'Rule-of-Thumb' Instructions to Improve Fertilizer Management: Experimental Evidence from Bangladesh

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Abstract

Heavy government subsidies have led to inefficient application and overuse of fertilizer in Bangladesh. This results in higher than optimal costs to farmers and environmental and public costs. In a randomized controlled trial, we provide farmers with a simple tool (leaf color chart) and basic 'rule-of-thumb' instructions to guide the timing and quantity of urea (nitrogen) application. Treatment farmers reduce urea use by 8% without compromising yield, suggesting significant scope for improving urea management. The results are mainly driven by farmers delaying urea application as returns to urea are low early on in the season and urea applied is likely to be wasted. Cost-effectiveness estimates suggest that each dollar spent on this intervention produces a return of $2.8 dollars due to reduction of urea use over three seasons, as well as significant environmental benefits. We also find suggestive evidence that optimizing the timing of urea application affects farmers' yields, plausibly as the intervention allows farmers to reallocate urea application to times when returns to urea are highest.

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

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1 Introduction

Several countries, including Bangladesh, have used fertilizer subsidies to induce their adoption 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 (Rasul and Thapa, 2003; Huang et al., 2017). Moreover optimal timing of fertilizer application is essential for profitability; too much fertilizer applied at the wrong time or too little at the right time can result in higher than optimal costs in the former case and lower overall output in the latter. Effective management of fertilizer has the potential to increase both efficiency and productivity.

In Bangladesh, the use of chemical fertilizers is widespread—particularly, urea provides nitrogen that is vital for plant growth and is used almost universally by rice farmers (Jahiruddin et al., 2009). Despite significant experience in using fertilizer, farmers may fail to optimize the quantity and timing of urea application as particular properties of urea require farmers to understand the precise nitrogen needs of plants throughout the season. Since urea is volatile and thus not continuously retained by the soil, it needs to be applied several times during a season when the plants' demand for nitrogen is high (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 have little or no effect on yields, while increasing farmers' cost. Unabsorbed urea can also leach from soil to surface or ground water and cause negative environmental effects (Gilbert et al., 2006; Eggelston et al., 2006).[4] Failure to supply adequate urea at the right time would deprive crops of nitrogen and negatively affect yield.[5] Thus,

[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] The extent of environmental pollution due to fertilizers, or otherwise, is not well studied or monitored in Bangladesh.

[5] Extremely high levels could be toxic and lower productivity (World Bank, 2007).

better fertilizer management through optimal quantity and timing of application can minimize wastage, lowering the direct fertilizer expense and the associated environmental costs, and can also improve productivity by ensuring nitrogen is available when it is most 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. A leaf color chart (LCC) is a simple tool that can be used to check 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 the nitrogen requirement of crops and time urea applications accordingly (Alam et al., 2005; Buresh, 2010; Witt et al., 2005), thus improving decisions on both quantity and timing.

Through a household-level randomized control trial, we provided farmers in the treatment group with an LCC along with a basic training on how to use the chart and instructions on when and how much to apply.[6] 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.[7] 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 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

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

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

each application.[8] The quantity of urea that the farmers were instructed to use at each application was less than the average amount used, encouraging less use of urea per application.

Prior to the intervention, we conducted a baseline survey that collected data on urea usage and yields 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 intervention. Short midline surveys were also conducted in the period between the baseline and endline to explore time use by farmers, and the date and quantity for each urea application during the season.[9]

We note that on average farmers apply urea earlier than the recommended time and urea usage at each application is significantly higher than the recommended amount. Thus, we expect the intervention to change farmers' urea application practices, particularly induce a delay in first urea application and a reduction in quantity used at each application. Frequency and timing of application after the first time would vary with plot specific nitrogen needs determined using the LCC. The intervention may also lead farmers to pay attention to leaf colors and fertilizers more broadly, and spend more time in the field.

We estimate 'intent-to-treat' effects of gaining access to the intervention (LCC and accompanying training) on urea application patterns, total urea use and yields. We find that treatment farmers reduce urea usage without compromising yield, suggesting scope for improvement in management of urea. We observe that, as hypothesized, 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.[10] Treatment farmers reduce the quantity of urea used at

[8]Existing literature suggests that rule-of-thumb training can be much more effective than a more-complex training program (Drexler et al., 2014).

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

[10]Department of Agriculture Extension recommends that urea should be applied 3 times during the period between 21 days after the planting date until a month before harvest.

each application in the low-return period, while there is no significant difference in the quantity of urea used per application in the high-return period. We find suggestive evidence that farmers apply urea more frequently in the high-return period and are also marginally more likely to visit their fields.

Examining overall output and urea usage during the season, we find that farmers in the treatment group reduce total urea used by 0.079 kilograms per decimal (1 acre = 100 decimals), which is a decrease of about 8% compared to baseline levels and is driven predominantly by a delay in first urea application. We also find that treatment farmers experience a yield increase ranging from 3% to 7%, though this effect is not always precise. The marginal treatment effect on yield is consistent with the suggestive evidence indicating treatment farmers apply urea more frequently in the high-return period and visit their fields more often. Even though the quantity of urea in the high return period is unchanged, farmers may be able to use the LCC to time urea application according to the nitrogen requirement of plants, increasing the amount of nitrogen that the crops can effectively absorb, which in turn may lead to improved yield.[11]

Together, the 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.

We also conduct a cost-effectiveness analysis and find that the intervention is cost-effective if 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 would generate

[11] 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. Nevertheless, we present the yield effects with caution as the estimates are not stable, and assume no yield change in the cost-effectiveness calculation.

a return of $1.8 through urea savings over two seasons and $2.8 over 3 seasons. At a national level, the individual urea savings would aggregate to $40 million in subsidy costs saved by the government during the 2012–13 agricultural year, and approximately the same amount in farmer-incurred costs. The aggregate urea cost saved is approximately 14% of the agricultural input subsidy budget in that year.

The LCC intervention is effective, as it provides simple rules and gives understandable signals on whether or not plants are nitrogen-sufficient, improving management of urea. Conservation and optimization of urea usage reduces farmers' costs, which has implications for national budgets and has positive externalities in the form of reduced runoff and pollution. The findings also show that in countries like Bangladesh, with widespread overuse of fertilizer, there may be 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 overuse may occur in a context with high fertilizer subsidies. 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 discusses the challenges of using urea efficiently and the ways the intervention can help in optimizing urea usage. Section 3 presents the experimental design, data and the empirical strategy. Section 4 provides 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 and Intervention

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 to farmers was increased in 2011. The subsidy on urea was approximately 51% in the 2012–13 agricultural year and 62% in 2013–14 (Huang et al., 2017), and urea usage is close to 100% in our sample at baseline. While urea application is the 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 2012, urea made up 58% of the total commonly used fertilizers in the country (Bangladesh Fertilizer Association, 2019).

Compared to other fertilizers, urea is particularly challenging to use, as the timing of the applications is crucial and can be difficult for farmers to learn. Farmers need to account for differences in nitrogen requirement across crops, plots and seasons to determine the appropriate time and amount for application. Farmers typically apply all non-urea fertilizers once just before planting, the transplanting of the seedling from a nursery to the main plot, although some farmers also apply urea at that time.[12] More commonly, urea is first applied a few weeks after planting, followed by one or two additional applications until the start of the flowering stage, which is about a month before harvest. Non-urea fertilizer that is not used by the crop is retained by the soil, ensuring the nutrients are available for crops later in the season or during future seasons. In contrast, urea is highly volatile and can leave the soil fairly quickly if not absorbed by plants (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, but that may not be sufficient to minimize wastage.[13] 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 or timing the application incorrectly.

Inefficient fertilizer use can have three possible effects. First, there are direct costs—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. Second, 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 as leaching downwards and run-off away from the roots.[14] An FAO report finds that nitrate toxicity in drinking water is increasingly observed and nitrous oxides have built up in the atmosphere

[12]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 as a caution and to protect against yield loss.

[13]Typically there are two or three separate urea applications over a period of approximately 40 days between planting and flowering. A stylized timeline of rice cultivation is shown in Appendix Figure A1.

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

because of the unscientific use of fertilizers (FAO, 2011). Last, farmers may be compromising profits by not optimizing urea applications. Depending on the rate of loss, if urea is applied at a time when the crop does not require nitrogen, it will not contribute towards yield. Similarly, failure to supply urea at precisely the time when the crop is deficient in nitrogen would lower yield.

2.2 Intervention Details

A Leaf Color Chart (LCC) is a simple tool that allows farmers to understand whether urea is needed by the crop at any time.[15] It is a plastic, ruler-shaped strip containing four panels that range in color from yellowish green (nitrogen deficient) to dark green (nitrogen sufficient).[16] As discussed above, rice farmers usually apply urea in several split applications during a season. Farmers can compare the color of the paddy leaf to the LCC chart to determine if nitrogen is needed before they apply urea. This should allow famers to apply urea efficiently, timing it during periods when uptake by crops will be high (Alam et al., 2005; Buresh, 2010; Witt et al., 2005).

The literature in agricultural journals on LCCs in South Asia usually finds an increase in returns, either through substantial reduction in the use of nitrogen fertilizers without any reduction in yields, or through substantial reduction in nitrogen fertilizers as well as improvement in yields (Alam et al., 2005, 2006; Islam et al., 2007; Singh et al., 2002). However, many of the studies are from demonstration plots which were closely supervised by agricultural workers. If farmers are provided LCCs along with basic training, whether they would choose to adopt and use LCCs effectively is an empirical question. LCCs will only change urea use or yields if farmers use LCCs correctly and are otherwise

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

[16] A picture of the LCC is provided in Appendix Figure A2, and the accompanying instructions are in Table A1, based on instructions developed by the Bangladesh Rice Research Institute (http://knowledgebank-brri.org/how-to-use-lcc.php), but simplified further.

unable to learn how to time urea application well on their own.

In the intervention we study, primary farmers from treatment households 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 Center for Development Innovation and Practices (CDIP) staff and led by an extension worker or agriculture officer invited from the Department of Agricultural Extension (DAE).[17] During the session, each farmer received a leaf color chart and instructions on how to use the chart.[18]

The LCC guidelines and the training were based on instructions developed by the Bangladesh Rice Research Institute and instructed farmers to first check leaf colors 21 days after planting to determine if they should start applying urea, as urea is not beneficial for rice crops during the first three weeks after planting.[19] Lighter leaf colors indicate urea is required, in which case farmers were advised to apply 9 kilograms of urea per 33 decimals of land (0.27 kg/decimal). After an application, farmers were instructed to re-check the leaves in 10 days. If the LCC 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 to provide the LCC and instructions to farmers who did not attend the training. 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, but before the time urea is generally applied.

[17] CDIP is a non-government organization in Bangladesh. It is primarily a micro-finance institution that also has education programs.

[18] The extension workers were generally not local to the village. Beside the training, they had limited interaction with the study farmers.

[19] Conversations with agriculture specialists in Bangladesh revealed that although the crop may respond to urea applied very early in the season, the returns are lower in that period, which is why the recommended time for starting urea application is three weeks after planting. The first urea application is timed with early tillering (seminal roots and up to five leaves develop), which occurs around 21 days post-planting during the *Boro* season when temperatures are low (Alam et al., 2005).

Figure A3 in the Appendix shows a timeline for the study.[20]

3 Experimental Design, Data & Empirical Strategy

3.1 Study Sample and Data

We conducted this study 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 A2 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.

CDIP selected 20 of their branch offices to participate in the study, and we selected approximately 100 farming households from the villages covered by each branch. Within each branch, approximately one-third of the sample was drawn from CDIP micro-finance clients and the remaining two-thirds were drawn from households residing in villages with a CDIP school. Further details on sampling are discussed in Appendix A.[21]

All surveys and the intervention training were conducted with one primary farmer from each of the sampled households. We conducted a long-form baseline survey with 1440 sample households during September–October 2012. We collected data at the plot level on all crops grown, inputs, output and respective

[20] 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.

[21] 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 that for an average farmer in Bangladesh (25.78 kilograms/decimal in the HIES and 26.22 kilograms/decimal for sample farmers. 100 decimals = 1 acre). 62% of farmers in the HIES grow rice on 95 decimals per household on average (in the study sample, average area under rice cultivation is 66 decimals per household).

prices during the *Boro* season of 2012. A short baseline survey was conducted with an additional 605 farmers in December 2012.[22] We provided training to CDIP staff members, who then conducted the baseline surveys in their program locations.

CDIP staff also conducted brief midline surveys after the intervention had been delivered to treatment farmers. Two of the midline surveys focused on time use by a subsample of the farmers.[23] One of midline surveys focused on the timing of urea applications and was conducted for all farmers. An endline survey was administered after harvest from June to August 2013, which attempted to collect information about the *Boro* season of 2013 from all farmers.[24] 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 from baseline, but only farmers who cultivated rice during the *Boro* season of 2013 were included in the follow-up rounds.[25]

3.2 Randomization

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

[22]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 farmers.

[23]Sample size was limited by funding constraints. We selected the locations randomly after excluding some areas with expected staff shortages in that time period. Appendix Table A4 compares farmers included in the midline farmers to those not included.

[24]Table A3 provides the sample sizes and other details for each of the survey rounds.

[25]Of the baseline households that we successfully revisited, 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. The intervention training took place in January, around the time of planting, and farmers 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 (which determines inclusion in training and followup rounds) or what varieties to cultivate will not be related to treatment.

household.[26] We stratified the sample by CDIP branch and by type of sub-sample (CDIP micro-finance clients and farmers from villages with CDIP schools) in the branch and assigned half the farmers in each stratum to treatment and the other half to control.[27] 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 increased statistical power compared to the alternative of randomizing at the village level, and as we discuss in Section 3.3, spill-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, 1.01 kilograms of urea are applied per decimal and average yield is 26.22 kilograms per decimal (Figure 1 shows histograms of per decimal urea and yield at baseline). 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 test how attrition at each follow-up stage varies by treatment status in Appendix Table A5, and confirm there is no evidence of differential attrition across treatment and control groups.[28] We also conduct randomization checks

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

[27]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.

[28]Since only a sub-sample was selected for the time use midline, attrition at this midline refers to farmers not selected as well as farmers who were not found or were not cultivating rice. We attempted to follow up with everyone at endline, so attrition at endline represents households who were not surveyed because they were not found or had stopped rice cultivation.

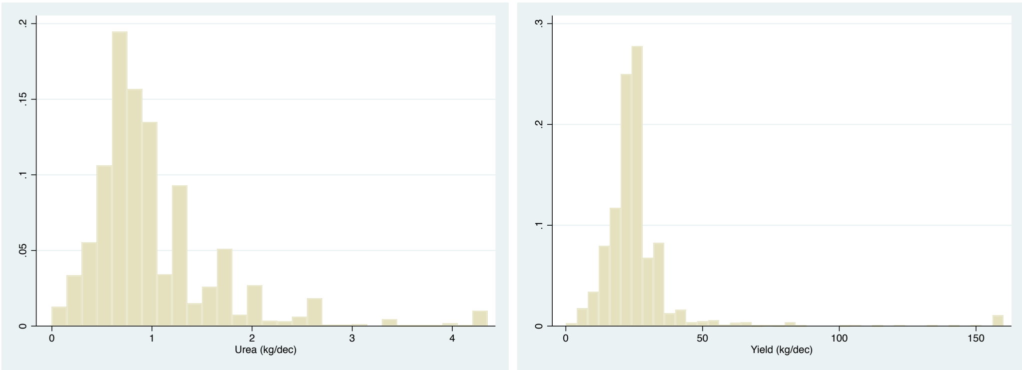
Table 1

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*



for the midline and endline samples as shown in Appendix Table A6. Baseline covariates for the midline sample are balanced across the treatment and control groups. For the endline sample, revenue and costs are marginally lower (significant at 10% level), but the estimates have similar magnitudes as estimates for the baseline sample. The coefficients are not jointly significant.

3.3 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. About 75% of the treatment group state they received a LCC. The training and surveys targeted the primary farmer in a household — only 59% reported attending the DAE training session at endline, while CDIP records indicated almost full attendance. Qualitative interviews with a subsample of farmers 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 another family member attended instead. However, the representative may

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.

have 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.

Spillovers to the control group were possible as treatment and control farmers may belong to the same village. Indeed, 7.9% of the control group state they received an LCC and 5.5% reported using it. 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 were present. CDIP records and qualitative work indicate that the control group farmers with an LCC usually received it from the DAE representative or extension worker outside the training or, in a few cases, because they attended the training. Thus some spillovers are apparent in the data, but such cases are very limited. Treatment farmers could also share information received during the training with other farmers in their village network. Any spillover of the intervention among control farmers would bias our analysis against finding treatment effects, and the detected effect sizes would be understated.

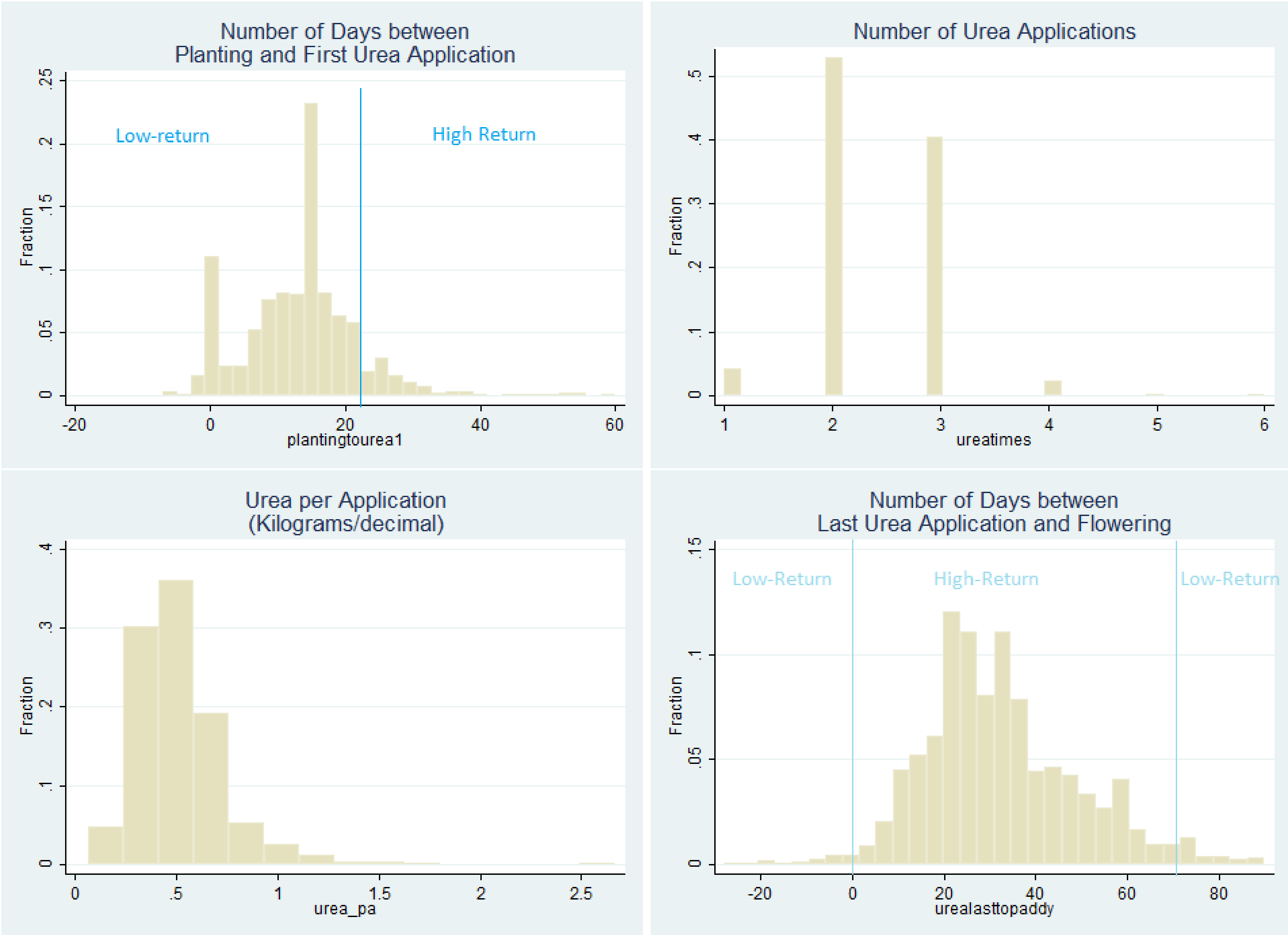
3.4 Expected Changes due to the Intervention

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 or before planting. Most farmers apply urea 15 days after planting, and less than 20% wait for the recommended 21 days. Therefore, most farmers apply urea early, during a period where returns may be low. The second graph plots the frequency of applications and demonstrates that most farmers apply urea at least twice, while almost 40% apply urea three times as is traditionally recommended. The distribution of urea per application in the third chart indicates that, on average, farmers use 0.52 kg/dec at each application with a longer right tail (driven by farmers who apply only once).[29] The recommended amount of 0.27 kg/dec is about half of the average application quantity observed for farmers. The last histogram shows 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.

There are several possible expected changes in behavior due to the intervention; the first four predictions are with respect to timing and quantity of each urea application, and the last three are with respect to overall urea, labor usage and production during the season. First, farmers may delay urea application until 21 days after planting. Second, treatment farmers are less likely to apply urea after flowering, though the rate at which control farmers make this mistake is low. Third, farmers may change the frequency of applications, though the direction of change is ambiguous; even though the Bangladesh Rice Research

[29] 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, about 1.6 times the recommended application.

Figure 2: *Urea Application Patterns for Control Group*



Institute estimates that most farmers using the LCC would apply urea four times instead of recommended number of three applications, farmers are not explicitly instructed to apply more frequently, but rather to allow the leaf colors to indicate if they should apply at any point in time. Fourth, farmers are expected to apply smaller quantities of urea at each application. Fifth, we can expect labor usage to increase as the LCC instructions require farmers to go into the field to check leaf colors every 5-10 days during the period between three weeks after planting and flowering. Sixth, we predict that overall urea usage would decline if the reduction in urea per application offsets any increase in frequency of application. Farmers are not specifically instructed to reduce overall urea usage, however, the average quantity of urea (0.52 kg/dec) per application is significantly higher than the quantity recommended during the training (0.27 kg/dec). Last, yield would increase if treatment farmers can improve the timing of urea application to match the period when crops' demand for nitrogen is high. We test these expected changes in urea application patterns and time use as well as treatment effects on overall urea use and yields.

3.5 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.

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

y_{ph} is a urea application pattern for 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 the household, and non-agricultural household income. Z_{ph} includes plot level controls for 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).

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

y_{pht} the outcome for plot p of 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 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 Equation (1), including the baseline dependent variable on the RHS (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. In Section 4.1 we estimate whether we observe any changes in urea application timing due to the intervention. In Section 4.2, we present the treatment effects on urea and yields as well as treatment effects on revenue, costs and profits.

4.1 Treatment Effects on Timing, Frequency and Quantity of Urea Applications

In this section, we identify changes in urea application by farmers as discussed above.[31] Specifically, we test whether farmers (i) delay urea application until 21 days after planting, (ii) stop applying urea after flowering, (iii) change the number of urea applications, and (iv) 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).[32] 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

[31] 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.

[32] 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 a very small proportion of control farmers apply this late. The mean interval between urea applications overall, in Column (3) 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.[33] 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, and during the high- and low-returns periods, respectively. 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.

In Appendix Figure A6 we show the distributions for the timing of first urea application and the frequency of applications separately for the treatment and control groups. While some treatment farmers continue to apply too early (at the planting stage) or too late, farmers who would have applied in the first 3 weeks

[33] 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)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Applied 1^{st} Urea After 21 days	Applied Urea After Flowering	Mean Interval Between Applications (days)	# Times Urea Applied	# Times Urea Applied High-return Period	# Times Urea Applied Low-return Period	Urea per app. (kg/dec.)	Urea/app. High-return Period (kg/dec.)	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. Column (3) includes farmers who apply urea more than once during the season. 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.

after planting shift their application to after the 21-day period as recommended in the LCC instructions. Distribution of number of applications in the top-right of Figure A6 shows that the proportion of farmers who apply twice is lower among the treatment group, and the proportion who apply thrice is slightly higher. To test if the effects on timing of first application are driven by the choice for cut off, we present the treatment effects on timing of first application varying the cut off values, and additionally test for the treatment effect in a broader time window around the 21-day mark. These results presented in Table A7, in addition to Figure A6, confirm that the delay in first urea application is not driven by farmers at the margin and that farmers who were incorrectly applying urea too early wait to apply until urea is expected to be beneficial. Changes in the overall timeline of urea application (intervals measured in days) are shown in Appendix Table A8.

As discussed in Section 3.4, we can expect farmers to increase time spent in the field due to the intervention. During the midline surveys, farmers were asked about time spent on various agricultural activities in the last seven days. The results are shown in Appendix Table A9. We compute Tobit estimates, since the variables are highly censored at zero, and also report OLS estimates in Appendix Table A10. 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. Treatment farmers visit their plots 0.13 times more often, an effect that is significant at the 10% level.

Overall, these results show strong evidence that treatment farmers delay the starting date of urea applications to a more productive period and reduce urea used per application in the low-return period. The results additionally

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.

provide suggestive evidence that the intervention increases the frequency of urea applications in the high-return period and the frequency of field visits.[34]

4.2 Treatment Effects on Total 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. Column (1) shows that having

[34]The family-wise adjusted p-values correct for testing multiple 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.

access to the intervention results in a decrease in urea use 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.

Column (3) shows that getting access to the intervention leads to an increase in yield of 1.757 kilograms per decimal (statistically significant at the 5% level).[35] The mean price of rice is Tk 15 per kilogram, thus for an 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, but standard errors could be magnified in this specification due to the structure of the data.[36]

In the Appendix, we present effects using alternate specifications. Estimates using logs of urea per decimals and logs of yield per decimal are shown in Table A11. The results are consistent with the previous specifications, however, the estimates for the 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 yield increases at 3.8% but is not statistically significant. Table A12 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 an 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

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

[36]Figures A6 shows that 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 yield for treatment farmers has higher density at higher values of yield relative to control farmers.

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

ANCOVA specification.

We also estimate the effects on total revenue, costs and profits, to further understand the magnitude of the returns. As discussed in the section above, prices 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 in the 'long survey' sample. The difference between the treatment and control groups at endline can be estimated for all farmers, and is shown in columns (4) to (6).

The table shows estimates after controlling for household characteristics and rice variety. For the 'long survey' sample, revenue increases by Tk 34.4 per decimal (significant at 5% level); total cost is higher by Tk 16 per decimal for the treatment group, but it is not significant. Profits are higher by Tk 18 per decimal and are also not statistically significantly different from the control group change. 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 and profits are higher but the estimated effects are not statistically significant.[37] In the Appendix we also present the regressions at the household level, and using an ANCOVA specification, finding very similar effects (Tables A14-A15).[38]

Based on these results, we claim that the intervention resulted in farmers using 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 below show large quantities of savings of urea over multiple seasons. This implies that inefficiencies exist in the way urea is applied by the average farmer. With better information that farmers obtain due to this intervention they are able to save urea.

Since the effect on yield is non-negative, and even positive in some specifications, it rules out large decreases in yield despite significant reductions in urea usage. 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 improve the timing of urea use and also spend more time on fertilizer application. Applying urea at the optimal time would ensure nitrogen supply when returns to nitrogen are highest, which guarantees higher effective absorption of nitrogen by plants and improved output, even if the quantity of urea supplied remains unchanged. It is not possible to directly test if farmers use the LCC effectively, however suggestive evidence supports that they do. First, we observe that treatment farmers apply urea more frequently in the high-return period and second, we find more frequent field visits. We recognize that the impacts on yield and on time use and allocation of urea to the high return period are modest and suggestive.

[37] 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 A13 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.

[38] Table A16 in the appendix also shows the treatment effect on costs broken down by type.

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 Table A17.

5 Cost-Effectiveness of Intervention

5.1 Direct cost savings due to urea reduction

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. Other 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, we estimate that farmers 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 multiple seasons. Moreover, these estimates show returns during the *Boro* season, but the LCC can also be used during the *Aman* season. We provide the estimates of urea savings if the LCC is used for two or three seasons. Dividing the LCC cost over multiple seasons, we find that each dollar spent on

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 2 seasons:	1.84
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.

the LCC generates a return of $1.84 due to urea savings over two seasons and $2.76 over three seasons.[39]

Using the average treatment effect of 8% urea savings and annual consumption and prices from Bangladesh Ministry of Agriculture,[40] we estimate that a total of 180,000 metric tons of urea, worth $80 million or 14% of agricultural input subsidy budget, could be saved during the 2012–13 season.[41] Under the subsidy provided during that period, the government pays 49% of the cost of urea consumed, which implies savings of $40 million of the urea subsidy cost (or 7% of the input subsidy budget) to the government of Bangladesh.[42]

5.2 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 run-off 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

[39] 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 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 intervention results in a gain of $0.88 over 1 season through urea savings (accounting for labor cost) and $2.64 over three seasons.

[40] 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).

[41] Global Agricultural Information Network (2013).

[42] 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.

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) 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 A18 shows how these costs are estimated. Assuming a 46% nitrogen content of urea, we estimate that with each farmer exposed to the 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 of \$40 per ton (Interagency Working Group on the Social Cost of Carbon, 2013), we estimate that the overall environmental damage averted by the 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. Over the 2012–13 agricultural season, which corresponds to the intervention period, the aggregate national savings of 180,000 tons of urea corresponds to 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 learning how to reduce wastage of urea is challenging, farmers can 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 'rule of thumb' guidelines that help with the management of urea fertilizers. We find that farmers reduce urea by 8% on average when they gain access to the intervention, which suggests a failure to learn how to effectively apply urea despite 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 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. 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 and trainings can help farmers in the presence of many of these barriers. The intervention provides farmers with an LCC and 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 intervention may be effective due to its application of rule-of-thumb learning. The literature demonstrates the potential effectiveness of using simple rules to promote learning. Drexler et al. (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 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 when applied over two or more seasons, and therefore disseminating LCCs and training to farmers in the region could lead to large gains.

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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.[43] The second group of farmers may or may not be directly connected with CDIP.[44] 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.[45] 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

[43] 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.

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

[45] 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.[46] 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.

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

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 A17 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

[46] 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.[47] 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 A19 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.

[47] 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*

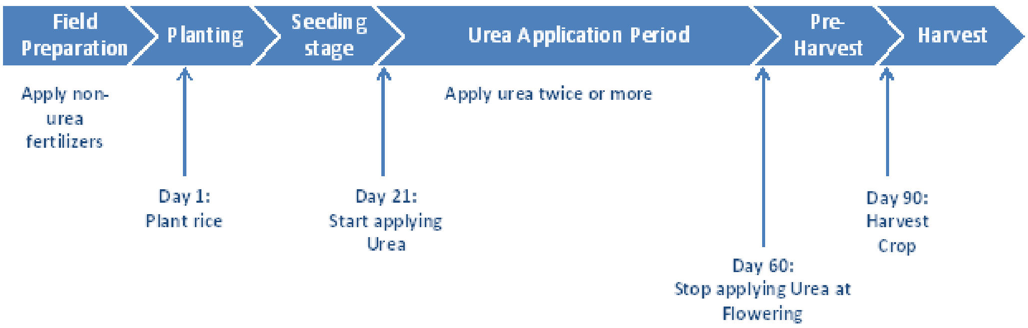


Figure A2: *A Left Color Chart*

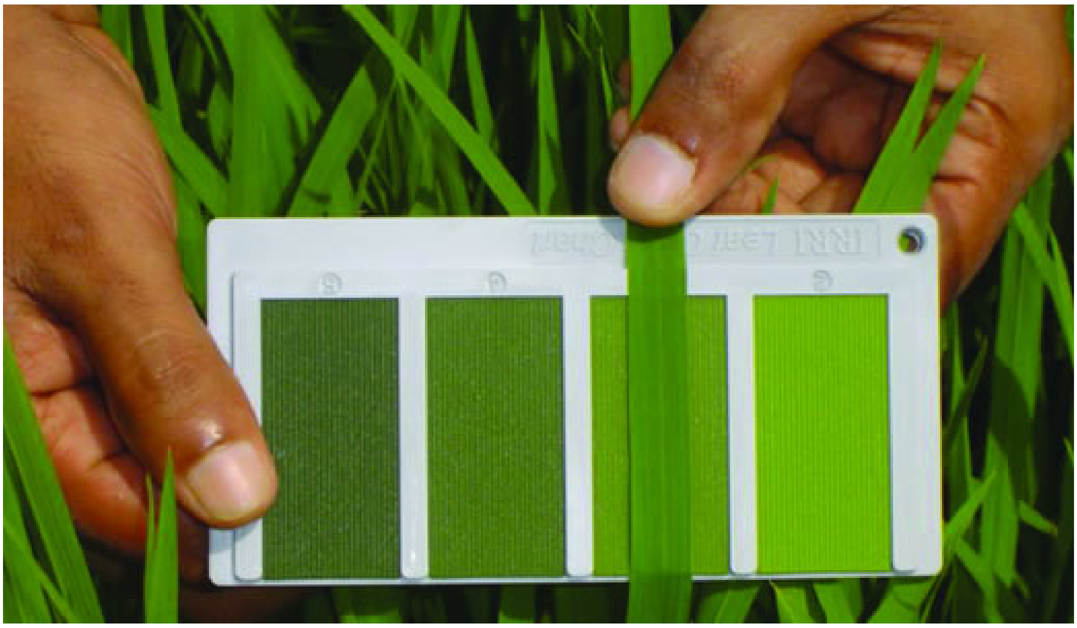


Figure A3: *Timeline of Study*

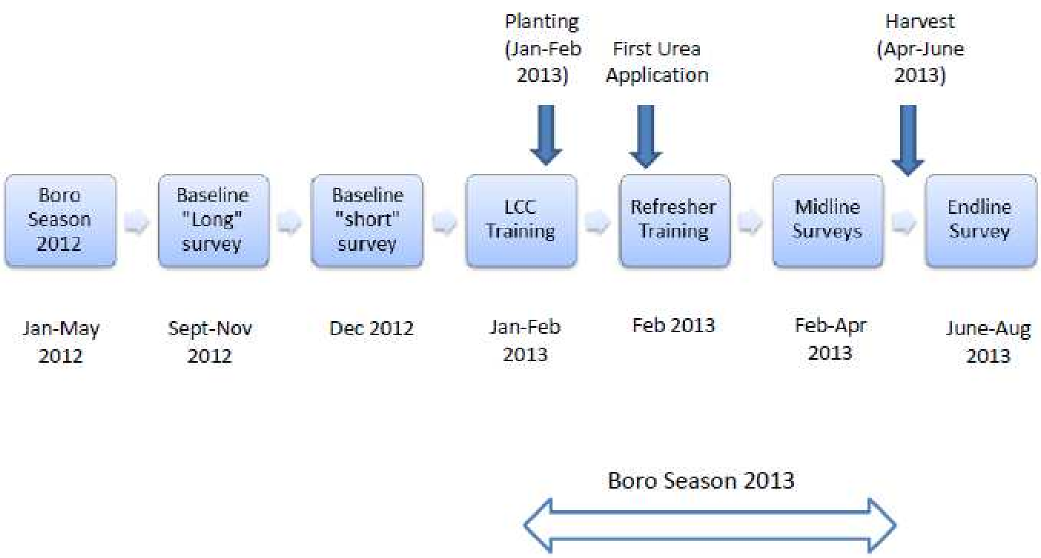


Figure A4: *Study Areas (Districts) in Bangladesh*

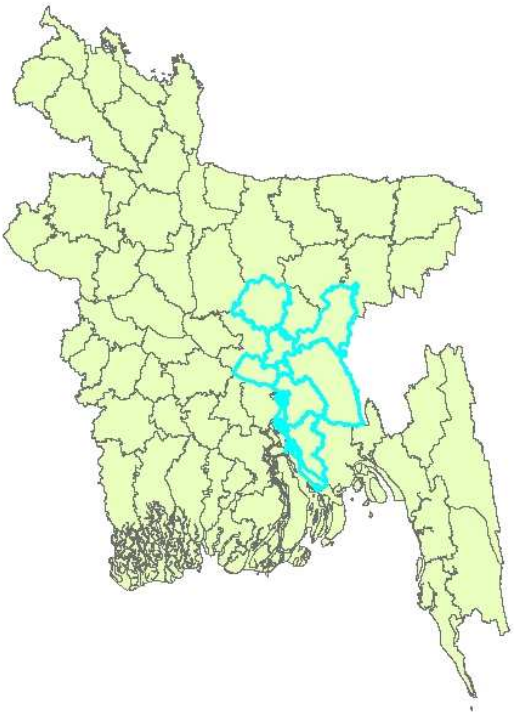


Figure A5: *Urea per Application by Number of Total Applications*

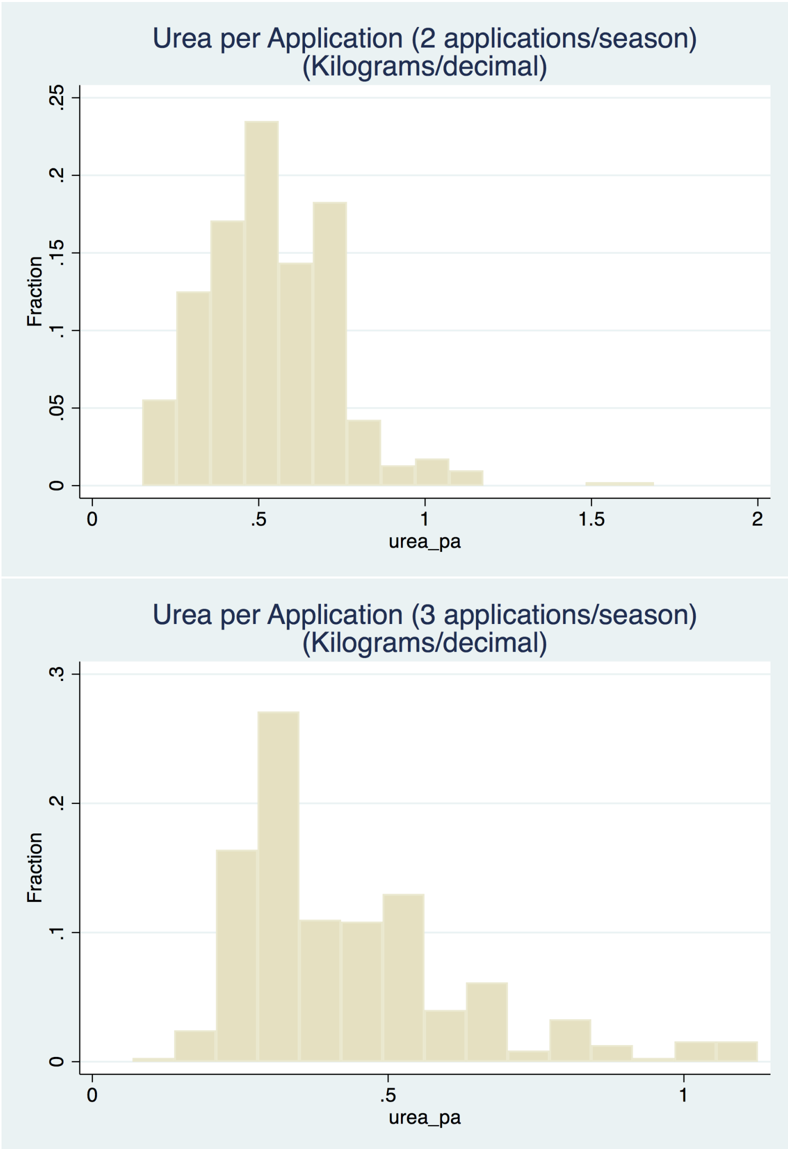
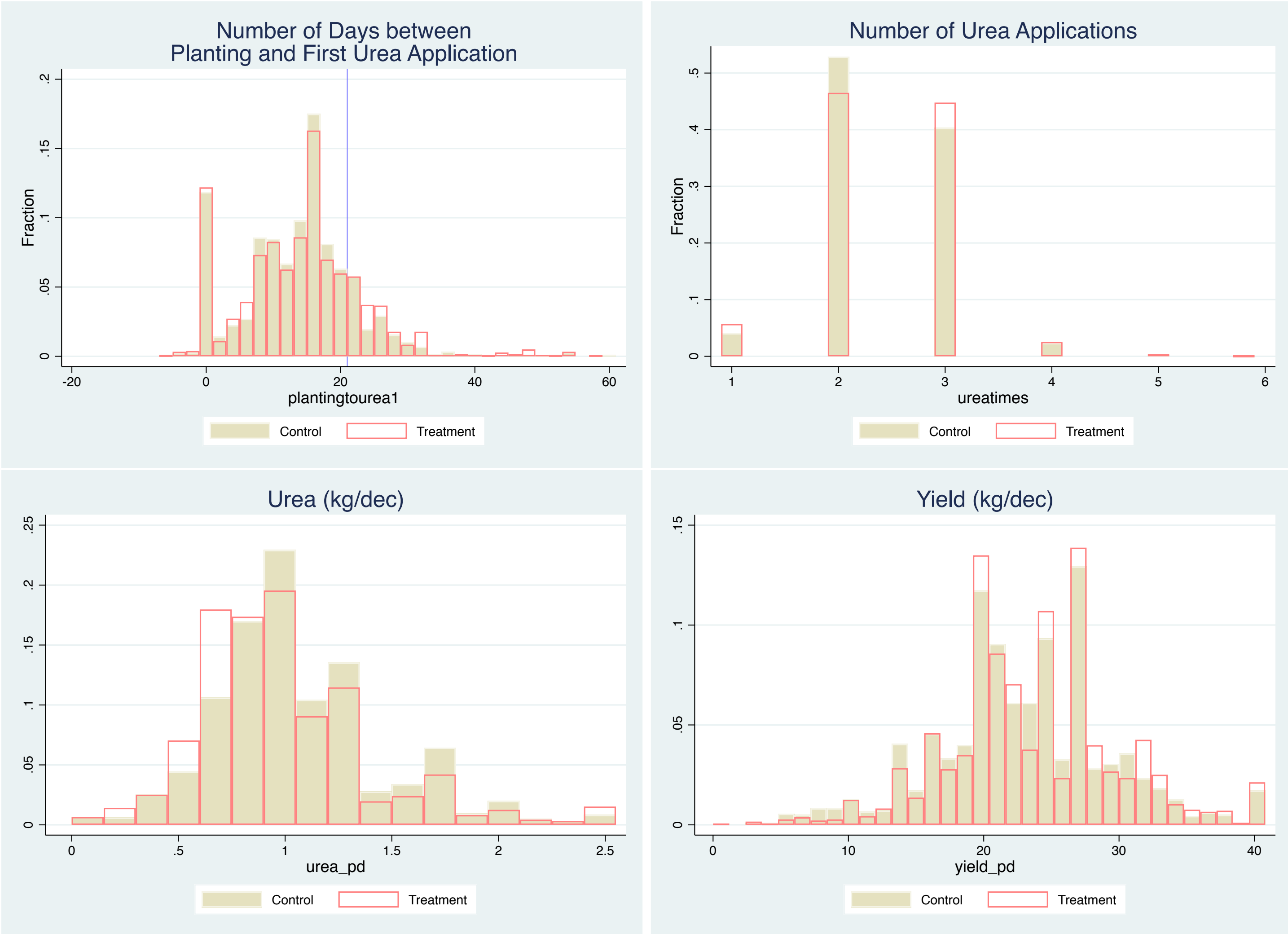


Figure A6: *Urea Application and Yield for Treatment and Control Group*



D Supplementary Tables

Table A1

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 A2

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 A3

Survey Types, Samples, and Outcomes

Survey Type	Survey Detail	Sample	Outcomes
Baseline	Long Survey	1440	Urea, Yield, Inputs, Profits
Baseline	Short Survey	605	Urea, Yield
Midline	Time use survey 1	1080	Time use
Midline	Time use survey 2	1080	Time use
Midline	Urea use survey	1569	Urea Application Timing
Endline	Long Survey	1549	Urea, Yield, Inputs, Profits

Notes: The urea use and endline surveys were intended for all baseline households involved in rice cultivation in the Boro 2012-13 period. The sample numbers reflect the households that were successfully interviewed. See Table A5 for checks for differential attrition by treatment status at the various followup data collection rounds, and Table A6 for additional balance checks.

Table A4

Household and Plot Characteristics across Samples

	(1)	(2)	(3)
	Summary Statistics		Difference
	No Midline	Midline Timeuse	(2)-(1)
Farmer & Household Characteristics:			
Age (years)	45.15	45.59	
	(12.69)	(12.47)	
Schooling (years)	5.796	5.797	
	(4.23)	(4.42)	
Number of Plots	2.230	2.500	***
	(1.13)	(1.21)	
Non-agricultural income (Tk)	7,887	11,807	***
	(9,440)	(11,161)	
Total Plot Area (decimals)	66.52	65.94	
	(46.2)	(41.0)	
Number of Household Assets	4.299	4.316	
	(1.97)	(2.26)	
Observations	965	1080	2045
Plot Level Variables—All Households:			
Plot Area (decimals)	30.92	28.40	***
	(23.12)	(20.76)	
Urea used(Y/N)	0.999	0.999	
	(0.03)	(0.04)	
Urea (kg/decimal)	0.945	1.067	***
	(0.64)	(0.66)	
Yield (kg/decimal)	25.51	25.91	
	(17.81)	(17.92)	
Observations	2,034	2,482	4516
Plot Level Variables—Long Survey:			
Revenue (kg/decimal)	348.9	353.9	
	(256.5)	(238.4)	
Total Cost (Tk/decimal)	223.6	247.3	**
	(165.2)	(211.5)	
Profit (Tk/decimal)	125.3	106.6	**
	(226.2)	(265.9)	
Observations	1,063	2,325	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. *** p<0.01, ** p<0.05, * p<0.1.

Table A5

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 A6

Randomization Checks after Attrition

Differences at Baseline for Midline & Endline Samples

	Individual/Household level Variables				Plot level Variables						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Age	Schooling (years)	Non-agri. Inc. (Tk)	Total Plot Area (dec.)	Plot Size (dec.)	Urea (kg/dec)	Yield (kg/dec)	Revenue (Tk/dec)	Total Cost (Tk/dec)	Profit (Tk/dec)	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 A7

Timing of Initial Urea Application

Applied first urea:	(1) In Third Week	(2) After 18 Days	(3) After 19 Days	(4) After 20 Days	(5) After 22 Days	(6) After 23 Days	(7) After24 Days
Treatment	0.035*	0.035*	0.043**	0.037**	0.038***	0.031**	0.021*
	(0.018)	(0.018)	(0.018)	(0.016)	(0.013)	(0.013)	(0.012)
Observations	3,541	3,541	3,541	3,541	3,541	3,541	3,541
R-squared	0.342	0.342	0.335	0.357	0.334	0.356	0.334
Means (control group)	0.220	0.220	0.189	0.157	0.0990	0.0887	0.0794

Notes: This table shows differences the delay in timing of first urea application 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 A8

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 A9

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 A10

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 A11

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 A12

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 A13

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 A14

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 A15

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 A16

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 A17

Treatment Effects by Time Preferences, Cognition and Baseline Household Income

Urea & Yield in Kilograms per Decimal

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Urea	Yield	Urea	Yield	Urea	Yield	Urea	Yield	Urea	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. 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 A18

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)

Table A19

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.