependent variables in Takas per decimal

	Long Survey Sample			Full Sample		
	(1)	(2)	(3)	(4)	(5)	(6)
	Revenue	Total Cost	Profit	Revenue	Total Cost	Profit
Panel A: Without Controls						
Treatment*Post	35.597**	16.940	18.657			
	(15.810)	(16.973)	(20.061)			
Treatment	-21.416	-13.413	-8.003	9.453**	4.126	5.327
	(13.503)	(9.170)	(12.968)	(4.660)	(10.514)	(11.351)
Post	-30.629**	39.619***	-70.248***			
	(12.724)	(11.114)	(14.136)			
Means (Baseline/control group)	352.3	240.0	112.3	344.0	289.1	54.92
Observations	6,102	6,102	6,102	3,632	3,632	3,632
Panel B: Including Controls						
Treatment*Post	34.412**	15.998	18.414			
	(15.454)	(16.873)	(20.001)			
Treatment	-19.615	-11.429	-8.186	10.035**	5.213	4.950
	(13.164)	(8.982)	(12.894)	(4.626)	(10.672)	(11.636)
Post	-28.206**	42.406***	-70.612***			
	(13.348)	(11.193)	(14.531)			
Means (Baseline/control group)	352.3	240.0	112.3	344.0	289.1	54.92
Observations	6,102	6,102	6,102	3,632	3,632	3,632

Notes: Controls variables include age, schooling, total plot area cultivated, non-agricultural income and rice variety. Standard errors clustered at the household level are shown in parentheses. All regressions include strata fixed effects.
100 decimals = 1 acre
*** p<0.01, ** p<0.05, * p<0.1.

Table 7:
Treatment Effects by Time Preferences, Cognition and Baseline Household Income

Urea & Yield in Kilograms per Decimal

	(1) Urea	(2) Yield	(3) Urea	(4) Yield	(5) Urea	(6) Yield	(7) Urea	(8) Yield	(9) Urea	(10) Yield
Panel A: Without Controls										
Time Preference (Low Stakes)*Treatment*Post	0.033	0.849*								
	(0.021)	(0.460)								
Time Preference (High Stakes)*Treatment*Post			-0.008	0.228						
			(0.022)	(0.506)						
Math Score*Treatment*Post					-0.013	-0.253				
					(0.030)	(0.806)				
Ravens Score*Treatment*Post							0.055	0.789		
							(0.037)	(1.118)		
Non-agri Income*Treatment*Post									0.002	-0.030
									(0.003)	(0.074)
Mean at Baseline	1.011	25.73	1.011	25.73	1.011	25.73	1.011	25.73	1.011	25.73
Observations	7,080	7,080	7,080	7,080	7,080	7,080	7,080	7,080	7,468	7,468
Panel B: Including Controls										
Time Preference (Low Stakes)*Treatment*Post	0.026	0.706								
	(0.021)	(0.443)								
Time Preference (High Stakes)*Treatment*Post			-0.015	0.077						
			(0.021)	(0.494)						
Math Score*Treatment*Post					-0.010	-0.263				
					(0.030)	(0.799)				
Ravens Score*Treatment*Post							0.051	0.654		
							(0.036)	(1.086)		
Non-agricultural Income*Treatment*Post									0.002	-0.039
									(0.003)	(0.074)
Mean at Baseline	1.011	25.73	1.011	25.73	1.011	25.73	1.011	25.73	1.011	25.73
Observations	7,080	7,080	7,080	7,080	7,080	7,080	7,080	7,080	7,468	7,468

Notes: Controls include age, schooling, total plot area cultivated and rice variety. Regressions in columns (1)-(6) also control for non-agricultural income in Panel B. Coefficients not shown for the variables Treatment, Post, Treatment*Post, the specific characteristic variable in each column as well as the interactions of the variable with the Treatment and Post variables. Standard errors clustered at the household level are shown in parentheses. All regressions include strata fixed effects.

Time preference variables range from 0 (most patient) to 6 (least patient)

Math scores and Raven's score measure the number of correct answers and range from 0 to 7 and 0 to 8 respectively.

Non-agricultural income is the reported month non-agricultural income in 1000 Takas per month as reported at the baseline survey.

100 decimals = 1 acre

*** p<0.01, ** p<0.05, * p<0.1.

Table 8:
Cost-Benefit Analysis of Program

Costs:	
Cost of 1000 LCCs[1]	\$1,100
Costs of Training & Distribution[2]	\$1,500
Total cost of intervention	\$2,600
Direct Cost per LCC	\$1.10
Total Cost per LCC	\$2.60
Benefits:	
Savings in Urea for Mean Farmer	\$1.34
(0.079 kg/dec. urea saved *66 decimals of land*Tk 20/kg of urea*\$0.012/Tk)	
Increase in Returns for Mean Farmer	\$22.34
(1.76 kg/dec yield gain.*66 decimals of land*Tk 15/kg of rice*\$0.012/Tk)	
Total Benefit per farmer per season	\$23.68
Cost-Effectiveness (Benefits/Costs):	9.10

Note: [1]Includes cost of importing 1000 LCC from the Philippines, including shipping (\$1000) and bank and agent fees (\$100).
[2]Includes honorarium for DAE trainers, refreshments during training, transport of LCCs, additional training costs for CDIP staff and printing.
I use the DD estimates of treatment effects of urea and yield from Table 5.
The average land area cultivated for rice is 66 decimals, price of urea is Tk 20/kg (official price) and mean reported price of rice is Tk 15/kg.
I use an exchange rate of 1 USD = Tk 78 to convert returns to dollars.

Appendix

A1 Sample Selection

CDIP selected 20 of their branch offices to participate in the study and and I selected approximately 100 farmers from villages covered by each branch. Within each branch, approximately, one-third of the sample was drawn from CDIP micro-finance clients and the remaining two-thirds were drawn from farmers residing in villages with a CDIP school[26]. The second group of farmers may or may not be directly connected with CDIP[27]. For the first sub-sample, I randomly selected four micro-finance groups from the list provided by CDIP for each branch, and then randomly selected 10 rice farmers from each group. For the second sub-sample, two villages were selected by CDIP in each branch. I conducted a census of farmers in those villages and then randomly selected 30 rice farmers from each village[28]. To be included in the study, the farmer had to meet the following criterion: (1) agree to participate, (2) have cultivated rice in the 2012 *Boro* season, (3) at the time of the survey expect to cultivate rice in 2013 and (4) cultivate no greater than five plots in the 2012 season. I did not conduct a census for the short survey, but farmers were selected by CDIP based on these criterion above. In all cases, the primary farmer in the household was interviewed, and multiple farmers were never selected from the same household. At the time of the survey, if the enumerator realized that we had earlier received the name of the household head instead of the main agricultural decision maker, then he or she interviewed the primary farmer instead. Therefore, the household can be considered to be the unit of analysis.

[26]The total number of farmers and proportion of CDIP clients in the sample varied in some branches due to logistical constraints or in branches with fewer rice producing areas

[27]Sample drawn this way for logistical purposes, based on preferences stated by CDIP.

[28]The number of villages or micro-credit groups in each branch sometimes varied based on availability of CDIP staff.

Figure A1:
Timeline for Rice Cultivation during *Boro* Season

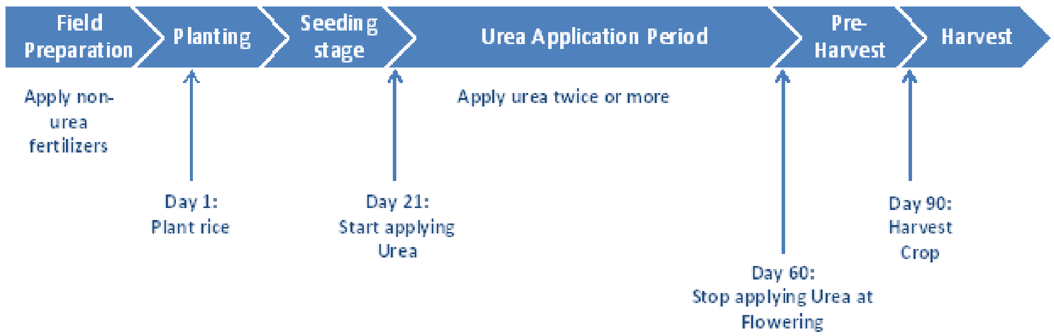


Figure A2:
Timeline of Study

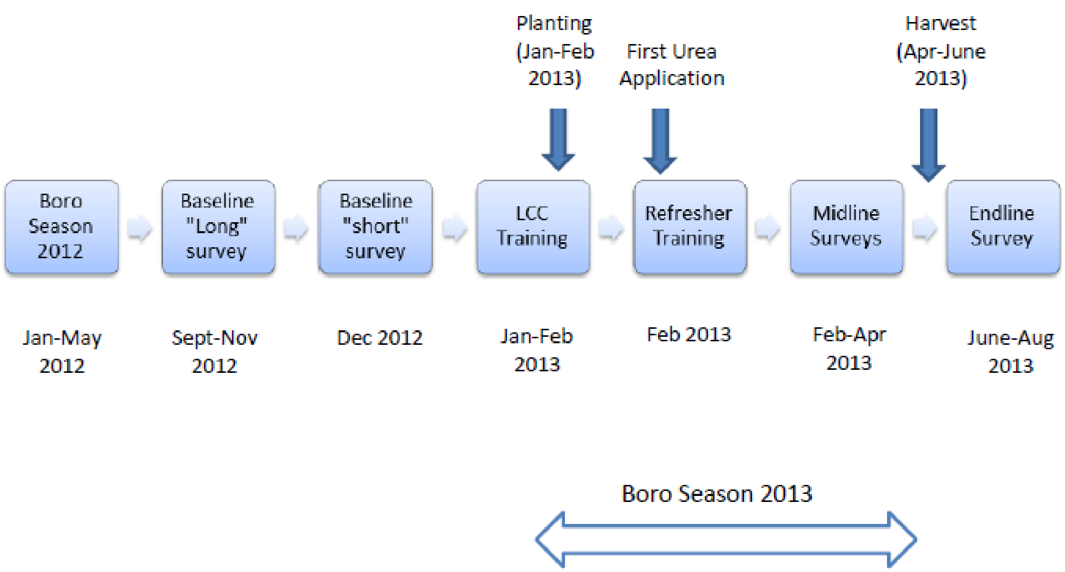


Figure A3:
Study Areas (Districts) in Bangladesh

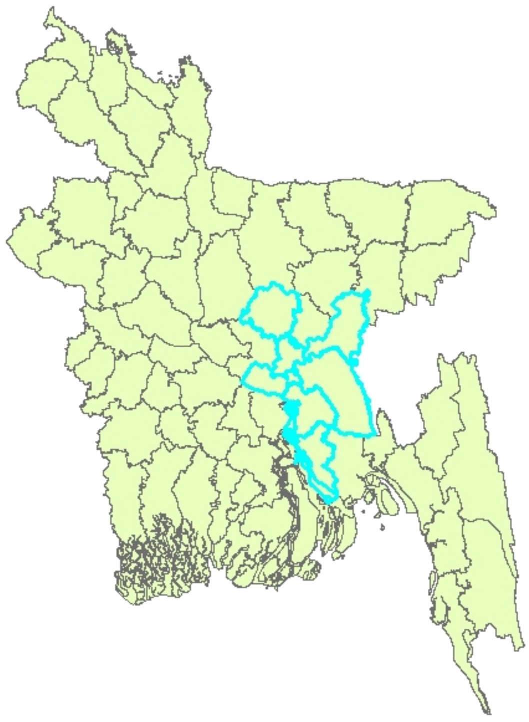


Table A1:
Descriptive Statistics for Districts in Study Area

District	% Population in Rural Areas	% Population in Agriculture	Average Household Size (Rural)	Urbanization (%)	Literacy Rate (%)
Brahmanbaria	84.21	30.02	5.28	15.79	45.3
Comilla	84.40	30.54	5.10	15.60	53.3
Chandpur	81.97	25.56	4.76	18.03	56.8
Gazipur	69.52	24.02	4.14	30.48	62.5
Lakhipur	84.79	25.10	4.71	15.21	49.4
Munshiganj	87.13	13.29	4.56	12.87	56.1
Narayanganj	66.46	6.30	4.40	33.54	57.1
Noakhali	84.02	19.61	5.20	15.98	51.3
Bangladesh	**76.70**	**23.85**	**4.46**	**23.3**	**51.8**

Note: Source: Bangladesh Bureau of Statistics.
% Urbanization, Literacy rate obtained from Community Reports for each district from the Bangladesh Population & Housing Census 2011. % Population in rural areas computed from total rural population and total population for each district from the same source.
% Population in Agriculture computed from total population and total population in agriculture obtained from Statistical Yearbook of Bangladesh, 2010.
All data obtained online at http://www.sid.gov.bd/

Table A2:
Instructions to Use LCCs

Five Most Important Information

1.	Check leaf color with LCC every 10 days, starting 21 days after planing until the paddy comes out (If urea is not needed on a day when you check with the LCC, check back again in 5 days).
2.	Every time you check leaf color with an LCC, pick out 10 healthy leaf samples (Walk diagonally across the field from one end to the other to pick 10 bunches).
3.	For each bunch of leaves, select the topmost fully developed leaf and place it on the LCC to match a color. Compare in the shade of your body.
4.	Out of the 10 samples, if 6 or more are light in color (it matched the first two panels of the LCC, then apply 9 kilograms of urea every 33 for decimals of land. Check leaf color with LCC again in 10 days.
5.	If urea is not needed on the day you measure (out of the 10 leaf samples, 4 or fewer are light), then check the leaf color again in 5 days with the LCC to see if urea needs to be applied.

Table A3:
Randomization Checks after Attrition

Differences at Baseline for Midline & Endline Samples

	Individual/Household level Variables				**Plot level Variables**						
	(1) Age	(2) Schooling (years)	(3) Non-agri. Income (Tk)	(4) Total Plot Area (dec.)	(5) Plot Size (dec.)	(6) Urea (kg/dec)	(7) Yield (kg/dec)	(8) Revenue (Tk/dec)	(9) Total Cost (Tk/dec)	(10) Profit (Tk/dec)	(11) Chi-squared Test
Panel A: Midline (Time Use) Sample											
Treatment	0.006	-0.163	-521.520	-0.327	0.865	-0.010	-0.956	-5.675	-9.178	3.977	0.67
	(0.744)	(0.268)	(661.530)	(2.188)	(0.929)	(0.028)	(0.847)	(10.825)	(10.794)	(13.563)	(0.4138)
Control Mean	45.84	6.077	12934	78.04	45.84	1.069	26.81	362.9	251.8	109.9	
Observations	1,062	1,013	1,016	1,080	2,548	2,488	2,488	2,327	2,346	2,327	
Panel B: Endline Sample											
Treatment	0.361	-0.172	-797.780	1.594	1.237	-0.006	-1.291	-23.644*	-18.369*	-4.293	2.41
	(0.629)	(0.213)	(549.472)	(2.126)	(0.869)	(0.027)	(0.801)	(12.115)	(9.413)	(13.387)	(0.1205)
Control Group Mean	46.25	5.973	10985	80.51	46.25	1.005	26.23	354.6	241.7	111.4	
Observations	1,524	1,477	1,428	1,549	3,638	3,567	3,566	2,703	2,724	2,703	

Notes: This table shows randomization checks for the midline (time-use) sample and the endline sample after attrition. It reports coefficient of *Treatment* for regressions of each dependent variable on *Treatment* and strata fixed effects for the midline time-use surveys. Robust standard errors for regressions with individual/household level variables and standard errors clustered at household level for regressions with plot level variables are shown in parentheses.
The joint test used a chi-squared test to estimate whether the coefficients are jointly significant.
*** p<0.01, ** p<0.05, * p<0.1.

Table A4:
Changes in Urea Application Intervals over the Season

	(1) # Days from Planting to 1^{st} Application	(2) # Days between 1^{st} and 2^{nd} Applications	(3) # Days between 2^{nd} and 3^{rd} Applications	(4) # Days between 3^{rd} and 4^{th} Applications	(5) # Days between 5^{th} and 6^{th} Applications	(6) # Days from Last Application to Flowering
Panel A: Without any Controls						
Treatment	0.446	-0.609**	0.176	0.745	-0.525	-0.405
	(0.377)	(0.298)	(0.518)	(1.148)	(3.074)	(0.718)
Control Group Mean	13.27	20.72	19.66	17.42	19.40	32.30
Observations	3,541	3,115	1,481	96	13	3,541
Panel A: Including Controls						
Treatment	0.435	-0.598**	0.164	0.489	0.930	-0.346
	(0.372)	(0.298)	(0.527)	(1.030)	(4.699)	(0.711)
Control Group Mean	13.27	20.72	19.66	17.42	19.40	32.30
Observations	3,541	3,115	1,481	96	13	3,541

Notes: This table shows differences in urea application over the season between the treatment and control groups. Control variables include age, schooling, non-agricultural income and total plot area.
Standard errors, shown in parentheses, are clustered at household level. All regressions include strata fixed effects.
*** p<0.01, ** p<0.05, * p<0.1.

Table A5:
OLS Estimates of Time Use by Farmers (7 day recall)

	(1) #Times in Field	(2) Fertilizer Application (minutes)	(3) Weeding (minutes)	(4) Pesticide Application (minutes)	(5) Other Activities (minutes)
Panel A: Without any Controls					
Treatment	0.128*	3.919	6.028	0.825	1.684
	(0.073)	(3.464)	(4.607)	(0.871)	(3.084)
Control Group Mean	2.700	50.31	57.35	4.471	38.85
Observations	2,066	2,066	2,066	2,066	2,066
Panel B: Including all controls					
Treatment	0.112	3.921	5.827	0.786	1.349
	(0.071)	(3.436)	(4.554)	(0.866)	(3.032)
Control Group Mean	2.700	50.31	57.35	4.471	38.85
Observations	2,066	2,066	2,066	2,066	2,066

Notes: This table shows OLS estimates of treatment effects on on time use by farmers using data from Rounds 2 and 4 of the midline surveys. The dependent variables in Columns (2) to (5) are total time spent in minutes in the last seven days on different agricultural activities. Control variables in Panel B include age, schooling, total plot area cultivated and non-agricultural income.
Standard errors clustered at the household level are shown in parentheses. All regressions control for survey round and strata FE.
*** p<0.01, ** p<0.05, * p<0.1.

Table A6:
Full Sample: Treatment Effects on Urea & Yield (Logs)

	Log Urea			Log Yield		
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment*Post	-0.113***	-0.120***	-0.126***	0.041	0.038	0.032
	(0.033)	(0.033)	(0.039)	(0.025)	(0.025)	(0.029)
Treatment	0.031	0.034		-0.010	-0.007	
	(0.023)	(0.023)		(0.019)	(0.019)	
Post	0.169***	0.199***	0.198***	-0.054***	-0.042**	-0.040*
	(0.024)	(0.025)	(0.029)	(0.019)	(0.019)	(0.023)
Controls	No	Yes	Yes	No	Yes	Yes
Household FE	No	No	Yes	No	No	Yes
Mean at Baseline	1.011	1.011	1.011	25.73	25.73	25.73
Observations	8,131	8,131	8,131	8,144	8,144	8,144

Notes: This table shows treatment effects on log urea use and log yield. Control variables include age, schooling, total plot area cultivated, income, rice variety.
Standard errors clustered at the household level are shown in parentheses. All regressions include strata fixed effects.
*** p<0.01, ** p<0.05, * p<0.1.

Table A7:
Revenue, Cost & Profits: Price Data from Village Stores

All dependent variables in Takas per decimal

	Long Survey Sample			Full Sample		
	(1)	(2)	(3)	(4)	(5)	(6)
	Revenue	Total Cost	Profit	Revenue	Total Cost	Profit
Panel A: Without Controls						
Treatment*Post	35.597**	22.285	13.312			
	(15.810)	(19.882)	(22.114)			
Treatment	-21.416	-24.154	2.737	9.453**	-0.443	9.896
	(13.503)	(15.070)	(16.782)	(4.660)	(10.391)	(11.232)
Post	-30.629**	40.099***	-70.729***			
	(12.724)	(13.754)	(15.825)			
Means (Baseline/control group)	352.3	240.0	112.3	344.0	289.1	54.92
Observations	6,102	6,102	6,102	3,632	3,632	3,632
Panel B: Including Controls						
Treatment*Post	34.412**	20.126	14.286			
	(15.454)	(19.145)	(21.563)			
Treatment	-19.615	-22.176	2.561	10.035**	0.950	9.999
	(13.164)	(14.693)	(16.529)	(4.626)	(10.657)	(11.482)
Post	-28.206**	39.247***	-67.453***			
	(13.348)	(13.898)	(16.240)			
Means (Baseline/control group)	352.3	240.0	112.3	344.0	289.1	54.92
Observations	6,102	6,102	6,102	3,632	3,632	3,632

Notes: Controls variables include age, schooling, total plot area cultivated, non-agricultural income and rice variety. Standard errors clustered at the household level are shown in parentheses. All regressions include strata fixed effects.
100 decimals = 1 acre
*** p<0.01, ** p<0.05, * p<0.1.

Table A8:
Costs Breakdown (Long Survey)

All costs are in Takas per decimal

	(1) Fertilizers	(2) Manure	(3) Pesticides	(4) Other Expenses	(5) Labor
Panel A: Without Controls					
Treatment*Post	6.711	1.079	0.848	7.493*	-2.241
	(6.872)	(1.252)	(1.165)	(3.894)	(5.493)
Treatment	-7.838	0.356	-0.829	-5.245*	-0.426
	(6.476)	(0.448)	(0.662)	(3.174)	(3.639)
Post	8.351	-0.570	-2.712***	2.065	13.211***
	(5.805)	(0.490)	(0.945)	(3.085)	(3.910)
Mean at Baseline	35.22	1.974	7.013	84.28	111.7
Observations	6,096	5,164	5,705	6,102	6,102
Panel B: Including Controls					
Treatment*Post	6.771	0.840	0.882	7.151*	-2.560
	(6.836)	(1.204)	(1.148)	(3.769)	(5.401)
Treatment	-7.810	0.488	-0.719	-4.834	0.322
	(6.502)	(0.450)	(0.632)	(3.073)	(3.563)
Post	9.759*	-0.456	-2.680***	2.241	13.737***
	(5.282)	(0.516)	(0.991)	(3.207)	(3.927)
Mean at Baseline	35.22	1.974	7.013	84.28	111.7
Observations	6,096	5,164	5,705	6,102	6,102

Notes: Controls variables include age, schooling, total plot area cultivated, non-agricultural income and rice variety.
Standard errors clustered at the household level are shown in parentheses. All regressions include strata fixed effects.
100 decimals = 1 acre
*** p<0.01, ** p<0.05, * p<0.1.