Can Rules-of-Thumb Improve Fertilizer Management? Experimental Evidence from Bangladesh

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Abstract

Adoption of fertilizers has shown high increases in Bangladesh as a result of large government subsidies, but farmers may still fail to apply fertilizer efficiently. In particular, overuse or application of fertilizer at the wrong time may result in higher than optimal costs to the farmer as well as environmental and public costs. In a randomized controlled trial, we provide farmers with a simple tool (leaf color chart) and basic rules-of-thumb training to guide the timing and quantity of urea (nitrogen) application. Treatment group farmers reduce urea use by 8% without compromising yield, suggesting significant scope for improving 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. Cost-effectiveness estimates suggest that each dollar spent on this intervention produces a return of $2.8 dollars due to savings of urea over three seasons, as well as significant environmental benefits. At the national level, urea reduction due to the treatment would save $80 million in direct urea cost and $11 million in carbon emission cost, all within a year. We also find suggestive evidence that improving the timing of urea application also affects farmers' yields. The results demonstrate high returns to a simple tool and rules-of-thumb training to help farmers manage the use of fertilizers, suggesting scope for productivity gains through better management of inputs.

Keywords: Technology Adoption, Farm Management, Environmental Economics, Resource Management

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1 Introduction

Several countries, including Bangladesh, have used subsidies to induce adoption of fertilizer and stimulate agricultural output (Huang et al., 2017).[3] Duflo et al. (2011) demonstrate that in theory, heavy subsidies can induce overuse of fertilizer. Overuse of fertilizer is costly to the farmer and the government and has negative environmental spillovers. In Bangladesh, Rasul and Thapa (2003) and Huang et al. (2017) note the excess and imbalanced use of fertilizers and the associated direct and indirect costs. Imbalanced use can imply that too much fertilizer is applied at the wrong time or too little at the right time, resulting in higher than optimal costs in the former case and lower overall output in the latter. Thus, effective management of inputs like fertilizer has the potential to increase both efficiency and productivity.

In Bangladesh, agricultural land is intensively cultivated with widespread usage of chemical fertilizers, particularly urea. Urea provides nitrogen that is vital for plant growth and is used almost universally by rice farmers, representing 65% of the country's total fertilizers used (Jahiruddin et al., 2009; Kafiluddin and Islam, 2008). Despite significant experience in using the fertilizer, farmers may fail to optimize the quantity and timing of urea application. Unlike other fertilizers, urea needs to be applied several times during a season, because its volatility does not allow prolonged retention in the soil (Choudhury and Kennedy, 2004, 2005; Koenig et al., 2007). Excess urea or urea applied at the wrong time would not be absorbed by the plant and has little or no effect on yields, while increasing farmers' cost. Furthermore, unabsorbed urea can leach from soil to surface or ground water, causing pollution and other negative environmental effects (Gilbert et al., 2006; Eggelston et al., 2006).[4] Overuse of

[3] In 2012–13, the subsidy on urea (nitrogen fertilizer) in Bangladesh was 51%, and in 2013–14 it was 62% (Huang et al., 2017).

[4] Scientists broadly agree that level of urea use is still not high enough to cause significant pollution, partly due to the heavy seasonal rainfall that flushes away residues (FAO, 2011). However, no organizations systematically monitor this and the extent of environmental pollution is not well studied for Bangladesh.

fertilizer can eventually limit the returns to fertilizer and at extremely high levels it can be toxic and negatively affect output (World Bank, 2007). Even when adequate urea is applied, but not at the right time, plants would be deprived of nitrogen and yield is lower. Thus, better fertilizer management through optimal quantity and timing of application can minimize wastage, lowering the direct fertilizer expense and environmental costs, and can also improve productivity by allocating fertilizer to periods when nitrogen is beneficial for plant growth.

The urea requirements of the crop can be identified by the color of it's leaves. Crops with sufficient nitrogen have dark green leaves; in contrast, light green leaves indicate a need for urea, and urea application has the highest return at that time. A leaf color chart (LCC) is a simple tool that indicates whether a crop requires urea. It is a plastic, ruler-shaped strip containing four panels ranging 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 precisely identify when the crop needs nitrogen and time urea applications accordingly (Alam et al., 2005; Buresh, 2010; Witt et al., 2005), thus helping to improve decisions on both quantity and timing.

Through an individual-level randomized control trial, we provided farmers in the treatment group with an LCC, a basic training on how to use the chart and instructions on when and how much to apply.[5] 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.[6] During the training sessions, treatment farmers were instructed to begin fertilizer application 21 days after planting. Farmers were told to compare the color of the rice crop leaves with the LCC before applying urea and encouraged to apply a specified amount of urea only when the LCC indicated that the crop

[5]The intervention was thus a bundle of the LCC tool, training and guidelines, henceforth referred to as the LCC intervention.

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

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, when to apply the fertilizer and how much to use at each application.[7] The quantity of urea that the farmers were instructed to apply was less than what they usually apply on average, encouraging less use of urea.

Prior to the intervention, we conducted a baseline survey that collected data on urea used and yields obtained in the *Boro* season of 2012. We conducted a detailed endline survey at the end of the season after the intervention in order to determine any changes in urea use and yields caused by access to the LCC intervention. During the 2013 season, several short midline surveys were also conducted to explore time use by farmers, and the date and quantity for each urea application during the season.[8] We note that on average farmers apply urea earlier than the recommended time and urea usage is significantly higher than the recommended amount per application. Thus, we expect the intervention to address these constraints about lack of information on timing and quantity in general, particularly inducing a delay in first urea application and a reduction in quantity used. Frequency and timing of application after the first time would depend on the use of the LCC to determine the nitrogen requirement of plants. The training may also lead farmers to pay attention to leaf colors and fertilizer more broadly.

We estimate 'intent-to-treat' effects of gaining access to the LCC intervention on urea application patterns, total urea use and yields. We find that treatment farmers save urea without compromising yield, suggesting that there is scope for improvement in management of urea. We observe that treatment farmers 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 urea are low.[9] Treatment

[7]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., 2014).

[8]Some midline surveys were conducted for a sub-sample of farmers.

[9]Extension workers recommend that urea should be applied 3 times during the period between 21

farmers reduce the quantity of urea applied in the low-return period by 0.031 kilograms per decimal[10] per application, while there is no significant difference in the quantity of urea applied in the high-return period. We find suggestive evidence that farmers apply urea more frequently in the high-return period (a smaller amount per application) and are also marginally more likely to visit their fields more often.

We 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 is driven predominantly by delaying urea application as urea is not useful for rice plants immediately after planting. We also find that treatment farmers experience a yield increase ranging from 3% to 7%, though this effect is not always precise. This corresponds to the suggestive evidence indicating treatment farmers apply urea more frequently in the high-return period and visit their fields more often. These results establish that substantial inefficiencies exist in the way farmers typically apply urea fertilizer; despite using more urea on average, they fail to obtain higher yields. Standard notions of underuse and overuse of fertilizers may need to be redefined, as quantity and timing are both significant dimensions of fertilizer use.[11]

We also conduct a cost-effectiveness analysis and find that the intervention is cost-effective if the urea-savings occur over multiple seasons (the LCC is durable and can be used over several seasons). Based on a conservative approach, assuming no change in yield, every $1 spent on the intervention generated a return of $2.8 through just urea savings over 3 seasons. At a national level, the

days after planting date until a month before harvest.

[10] 1 acre = 100 decimals

[11] Within the correct urea application period, we find no significant difference in the quantity of urea applied by treatment farmers, which implies that treatment farmers may improve the timing of urea application within this period and increase the quantities of nitrogen that the crops can effectively absorb, which in turn generates the increase in yield for the treatment farmers. Although it is not possible to observe this directly with the available data, the findings that (a) treatment farmers apply urea more frequently in the high-return period and that (b) they visit their fields more often, together provide suggestive evidence that this is the case.

individual urea savings would aggregate to $40 million in subsidy costs saved by the government during the 2012–13 agricultural year.

The LCC intervention is effective, as it provides simple rules and gives understandable signals on whether or not leaves are healthy in terms of nitrogen sufficiency. These factors can improve management of urea. Conservation and optimization of urea usage reduces farmers' costs, which has implications for national budgets and positive externalities in the form of reduced runoff and pollution. The findings also show that in Bangladesh, as well as in countries that have shown success in fertilizer adoption, there is still significant scope for improving management of inputs within existing technology and resources, supporting recent research signifying the role of management practices in productivity (Bloom et al., 2013). Through this paper, we also contribute to the literature concerned with the usefulness of subsidies in motivating agents to change behavior (Duflo et al., 2011; Schultz, 1964; World Bank, 2007). While we don't address the merits of subsidies directly, our results indicate that in a context with high fertilizer subsidies, overuse may occur. We also contribute to an expansive literature on the environmental burden and greenhouse emissions due to soil management and fertilizer overuse (Eggelston et al., 2006).

The paper is organized as follows. Section 2 provides background on the cultivation of rice in Bangladesh, and it discusses the challenges of using urea efficiently and the ways that leaf color charts and rules of thumb training 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 discusses cost-effectiveness of the intervention and Section 6 concludes.

2 Context

2.1 Rice Farming and Urea Use in Bangladesh

The agricultural sector in Bangladesh contributes 21% to the GDP and employs about 50% of the labor force (BBS, 2009). Rice is the staple food of the approximately 160 million population, providing over 70% of direct calorie intake in the country (Alam et al., 2011). About 13 million agricultural households are involved in rice cultivation. With the green revolution, rice 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 (nitrogen-based) fertilizers has been common since the green revolution. Traditionally, urea prices are set and heavily subsidized by the government, although the price was increased in 2011. While urea application is most widespread, use of non-urea fertilizers also increased after subsidies were introduced in 2004. Fertilizer usage has increased by 400 percent in the last 30 years (Alam et al., 2011; Anam, 2014; BBS, 2012; Kafiluddin and Islam, 2008), and in 2008, urea made up 65% of all fertilizers used in the country.

Compared to other fertilizers, urea is particularly challenging to use, as the timing of the applications matter and can be difficult for farmers to learn. Farmers need to account for differences in nitrogen requirement across crops, plots and seasons in addition to determining the appropriate time for application. Farmers typically apply all non-urea fertilizers once just before planting,[12] although some farmers also apply urea at that time.[13] Typically, urea is applied in two or three separate applications, starting a few weeks after planting and ending at the

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

[13] 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.

start of the flowering stage, about a month before harvest (over a period of approximately 40 days).[14]. Non-urea fertilizer that is not used by the crop 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 (Choudhury and Kennedy, 2004, 2005; Koenig et al., 2007).

Due to this potential for quick loss, extension workers recommend that urea is applied in several applications instead of once, as described above, but that may not be sufficient to minimize wastage. The highly subsidized price for urea in combination with the inability of farmers to precisely gauge the need for nitrogen for any plot raises concerns that farmers may be over applying. The subsidy on urea was approximately 51% in the 2012–13 agricultural year and 62% in 2013–14 (Huang et al., 2017). Urea usage is close to 100% in our sample at baseline, but, overuse may potentially be a concern in a context with high subsidies; based on the average procurement price of $22.94/50-kg bag and a subsidy of 51% during the season studied in this paper, each additional ton of urea wasted corresponds to a cost of $225 borne by farmers and $234 borne by the government.

Moreover, excess fertilizer can result in significant losses to the atmosphere and surface and ground water (Huang et al., 2017) — the nitrogen from urea 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.[15] An FAO report finds that nitrate toxicity in drinking water is increasingly observed and that there has been a build-up of nitrous oxides in the atmosphere because of unscientific use of fertilizers (FAO, 2011).

[14] A stylized timeline is shown in Appendix Figure A1

[15] The rate of loss depends on soil pH, temperature, moisture and other soil properties, and these vary across plots and over seasons.

In addition, farmers may be compromising yields by not optimizing urea applications. 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 yields.

2.2 Leaf Color Charts

A Leaf Color Chart (LCC) is a simple tool that allows farmers to understand whether urea is needed by the crop at any time during the urea application period.[16] 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 timed to occur when uptake by crops will be high (Alam et al., 2005; Buresh, 2010; Witt et al., 2005). The instructions that accompany an LCC 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.[17]

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., 2005, 2006; 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

[16]The standardized LCCs used in this study were obtained from the International Rice Research Institute (IRRI), with instructions printed on the back.

[17]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 up to five leaves develop), which is usually around 21 days during the *Boro* season due to colder temperatures (Alam et al., 2005).

farmers are given LCCs and basic training, it is unclear if they would choose to adopt and use LCCs, and it is also unclear 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 may have been learned from prior experience.

3 Experimental Design, Data & Empirical Strategy

3.1 Study Area

We conducted this study in partnership with the Center for Development Innovation and Practices (CDIP), a non-government organization in Bangladesh.[18] 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 A4. 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

We conducted a baseline survey in September–October 2012, for 1440 farmers. We 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 605 farmers in December 2012.[19] CDIP staff

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

[19] Due to delays in receiving funding for the project, we could not 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 by following the same guidelines in selecting

conducted the baseline surveys in their program locations, after we provided training.

Treatment farmers were invited to attend a training session in their village in January 2013, just at the start of the *Boro* 2013 season. 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.[20] 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. If the LCC demonstrates urea is required, farmers were advised to apply 9 kilograms of urea per 33 decimals of land (0.27 kg/decimal), which is lower than the mean application. After an application, farmers were instructed to re-check the leaves in 10 days. If the chart indicated that urea was not needed, farmers were told to check again in 5 days. The instructions also told farmers to stop checking or applying urea after flowering.

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 around the time of planting. CDIP staff also conducted a more informal refresher training (either with individual farmers or in small groups) a few weeks after the main training (before the time urea is generally applied). Figure A3 in the Appendix shows a timeline for the study.[21]

CDIP staff conducted four short midline surveys electronically on about 67% of the sample.[22] These surveys focused on time use by farmers. A midline

farmers.

[20]The extension workers were generally not local to the village. Beside the training, they had limited interaction with the farmers. A picture of the LCC is provided in A2, and the accompanying instructions are in Appendix Table A2, based on instructions developed by the Bangladesh Rice Research Institute (http://knowledgebank-brri.org/how-to-use-lcc.php), but simplified further.

[21]Staff from CDIP's education program were recruited to conduct the home visits and the refresher trainings. They were not micro-finance officers; thus, we are not concerned that their ability to influence farmers' access to credit from CDIP may have led to more compliance by farmers.

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

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, which collected information about the *Boro* season of 2013. We 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.[23]

3.3 Randomization

CDIP selected 20 of their branch offices to participate in the study, and we selected approximately 100 farmers from villages covered by each branch. Within each branch, approximately one-third of the sample was drawn from CDIP microfinance 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 A.[24]

We 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.[25] To assign the farmers, we 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.[26] Since we randomized at the individual level, each village in the study has both treatment and control group farmers, although the proportion varies. This design

[23]Overall, 91.3% were still involved in agriculture and 75.7% were still involved in rice cultivation. As is typical in Bangladesh, farmers may move or choose to grow different crops in some seasons.

[24]Comparing our 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 the average farmer in Bangladesh (25.78 kg/dec in the HIES). 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 farmer).

[25]Random assignment was conducted after the baseline survey was completed, but before all the baseline data had been entered.

[26]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.

increased statistical power compared to the alternative of randomizing at the village level, and as we 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* 2012 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 (Figure 1 shows histograms of per decimal urea and yield at baseline).[27] 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.

We show attrition by treatment status in Appendix Table A3, which confirms there is no differential attrition.[28] Since some of the midline surveys were conducted on a sub-sample and there was also some attrition at endline, we also conduct randomization checks for the midline and endline samples as shown in Appendix Table A4.[29] There are no differences between treatment and control 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),

[27] 100 decimals = 1 acre.

[28] Since only a sub-sample was approached for the midline, attrition refers to farmers not found or not surveyed at midline stage. We attempted to follow up everyone at endline, so attrition at endline represents farmers who could not be surveyed.

[29] We selected the locations for the midline surveys randomly after excluding some areas with expected staff shortages in that time period. Appendix Table A5 compares farmers included in the midline farmers to those not included.

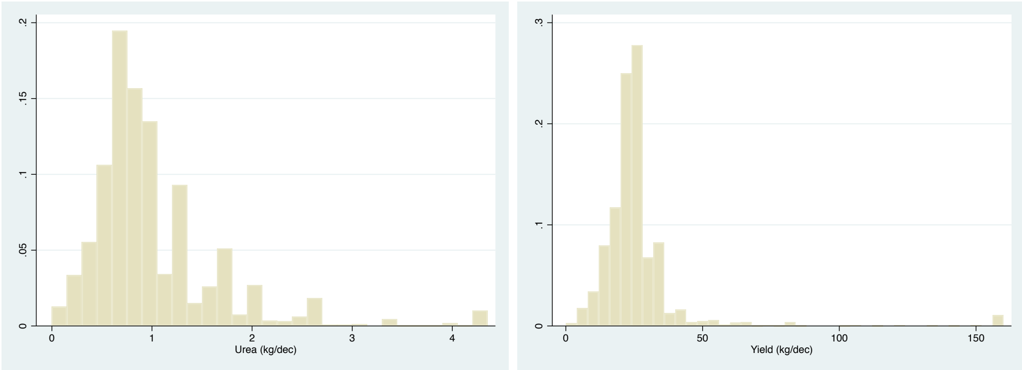
Table 1

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)
Schooling (years)	5.86	5.72	-0.136
	(4.38)	(4.28)	(0.189)
Number of Plots	2.37	2.36	-0.015
	(1.18)	(1.18)	(0.046)
Non-agricultural income (Tk)	10329.70	9657.928	-674.164
	(10759.79)	(10392.05)	(455.634)
Total Plot Area (decimals)	65.30	67.09	1.215
	(43.42)	(43.62)	(1.763)
Number of Household Assets	4.28	4.34	0.042
	(2.23)	(2.17)	(0.106)
Observations	1008	1017	2025
Plot Level Variables—All Households:			
Plot Area (decimals)	28.87	30.18	1.125
	(20.72)	(22.97)	(0.740)
Urea used(Y/N)	1.00	1.00	0.000
	(0.03)	(0.03)	(0.001)
Urea (kg/decimal)	1.01	1.01	-0.001
	(0.69)	(0.62)	(0.025)
Yield (kg/decimal)	26.22	25.25	-1.093
	(19.71)	(15.81)	(0.764)
Observations	2252	2260	4512
Plot Level Variables—Long Survey Households:			
Revenue (kg/decimal)	361.86	342.71	-21.641
	(278.02)	(205.08)	(13.198)
Total Cost (Tk/decimal)	245.92	233.87	-14.236
	(230.93)	(159.76)	(8.884)
Profit (Tk/decimal)	115.99	109.03	-7.455
	(292.69)	(209.38)	(12.658)
Observations	1682	1702	3384
Joint Test (chi-squared)			2.51
p-value			(0.1130)

Notes: For columns (1) & (2), standard deviations are shown in parentheses. 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. Number of observation in Column (3) is the total sample size. The long survey that collected costs and profits at baseline was conducted with a sub-sample, indicated by the lower number of observations. The joint test used a chi-squared test to estimate whether the coefficients are jointly significant.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Figure 1: *Urea and Yield at Baseline*



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 previously know about their treatment status. 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.

3.4 Empirical Strategy

We estimate the intent-to-treat effect of getting access to the LCC intervention (LCC and accompanying instructions and training). We 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 households in the treatment group and is 0 otherwise; X_h 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_{ph} includes plot level variables such as variety of rice. γ_s controls for strata fixed effects and ϵ_{ph} 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 endline (2013) season.[30]

For outcomes such as urea use and yields, for which data are available at baseline and endline, we 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 the LCC intervention was random, β_3 estimates the causal effect of gaining access to the intervention.

As a robustness exercise, we also present estimates from an ANCOVA specification, which is the same as 1, including the baseline dependent variable on the RHS, when available (Equation 3).

$$y_{ph}^{endline} = \phi_0 + \phi_1 Treatment_h + \phi_2 y_{ph}^{baseline} + \rho X_h + \delta Z_{ph} + \gamma_s + \epsilon_{ph} \tag{3}$$

30 Our preferred specification includes household and plot controls, X_h and Z_{ph}. All results are practically the same if additional controls are excluded from the regressions and can be made available on request.

4 Results

In this section we present the main findings of this study. We first show estimates of take-up of leaf color charts in section 4.1. In Section 4.2, we 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 we estimate whether we observe any of these changes after treatment. In Section 4.4, we 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 the intervention. During the endline survey, farmers were asked whether they received an LCC, whether they attended the main training and whether they used the LCC during the season; they 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 and use the LCC, and they could show the LCC to enumerators. The probability of stating that they received an LCC is 68.4 percentage points higher for the treatment group farmers compared to the control group farmers. About 75% of the treatment group state they received a LCC. 7.9% of the control group also state they received an LCC, most likely through government extension workers.[31] The primary farmer in the household is the person interviewed at the endline survey, and only 59% had attended the DAE training session. Qualitative interviews with some of the farmers later 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

[31]LCCs were not available in the market during the course of the study. Although CDIP staff were instructed not to allow anyone other than the invited farmers to attend the training, in a few cases other farmers came. We find from CDIP records and qualitative work that the control group farmers with an LCC usually received it from the DAE representative outside the training or, in a few cases, because they attended the training.

Table 2

Take-up & Stated use of LCCs

	(1) Received LCC	(2) Attended Training	(3) Used LCC	(4) Could Show LCC
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.

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. Some cross-overs did exist, therefore, but such cases were very limited.

4.2 LCC Instructions & Expected Changes

Figure 2 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, during a period where returns may be low. Most farmers apply urea at least twice and almost 40% apply urea three times as is traditionally recommended. The third chart shows the distribution of urea per application — on average, farmers use 0.52 kg/dec at each application with a longer right tail (driven by farmers who apply only once).[32] The last histogram is for the number of days between flowering and last urea application (negative numbers indicate applications after flowering) — most farmers time their last application a few days before flowering, and as above, the right tail is driven by farmers who apply fewer than three times. A small proportion of farmers apply after flowering, when there are no returns to urea.

We provided farmers in the treatment group with an LCC and gave them instructions on how to use the charts. Farmers were told to focus on a few simple instructions (a translated version of the handout is shown in Appendix Table A2).[33] 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. If the LCC demonstrates urea is required, farmers were advised to apply 0.27 kg/decimal, which is lower than the mean application. After an application, farmers were instructed to re-check the leaves in 10 days. If the chart indicated that urea was not needed, farmers were told to check again in 5 days. The Bangladesh Rice Research Institute estimates that with an LCC, most farmers will apply urea four times instead of recommended number of three applications.[34] The instructions also told farmers to stop checking or applying urea after flowering.

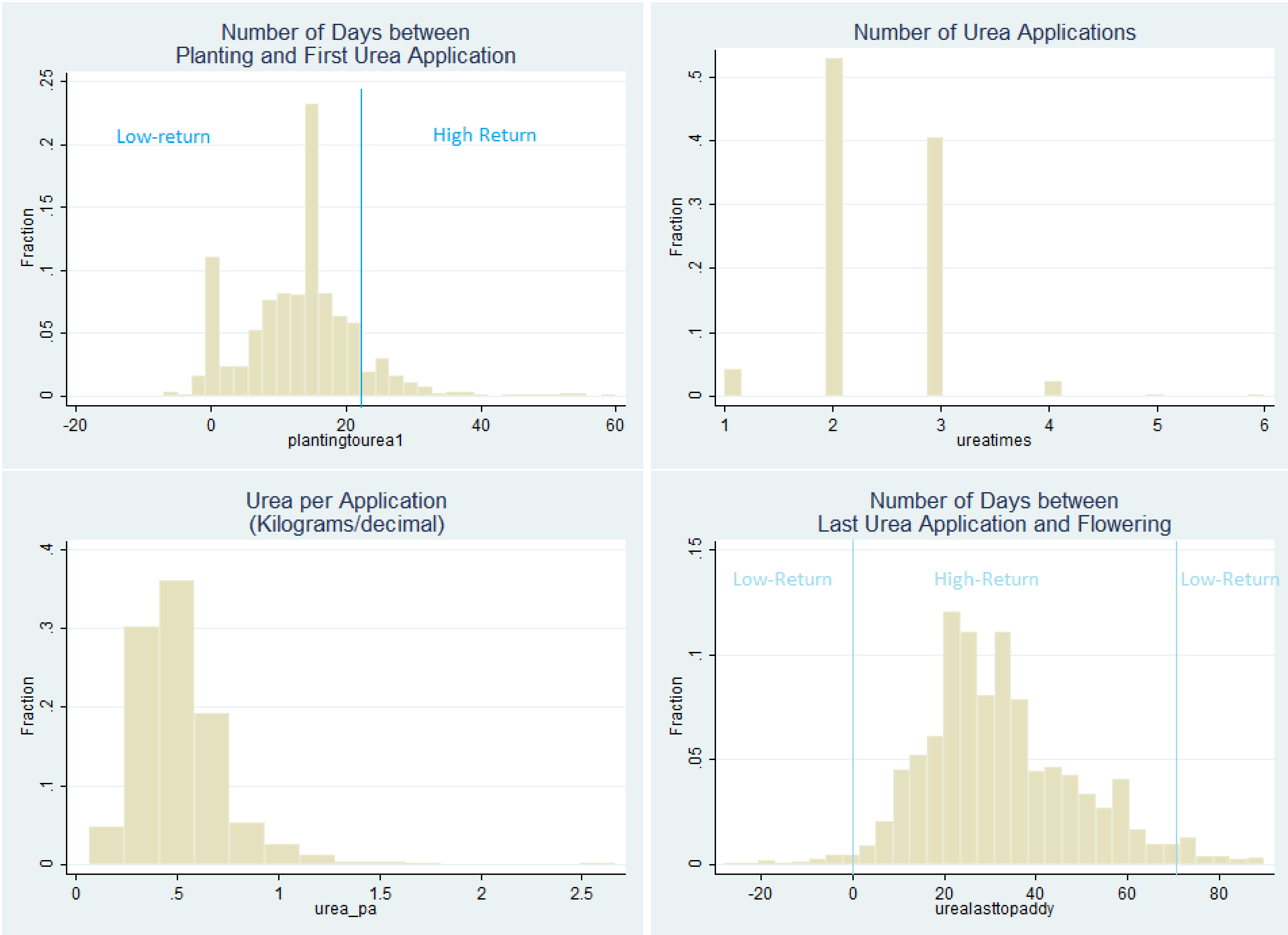
Based on these instructions, there are several possible expected changes in behavior. Farmers may delay urea application until 21 days after planting and apply smaller quantities of urea per application. We test these practices in addition to estimating overall treatment effects on urea use and yields. The instructions do not directly tell farmers to apply less urea overall during the season or apply more frequently, but rather allow the leaf colors to indicate if

[32] Appendix Figure A5 shows separate histograms for control farmers with 2 total applications and 3 total applications per season. Even for farmers who apply thrice or more frequently, average application is 0.44 kg/dec, higher than the recommended application.

[33] These were distributed during the refresher training sessions.

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

Figure 2: *Urea Application Patterns for Control Group*



they should apply at any point in time. It is not possible to directly test if farmers check leaf colors, but we test the treatment effect on frequency of applications and total urea used over the season. Given that the per application quantity of urea (0.52 kg/dec) is significantly higher than the quantity recommended during the training (0.27 kg/dec), and that most farmers are applying twice or thrice, we can expect overall urea usage to decline.

4.3 Timing of Urea Applications

In this section, we identify changes in behavior by farmers in the timing of urea applications as discussed above.[35] Specifically, we test whether farmers (i) delay urea application until 21 days after planting, (ii) apply urea more frequently, and (iii) apply smaller quantities of urea per application. In the last round of the midline survey, timed around the end of the urea application period, we collected data at the plot level for all midline survey farmers on urea application dates and quantities applied on each date. We use this data to estimate the changes discussed above. Since we are testing multiple hypotheses, we calculate family-wise adjusted p-values based on 1,000 bootstraps of the free step-down procedure of Westfall and Young (1993).[36] We 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. 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 post-planting. The table shows that farmers in the treatment group are much more likely to have waited until 21 days to start urea application compared to

[35]We caveat this section by pointing out that the data on timing was collected for a sub-sample of farmers by CDIP staff. Due to sample size and high measurement error, as these outcomes are based on recall about specific timing dates, we anticipate power concerns in testing the timing outcomes. These effects on timing are, however, useful in understanding the overall effects on urea usage and yields presented later.

[36]We use the *Stata* code implemented by Jones et al. (2018).

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 variable is split up into the number of applications at the period of high-returns and low-returns, respectively.[37] There is no significant difference in the frequency of urea applications overall, but the coefficient is 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.

Overall, these results show strong evidence that on average, treatment farmers delay the starting date of urea applications to a more productive period and reduce urea used in the low-returns period. There is weaker evidence that suggests that the intervention increases the frequency of urea applications in

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

Table 3

Changes in Behavior in Using Urea

	Change in Timing			Change in Frequency			Change in Quantity		
	(1) Applied 1st 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 app. (kg/dec.)	(8) Urea/app. High-return Period (kg/dec.)	(9) Urea/app. Low-Return Period (kg/dec.)
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)
Adjust p-value	[0.042]	[0.068]	[0.294]	[0.677]	[0.340]	[0.615]	[0.532]	[0.677]	[0.068]
Control 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. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. We report family-wise p-values in brackets that account for the 9 possible outcomes being tested.

the high-return period.[38] Changes in the overall timeline of urea application (intervals measured in days) are shown in Appendix Table A6.

In the second and fourth rounds of the midline surveys, the farmers were asked about time spent on various agricultural activities in the last seven days. The results are shown in Appendix Table A7. We compute Tobit estimates, since the variables are highly censored at zero, and also report OLS estimates in Appendix Table A8. The dependent variable in column (1) is the number of days during the last week that 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 activities in the field. Most of the coefficients 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 4 shows the ITT effects of the intervention on urea used and yields attained by farmers. Controls for age and years of education of the farmer, non-agricultural family income, total area cultivated by the farmer, and the variety of rice cultivated on the plot, are included in the regressions. Household fixed effects are also included in columns (2) and (4). The unit of observation is a plot and all regressions are clustered at the household level and include strata fixed effects.

We find that, on average, urea use declines while yield increases moderately for the treatment group relative to the control due to the intervention. Column (2) shows that having access to the intervention results in a decrease in urea use

[38] The family-wise adjusted p-values correct for testing nice possible hypotheses by using the free step-down procedure of Westfall and Young (1993). The effects on reducing urea use in the low return period are still significant after the adjustment.

Table 4

Full Sample: Treatment Effects on Urea & Yield

Urea & Yield in Kilograms per Decimal

	Urea		Yield	
	(1)	(2)	(3)	(4)
Treatment*Post	-0.079**	-0.089**	1.757**	1.352
	(0.034)	(0.041)	(0.849)	(0.941)
Treatment	0.001		-1.035	
	(0.025)		(0.759)	
Post	0.084***	0.088***	-3.238***	-2.932***
	(0.026)	(0.031)	(0.697)	(0.787)
Controls	Yes	Yes	Yes	Yes
Household FE	No	Yes	No	Yes
Mean at Baseline	1.011	1.011	25.73	25.73
Control Group Mean at Endline	1.065	1.065	22.83	22.83
Observations	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, and rice variety.
Standard errors clustered at the household level are shown in parentheses. All regressions include strata fixed effects.
100 decimals = 1 acre
*** $p<0.01$, ** $p<0.05$, * $p<0.1$.

of 0.079 kilograms per decimal (significant at the 5% level). The coefficient is not significantly different when household fixed effects are included (Column (2)), indicating a robust effect on urea. 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, a savings of Taka 104 (USD 1.33) for the farmer.

Column (3) shows that getting access to the LCC intervention leads to an increase in yields of 1.757 kilograms per decimal (statistically significant at the 5% level).[39] 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; however, it is possible that standard errors are magnified in this specification due to the structure of the data.

[39]The *Post* dummy is significant in these specifications. The time trend is expected due to the variable nature of agriculture in Bangladesh.

In the Appendix, we present effects using alternate specifications. Estimates using logs of urea per decimals and logs of yield per decimal is shown in Table A9. The results are consistent overall; however. the estimates for effect of urea have a larger magnitude, while those 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. Table A10 shows the outcomes from specification (3), showing a robust negative effect on urea and positive effect on yield (in both the linear and log-linear form of the specification). Additionally, household level (instead of plot-level) regressions are presented for the same outcomes. The effect on urea is stable, with a overall significant reduction of 0.08 kg/dec at the household level. The coefficient on yield is positive and significant in the difference-in-difference specification at the household level, but not in the ANCOVA specification.[40]

We also estimate the effects on total revenue, costs and profits for the farmers, to further understand the magnitude of the returns. As discussed in the section above, price 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 we estimate two sets of regressions. Columns (1) to (3) of Table 5 show 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.

The table shows estimates after controlling for individual, household char-

[40]In Appendix Figure A6, we show the distribution of the key variables separately for the treatment and control groups. The distributions allow us to infer what part of the distribution of treatment farmers drives the changes in application patterns. We note that while some treatment farmers continue to apply too early (just at planting) or too late, farmers who would have applied in the first 3 weeks after planting shift their application to after the 21-day period as recommended in the LCC instructions. The distribution of total urea shifts to the left due to the treatment, indicating that the reduction in urea is observed throughout the urea usage distribution. The distribution of number of applications shows that the proportion of farmers who apply twice is lower among the treatment group, and the proportion who apply thrice is slightly higher. The distribution of yield for treatment farmers has higher density at higher values of yield relative to control farmers, indicating that the yield improvement is experienced by treatment farmers throughout the yield distribution.

Table 5

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

acteristics and rice variety. For the sample for whom price data are available, revenue increases by Tk 34.4 per decimal (significant 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 are also not statistically significantly different. Using endline data for all farmers in the sample, revenue is higher by Tk 10 per decimal for the treatment group (significant at 5% level); total cost is higher but the estimated effect is not statistically significant.[41] In the Appendix we also present the regressions at household level, and using an ANCOVA specification, finding very similar effects.

Based on these results, we claim that the LCC intervention resulted in farmers using a significantly lower urea per decimal, which seems to be driven by lower urea application during the low return period. Overall, the treatment effects on urea savings are substantial. Back of the envelope calculations discussed above show large quantities of savings of urea over multiple seasons. This

[41] 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, we collected price data retrospectively at the village level (from local fertilizer stores) in March 2014. Table A11 in the Appendix 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.

implies that inefficiencies exist 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 potentially improve yields.

The effects on yield are not robust and thus confirm that urea reduction is possible without compromising yield. We take the yield effects as suggestive evidence that productivity improved, plausibly due to shift in urea application to the high return period. 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. We recognize that both the impact on yield and on allocation of urea to the high return period is modest and suggestive.

We also test for non-linearities in the treatment effect. We find little evidence of heterogeneity, except that farmers with higher baseline yields also experience a higher treatment effect on yield, indicating that more productive farmers were more likely to optimize urea usage and obtain relatively higher yield. Estimates of heterogeneous effects are provided in the Appendix.

5 Cost-Effectiveness of Intervention

Table 6 shows a cost-benefit analysis of the intervention and an estimate of the cost-effectiveness. Each LCC costs US $1.1 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, we use treatment effects on urea usage to compute back-of-the-envelope estimates of urea saved for the mean farmer. On average, farmers cultivate rice on 66 decimals of land. Using the official price of urea and the average reported price of rice at the endline survey, we estimate that farmers

Table 6

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 per season	$1.10
Total Cost per LCC per season	$2.60
Benefits:	
Savings in Urea for Mean Farmer (0.079 kg/dec. urea saved *66 decimals of land*$0.459/kg)	$2.39
Cost-Effectiveness (Benefits/Costs) per season:	0.92
Cost-Effectiveness (Benefits/Costs) if LLC cost is over 3 seasons:	2.76

Notes: [1]Includes cost of importing 1000 LCC from the Philippines, including shipping ($1000) and bank and agent fees ($100).
[2]Includes honorarium for DAE trainers, refreshments during training, transport of LCCs, additional training costs for CDIP staff, and printing.
We use the DD estimates of treatment effects of urea from Table 4.
The world price of urea is 0.459$/kg in 2012-13 (Huang et al., 2017)
We use an exchange rate of 1 USD = Tk 78 to convert returns to dollars.

save $2.39 on average from reducing urea use. Assuming no change in yield, the urea savings amount to approximately double the direct cost of one LCC, but lower than the total LCC cost per farmer (including fixed costs of training).

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. With savings in urea of $2.39, the program is cost-effective if the LCC is used for two seasons. Dividing the LCC cost over three seasons, we find that each dollar spent on the LCC generates a return of $2.76 solely due to urea savings.[42]

[42]The intervention leads farmers to spend time in the field checking leaf colors and applying fertilizer, amounting to higher labor time for treatment farmers. To account for labor time in the cost-benefit analysis, we need a measure of wages, which is not available from our data. We use the nationally representative Bangladesh Integrated Household Survey (Ahmed, 2013) from 2011–12 to obtain a measure of farming labor wages. The average male daily wage for farm work from the community survey of BIHS based on 50 village surveys is 209.8 Tk. The modal number of hours worked per day for agricultural workers is 8, amounting to an hourly wage of 26 Tk. Using the estimate from Table A8 that the intervention increases

Using the average treatment effect of 8% urea savings and annual consumption and prices from Bangladesh Ministry of Agriculture,[43] we estimate that a total of 180,000 metric tons of urea, worth $82 million, could be saved during the 2012–13 season. Under the subsidy provided during that period, the government pays 49% of the cost of urea consumed, which implies savings of $40.5 million of the urea subsidy cost to the government of Bangladesh.[44]

5.1 Socio-environmental cost averted due to urea reduction

Reducing urea has environmental benefits that are external to the farmer, including reduction in greenhouse gas emissions, nitrogen runoff into the waterways and the energy cost of urea production. To comprehensively estimate the benefit of the intervention, we need to account for the value that society would be willing to pay for these external benefits. In this section, we estimate the green house gas burden avoided due to the reduction in urea use. We abstract from the water quality effects associated with urea use and runoff, because while these are environmentally significant spillovers of fertilizer usage, it is difficult to accurately estimate the associated cost, as the complexity of the water quality system is outside the scope of the paper.

Urea application affects the environment through emissions of green house gases in two ways. Nitrous oxide (N_2O) emissions from additions of nitrogen to land due to deposition and leaching, and emissions of carbon dioxide (CO_2)

time spent on fertilizer activities by 3.9 minutes in a 7-day period and that the fertilizer application period is approximately 5 weeks long, we estimate the intervention increases labor time by 19.5 minutes in a season. Based on the hourly wage, the cost of this time is 8.5 Tk or $0.11 per farmer per season. This lowers the return of the intervention to $2.28 per season, implying that each dollar spent on the LCC intervention results in a gain of $0.88 over 1 season through urea savings (accounting for labor cost) and $2.64 over three seasons.

[43] The total consumption in Bangladesh is 2,247,000 metric tones and the price is 0.459$/kg or 459$/ton in 2012–13 (Huang et al., 2017).

[44] If we account for yield improvement due to better fertilizer management with LCCs, the average farmer achieves $22.34 additional returns. Combining urea saving and yield increase, the total benefit is $23.30. Overall, the cost-effectiveness of the intervention is 9.51, i.e. every $1 spent on the intervention generated a return of $9.51. Using the 95% confidence interval around the treatment effect on yield, the upper and lower bound of the total benefit per farmer is $3.61 and $45.85. The range for the cost-effectiveness is $1.39–$17.64. Thus the treatment is cost-effective in one season even if we use the lower bound for yield improvement.

following additions of the fertilizer. We estimate the social cost of these emissions, which are avoided due to reduction in urea use by treatment farmers, using the social cost of carbon from the Interagency Working Group on the Social Cost of Carbon (2013). Table A17 shows how these costs are estimated. Assuming a 46% nitrogen content of urea, we estimate that with each farmer exposed to the LCC intervention, N_2O and CO_2 emissions are reduced by 0.02 kg and 1.03 kg, respectively (Eggelston et al., 2006). Assuming a global warming potential of N_2O of 296 (CO_2 equivalent of N_2O), this amounts to 8.06 kg of CO_2 emissions avoided due to LCC usage by one farmer. Using a social cost of CO_2 if \$40 per ton (Interagency Working Group on the Social Cost of Carbon, 2013), we estimate that the overall environmental damage averted by the LCC intervention through reduction in urea usage is 32 cents per farmer over 1 season. Thus, the environmental cost savings alone can make up for the variable cost of the LCC (\$1.1, excluding the fixed training cost) in under 4 seasons. These benefits will accrue as more farmers utilize better fertilizer management practices over multiple seasons. Just over the 2012–13 agricultural season, which corresponds to the intervention period, the aggregate national savings of urea of 180,000 tons corresponds to a staggering 0.3 million tones, or \$11 million, of CO_2 emissions.

6 Conclusion

This paper explores the scope for 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, we provide rice farmers in the treatment group with an LCC and simple rules-of-thumb that help with the management of urea fertilizers. We find that farmers save urea by 8% on average when they gain access to a leaf color chart, which suggests 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, we 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 the LCC intervention.

The LCC intervention may be effective in improving urea management due to several features, most important of which is the ability of the chart to provide clear signals on nitrogen sufficiency accompanied by 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, 2013; Marenya and 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 farmers use an LCC, they get understandable signals in real time on how they are performing. Alternatively, the LCC intervention may be effective due to its application of rules-of-thumb learning. The literature demonstrates the potential effectiveness of using simple rules to promote learning. Drexler et al. (2014) conduct a field experiment with micro-entrepreneurs to promote financial literacy, finding that a simplified rule-of-thumb training is much more effective than a more-complex training program.

One of the paper's contributions to the literature is to demonstrate that overuse occurs in this setting, and urea savings can be achieved without compromising productivity. We also advocate that significance of timing of urea application, in addition to the quantity. 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 the management of urea for all farmers. The intervention is cost-effective, and therefore disseminating LCCs and training to farmers in the region can lead to large gains. In this study, we 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 rules-of-thumb trainings, there is significant scope to speed up awareness and dissemination by making use of alternate networks to complement traditional agriculture extension.

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Appendix

A Sample Selection

CDIP selected 20 of their branch offices to participate in the study and and we 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.[45] The second group of farmers may or may not be directly connected with CDIP.[46] For the first sub-sample, we 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. we conducted a census of farmers in those villages and then randomly selected 30 rice farmers from each village.[47] 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. We 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.

B Non-linearities: Who Benefits from the Intervention?

In this section we discuss who benefits from the intervention. We also investigate whether there is any evidence for heterogeneous treatment effects by time preferences, cognition or income in section B.1. We test heterogeneity with respect to baseline urea and usage in section B.2.

B.1 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

[45] 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.

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

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

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 we create a variable that measures where farmers switch from stating a preference for today to stating a preference for a larger amount tomorrow, which we use as a proxy for patience. We 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.[48] We 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, we use the endline measures to estimate whether treatment effects differ by measured levels of patience or cognition. We also estimate whether treatment effects vary by baseline levels of non-agricultural household income. To do so, we estimate Equation 3 for each of these measures.

$$\begin{aligned} y_{pht} = {} & \beta_0 + \beta_1 Treatment_h + \beta_2 Post_t + \beta_3 Treatment_h * Post_{ht} + \beta_4 C_h \\ & + \beta_5 C_h * Treatment_h + \beta_5 C_h * Post_h + \beta_6 C_h * Treatment * Post_h \\ & + \rho X_{ht} + \delta Z_{pht} + \gamma_s + \epsilon_{pht} \end{aligned} \tag{4}$$

C_h is an individual or household characteristic, such as time preference and cognition of primary farmer or non-agricultural household income. All other variables are the same as before. Table A15 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, we 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 we 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

[48] 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.

to use.[49] 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.

B.2 Treatment Effects by Baseline Urea and Yield

Table A16 shows the results from the regression of endline urea and yield as a function of treatment and its interaction with baseline urea and yield, respectively. The regression controls for household characteristics, strata fixed effects and the baseline value of the dependent variable. The treatment effects are not significantly different for farmers with different baseline levels for these outcomes. The log-linear specification with logged endline yield as an outcome shows a slightly higher yield improvement for farmers with higher baseline yield.

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

C Supplementary Figures

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

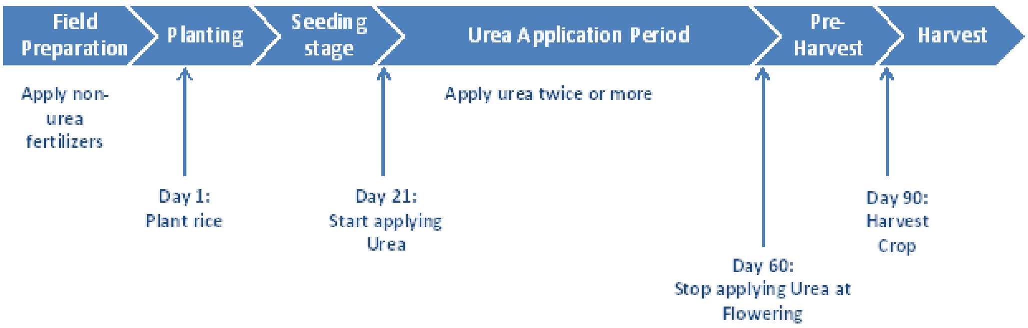


Figure A2: *A Left Color Chart*

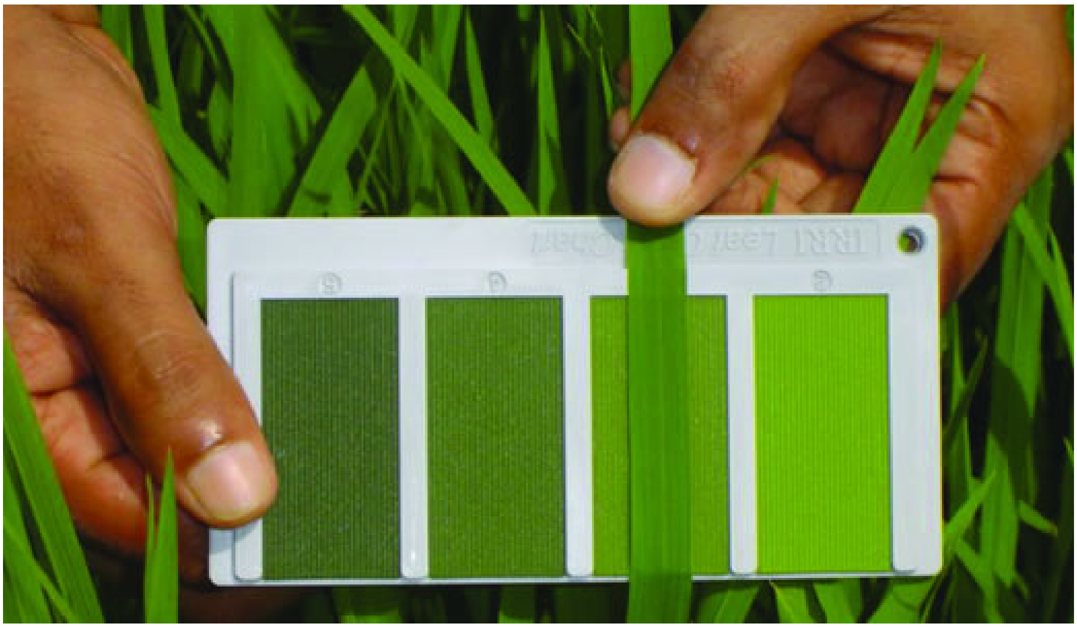


Figure A3: *Timeline of Study*

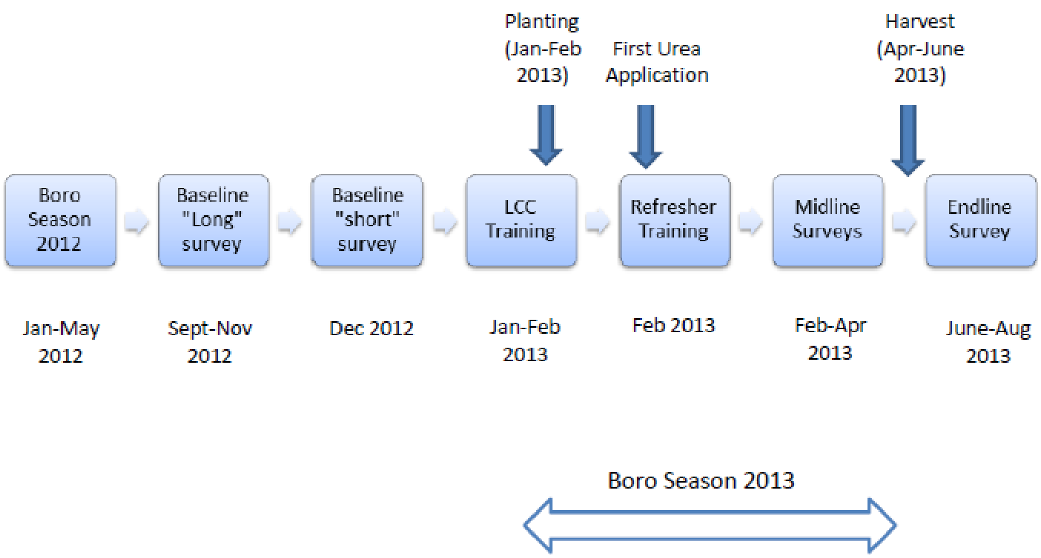


Figure A4: *Study Areas (Districts) in Bangladesh*

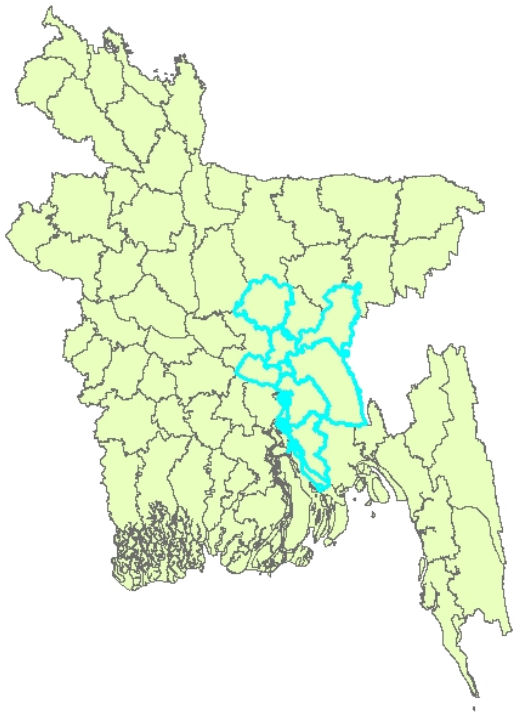


Figure A5: *Urea per Application by Number of Total Applications*

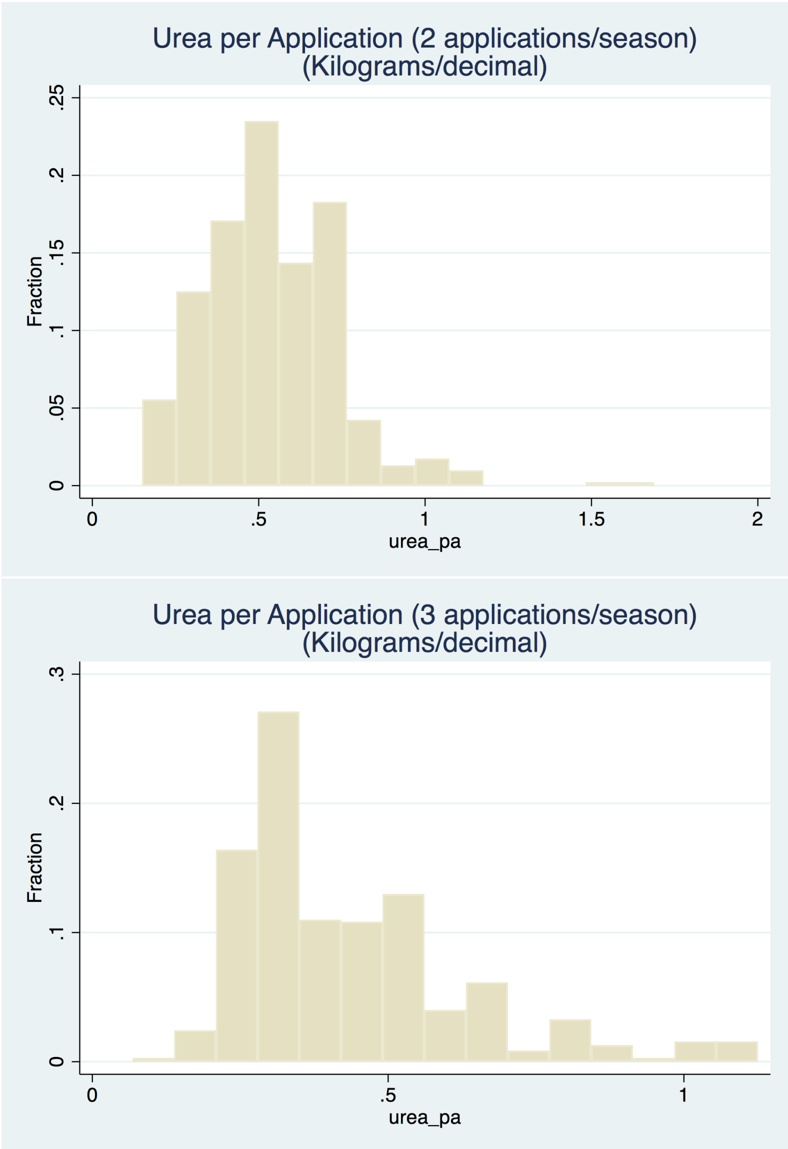
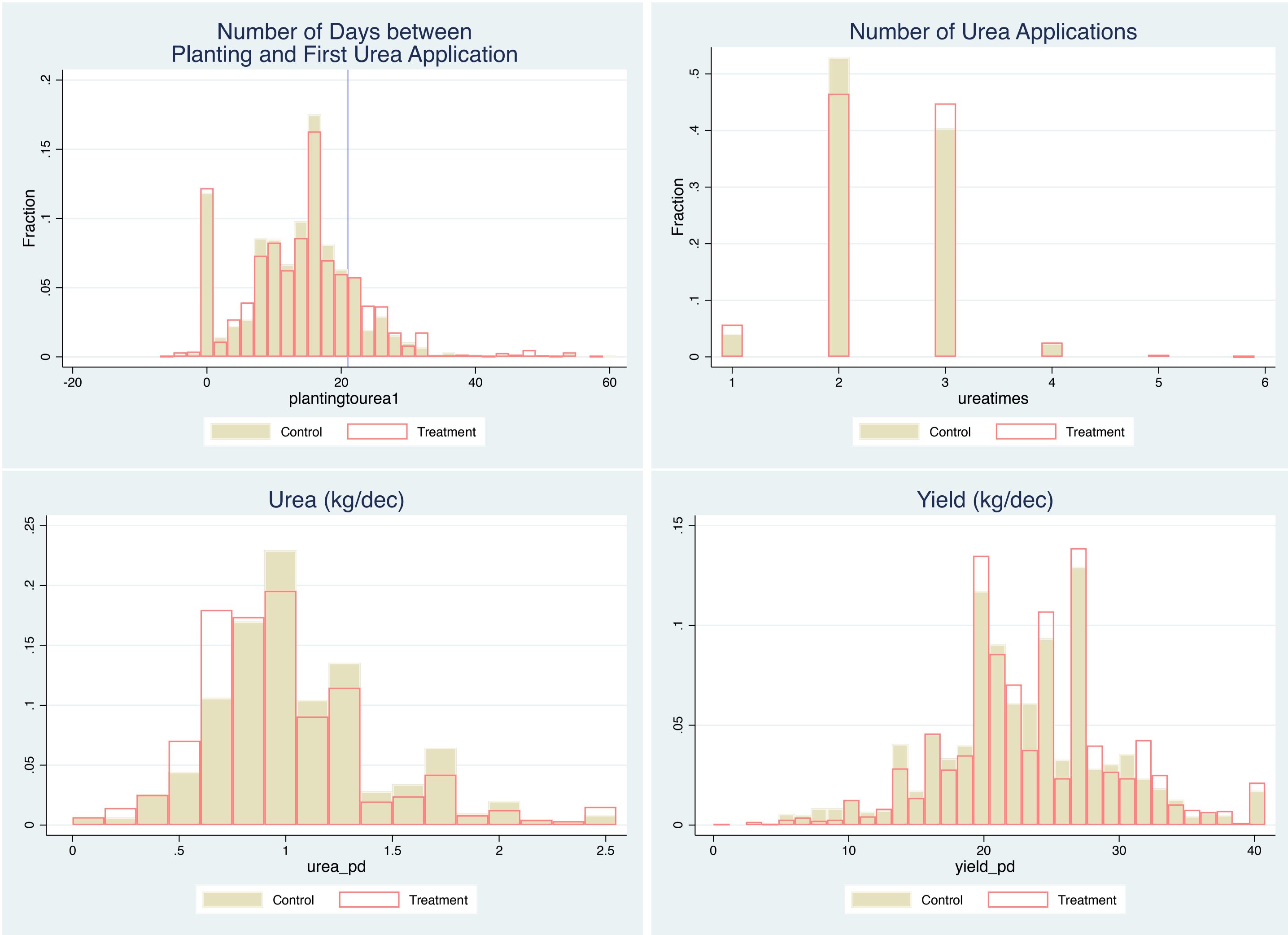


Figure A6: *Urea Application and Yield for Treatment and Control Group*



D Supplementary Tables

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 for Using LCCs

1. Check leaf color with LCC every 10 days, starting 21 days after planing until flowering (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

Attrition by Treatment

The dependent variable indicates HH not included in:	(1) Endline Survey	(2) Midline Time Use	(3) Midline Urea Use
Treatment	0.006	-0.014	-0.000
	(0.018)	(0.017)	(0.014)
Constant	-0.004	0.009	0.000
	(0.142)	(0.134)	(0.115)
Observations	2,025	2,025	2,025

Notes: Regressions include strata fixed effects. Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Table A4

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. Inc. (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 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 A5

Household and Plot Characteristics across Samples

	(1)	(2)	(3)
	Summary Statistics		Difference
	No Midline	Midline	(2)-(1)
Farmer & Household Characteristics:			
Age (years)	44.91	45.55	
	(11.93)	(12.77)	
Schooling (years)	6.059	5.741	
	(4.21)	(4.37)	
Number of Plots	2.074	2.470	**
	(1.12)	(1.18)	
Non-agricultural income (Tk)	8,981	10,282	**
	(9,318)	(10,935)	
Total Plot Area (decimals)	54.83	69.15	**
	(36.0)	(45.09)	
Number of Household Assets	4.182	4.345	
	(1.97)	(2.26)	
Observations	469	1556	2045
Plot Level Variables—All Households:			
Plot Area (decimals)	28.86	29.70	
	(18.27)	(22.69)	
Urea used(Y/N)	0.998	0.999	
	(0.04)	(0.03)	
Urea (kg/decimal)	1.02	1.01	
	(0.72)	(0.64)	
Yield (kg/decimal)	26.30	25.59	
	(19.48)	(17.45)	
Observations	892	3,624	4516
Plot Level Variables—Long Survey:			
Revenue (kg/decimal)	408.1	340.4	**
	(352.6)	(212.3)	
Total Cost (Tk/decimal)	274.6	232.4	**
	(241.8)	(187.0)	
Profit (Tk/decimal)	133.5	108.0	**
	(311.7)	(240.0)	
Observations	598	2790	3388

Notes: For columns (1) & (2), standard deviations are shown in parentheses. Number of observation in Column (3) is the total sample size. The long survey that collected costs and profits at baseline was conducted with a sub-sample, indicated by the lower number of observations. 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 A6

Changes in Urea Application Intervals during 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
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 A7

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)	(6) All Activities (minutes)	(7) All Activities Excl. Fert. (minutes)
Treatment	0.134*	7.949	10.047	9.245	2.200	19.930	18.503
	(0.079)	(10.186)	(18.639)	(14.903)	(9.130)	(12.165)	(13.246)
Control Mean	2.700	50.31	57.35	4.471	38.85	151	100.7
Observations	2,066	2,066	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 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 A8

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)	(6) All Activities (minutes)	(7) All Activities Excl. Fert. (minutes)
Treatment	0.112	3.921	5.827	0.786	1.349	11.883*	7.962
	(0.071)	(3.436)	(4.554)	(0.866)	(3.032)	(7.097)	(5.787)
Control Mean	2.700	50.31	57.35	4.471	38.85	151	100.7
Observations	2,066	2,066	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 A9

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
Control Group Mean at Endline	1.065	1.065	1.065	22.83	22.83	22.83
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 A10

Full Sample: Treatment Effects on Urea & Yield (ANCOVA specification)

	Urea (kg/dec)			Yield (kg/dec)		
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment	-0.070***	-0.073***	-0.079***	0.560**	0.577**	0.029**
	(0.018)	(0.018)	(0.019)	(0.260)	(0.256)	(0.013)
Urea (baseline)	0.032	0.030	0.026			
	(0.020)	(0.019)	(0.020)			
Yield (baseline)				0.079	0.025	-0.012
				(0.432)	(0.414)	(0.030)
Controls	No	Yes	Yes	No	Yes	Yes
Mean at Baseline	1.011	1.011	1.011	25.73	25.73	25.73
Control Group Mean at Endline	1.065	1.065	1.065	22.83	22.83	22.83
Observations	3,632	3,632	3,622	3,632	3,632	3,632

Notes: This table shows treatment effects on urea use and yield using an ANCOVA specification. The dependent variable is the Ln of urea in column (3) and Ln of yield in column (6). Control variables include lagged dependent variable (i.e. urea or yield from baseline) 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 A11

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
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 A12

Revenue, Cost & Profits (ANCOVA Specification)

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
Treatment	9.424*	6.054	3.533	10.230**	5.842	4.518
	(5.321)	(13.776)	(14.790)	(4.654)	(10.678)	(11.617)
Baseline Dependent Variable	0.000	0.006	0.036	0.000	0.006	0.036
	(0.023)	(0.032)	(0.026)	(0.022)	(0.033)	(0.026)
Means (control group)	329.6	283.8	45.73	344	289.1	54.92
Observations	2,722	2,722	2,722	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. A dummy is added to control for households without baseline measure in columns 4-6.
100 decimals = 1 acre
*** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table A13

Treatment Effects in Household Specification

Panel A: Difference in Difference Specification

	(1) Urea (kg/dec)	(2) Yield (kg/dec)	(3) Revenue (Tk/dec)	(4) Cost (Tk/dec)	(5) Profit (Tk/dec)
Treatment*Post	-0.079**	1.434*	19.259*	5.947	13.179
	(0.031)	(0.762)	(10.769)	(11.943)	(13.203)
Treatment	0.010	-0.868*	-10.561	-3.304	-7.135
	(0.021)	(0.514)	(7.270)	(8.062)	(8.913)
Post	0.101***	-1.672***	115.284***	132.087***	-17.065*
	(0.022)	(0.542)	(7.665)	(8.501)	(9.398)
Observations	3,406	3,406	3,406	3,406	3,406

Panel B: ANCOVA Specification

	(1) Urea (kg/dec)	(2) Yield (kg/dec)	(3) Revenue (Tk/dec)	(4) Cost (Tk/dec)	(5) Profit (Tk/dec)
Treatment	-0.081***	0.398	6.145	3.175	2.895
	(0.018)	(0.253)	(4.483)	(11.030)	(11.719)
Baseline Dep. Var.	0.053***	0.007	0.005	-0.015	0.043
	(0.019)	(0.010)	(0.019)	(0.053)	(0.043)
Observations	1,535	1,535	1,535	1,535	1,535

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 A14

Costs Breakdown (Long Survey Sample)

All costs are in Takas per decimal

	(1) Fertilizers	(2) Manure	(3) Pesticides	(4) Other Expenses	(5) Labor
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.

Table A15

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
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 A16

Treatment Effects by Baseline Urea and Yield

	(1)	(2)	(3)
	Urea	Yield	Ln(Yield)
Baseline Urea * Treatment	-0.021		
	(0.034)		
Baseline Yield * Treatment		0.035	0.002*
		(0.022)	(0.001)
Treatment	-0.051	0.377	0.018
	(0.037)	(0.288)	(0.015)
Observations	3,632	3,632	3,632

Notes: Control variables include lagged dependent variable (i.e. urea or yield from baseline) 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 A17

Socio-environmental Cost of Urea Averted by LCC

Average urea savings (kg)	5.16
0.079 kg/dec saved per farmer * average plot size of 66	
$N_2O - N$ **emissions saved from the management of soil with N:**	
N savings per farmer	2.37.
Based on nitrogen content of urea of 46%.	
$N_2O - N$ emissions saved	0.0237
Based on N_2O emission factor of 1% [a]	
CO_2 equivalent of $N_2O - N$ emission saved	7.02
GWP[b] of N_2O (in CO_2 equivalents) of 296	
CO_2 **emissions saved from urea application:**	
CO_2 emission saved per farmer	1.03
Based on CO_2 default emission factor of 20% of urea applied	
CO_2 equivalent of total green house gas emissions saved (kg)	8.06
Value of green house gas emission averted	*$0.290*
Based on social cost of CO_2 of $40/ton[c]	
Total value of green house gas emission averted across all farmers	*$322*

Notes:
a. Intergovernmental Panel on Climate Change (Eggelston et al., 2006) linear Tier 1 default rate
b. GWP stands for global warming potential
c. Interagency Working Group on the Social Cost of Carbon (2013)