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

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I. Introduction

Several countries, including Bangladesh, have used fertilizer subsidies to induce their adoption and stimulate agricultural output (Huang, Gulati, and Gregory 2017).[1] Duflo, Kremer, and Robinson (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, Gulati, and Gregory 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—urea, which provides nitrogen vital for plant growth, is used almost universally by rice farmers

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[1] The subsidy on urea (nitrogen fertilizer) in Bangladesh was 51% in 2012–13 and 62% in 2013–14 (Huang, Gulati, and Gregory 2017).

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(Jahiruddin, Islam, and Miah 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). 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 groundwater and cause negative environmental effects (Eggelston et al. 2006; Gilbert et al. 2006).[2] Failure to supply adequate urea at the right time would deprive crops of nitrogen and negatively affect yield.[3] Thus, better fertilizer management through optimal quantity and timing of application can minimize wastage, lowering the direct fertilizer expense and 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 its 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 whether 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; Witt et al. 2005; Buresh 2010), thus improving decisions on both quantity and timing.

Through a household-level randomized controlled trial, we provided farmers in the treatment group with an LCC, along with basic training on how to use the chart and instructions on when and how much to apply.[4] 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.[5] During the training sessions, treatment farmers were instructed to begin fertilizer application 21 days after planting. Farmers were told to compare

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

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

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

[5] The *boro* season is the main rice planting season that lasts from December–January to April–May. Field staff were instructed to time the refresher training session to the period when most farmers start applying urea.

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 each application.[6] 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, as well as the date and quantity for each urea application during the season.[7]

We note that, on average, farmers apply urea earlier than the recommended time and that urea usage at each application is significantly higher than the recommended amount. Thus, we expect the intervention to change farmers' urea application practices, and 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 to 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.[8] Treatment farmers reduce the quantity of urea used at 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.

[6] Existing literature suggests that rule-of-thumb training can be much more effective than a more complex training program (Drexler, Fischer, and Schoar 2014).
[7] Some midline surveys were conducted for a subsample of farmers.
[8] Department of Agriculture Extension recommends that urea should be applied three times during the period between 21 days after planting and a month before harvest.

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 with 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.[9]

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 under- 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 US$1 spent on the intervention would generate a return of US$1.8 through urea savings over two seasons and US$2.8 over three seasons. At a national level, the individual urea savings would aggregate to US$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 for the year.

The LCC intervention is effective as it provides simple rules and gives understandable signals on whether plants are nitrogen sufficient, improving the 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

[9] Although it is not possible to observe this directly with available data, the findings that (1) treatment farmers apply urea more frequently in the high-return period and (2) 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.

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 (Schultz 1964; World Bank 2007; Duflo, Kremer, and Robinson 2011). While we do not 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 gas emissions due to soil management and fertilizer overuse (Eggelston et al. 2006).

The paper is organized as follows. Section II 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 III presents the experimental design, data, and empirical strategy. Section IV provides the results, including changes in urea application patterns and treatment effects on urea use and yields. Section V discusses the cost-effectiveness of the intervention, and section VI concludes.

II. Context and Intervention

A. Rice Farming and Urea Use in Bangladesh

The agricultural sector in Bangladesh contributes 21% to the gross domestic product and employs about 50% of the labor force (BBS 2009). Rice is the staple food of the nation's approximately 160 million people, providing more than 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; BBS 2012; Anam 2014).

The use of urea (nitrogen-based) fertilizers has been common since the green revolution. Urea prices are traditionally 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, Gulati, and Gregory 2017), and urea usage is close to 100% in our sample at baseline. While urea application is the most widespread, the use of non-urea fertilizers also increased after subsidies were introduced in 2004. Fertilizer usage has increased by 400% in the past 30 years (Kafiluddin and Islam 2008; Alam et al. 2011; BBS 2012; Anam 2014), and in 2012, urea made up 58% of all commonly used fertilizers in the country (Bangladesh Fertilizer Association 2019).

Compared with 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 requirements across crops, plots, and seasons to determine the appropriate time and amount for application. Farmers typically apply all nonurea fertilizers once just before planting (i.e., when transplanting the seedling from a nursery to the main plot), although some farmers apply urea at that time as well.[10] Urea is more commonly first applied a few weeks after planting, followed by one or two additional applications before the start of the flowering stage, which is about a month before harvest. Nonurea 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). 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.[11] 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 overapplying 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 US$22.94 per 50-kilogram bag and a subsidy of 51% during the season studied in this paper, each additional ton of urea wasted corresponds to a cost of US$225 borne by farmers and US$234 borne by the government. Second, excess fertilizer can result in significant losses to the atmosphere as well as surface and groundwater (Huang, Gulati, and Gregory 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 through leaching and runoff away from the roots.[12] A report by the Food and Agricultural Organization finds that nitrate toxicity in drinking water is increasingly observed and that nitrous oxides have built up in the atmosphere 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 toward yield. Similarly, failure to supply urea at precisely the time when the crop is deficient in nitrogen would lower yield.

[10] In focus group discussions, most farmers stated that urea should be applied 2 to 3 weeks after planting, although some farmers mentioned that they apply urea at planting as a caution and to protect against yield loss.

[11] Typically, there are two or three separate urea applications over a period of approximately 40 days between planting and flowering. A stylized time line of rice cultivation is shown in fig. A1.

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

B. Intervention Details

A leaf color chart is a simple tool that allows farmers to understand whether urea is needed by the crop at any time.[13] It is a plastic, ruler-shaped strip containing four panels that range in color from yellowish green (nitrogen deficient) to dark green (nitrogen sufficient).[14] As discussed above, rice farmers usually apply urea in several split applications during a season. Farmers can compare the color of the paddy leaf against the LCC chart to determine whether nitrogen is needed before urea is applied. This should allow farmers to use urea efficiently, timing it during periods when uptake by crops will be high (Alam et al. 2005; Witt et al. 2005; Buresh 2010).

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 (Singh et al. 2002; Alam et al. 2005, 2006; Islam, Bagchi, and Hossain 2007). However, many of the studies are from demonstration plots that 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 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 2013 *boro* 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).[15] During the session, each farmer received a leaf color chart and instructions on how to use the chart.[16]

The LCC guidelines and the training were based on instructions developed by the Bangladesh Rice Research Institute. Farmers were instructed to first check leaf colors 21 days after planting to determine whether they should start applying urea, as urea is not beneficial for rice crops during the first 3 weeks after

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

[14] A picture of the LCC is provided in fig. A2, and a simplified version of instructions developed by the Bangladesh Rice Research Institute (http://knowledgebank-brri.org/how-to-use-lcc.php) are in table A1.

[15] The CDIP is a nongovernmental organization in Bangladesh. It is primarily a microfinance institution that also has education programs.

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

planting.[17] 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 recheck 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 the flowering stage.

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. Figure A3 in the appendix shows a time line for the study.[18]

III. Experimental Design, Data, and Empirical Strategy

A. Study Sample and Data

We conducted this study in 105 villages under 20 CDIP branches spread across 21 subdistricts in the eight districts of Brahmanbaria, Chandpur, Comilla, Gazipur, Lakhipur, Munshiganj, Narayanganj, and Noakhali. A map of Bangladesh identifying the districts is shown in figure A4. 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.

The 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 microfinance clients, and the remaining two-thirds were drawn from households residing in villages with a CDIP school. Further details on sampling are discussed in the appendix.[19]

[17] 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 3 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).

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

[19] Comparing our sample with a nationally representative sample from the 2010 Household Income and Expenditure Survey (HIES), we note that the average baseline rice yield for farmers in the study is practically equal to that for an average farmer in Bangladesh (25.78 kg/decimal in the HIES and

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 1,440 sample households during September–October 2012. We collected data at the plot level on all crops grown, inputs, output, and respective prices during the *boro* season of 2012. A short baseline survey was conducted with an additional 605 farmers in December 2012.[20] 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.[21] One of the 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.[22] 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.[23]

B. 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

26.22 kg/decimal for sample farmers; 100 decimals = 1 acre). In the HIES, 62% of farmers grow rice on 95 decimals per household on average (in the study sample, average area under rice cultivation is 66 decimals per household).

[20] 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.

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

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

[23] 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 follow-up rounds) or what varieties to cultivate will not be related to treatment.

household.[24] We stratified the sample by CDIP branch and by type of subsample (CDIP microfinance 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.[25] 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 with the alternative of randomizing at the village level, and as we discuss in section III.C, spillovers 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 2012 *boro* season, and have a monthly nonagricultural household income of Tk 10,330 (US$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 (fig. 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, nonagricultural 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 table A5 and confirm there is no evidence of differential attrition across treatment and control groups.[26] We also conduct randomization checks for the midline and endline samples, as shown in 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 the 10% level), but the estimates have similar magnitudes as estimates for the baseline sample. The coefficients are not jointly significant.

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

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

[26] Since only a subsample 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 that were not surveyed because they were not found or had stopped rice cultivation.

TABLE 1
BASELINE CHARACTERISTICS

	Summary Statistics		Randomization Checks Treatment
	Control Group (1)	Treatment Group (2)	(3)
	A. Farmer and Household Characteristics		
Age (years)	45.02	45.78	.663
	(12.73)	(12.40)	(.546)
Schooling (years)	5.86	5.72	−.136
	(4.38)	(4.28)	(.189)
Number of plots	2.37	2.36	−.015
	(1.18)	(1.18)	(.046)
Nonagricultural income (Tk)	10,329.70	9,657.928	−674.164
	(10,759.79)	(10,392.05)	(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	.042
	(2.23)	(2.17)	(.106)
Observations	1,008	1,017	2,025
	B. Plot-Level Variables: All Households		
Plot area (decimals)	28.87	30.18	1.125
	(20.72)	(22.97)	(.740)
Urea used (yes/no)	1.00	1.00	.000
	(.03)	(.03)	(.001)
Urea (kg/decimal)	1.01	1.01	−.001
	(.69)	(.62)	(.025)
Yield (kg/decimal)	26.22	25.25	−1.093
	(19.71)	(15.81)	(.764)
Observations	2,252	2,260	4,512
	C. 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	1,682	1,702	3,384
Joint test (χ^2)			2.51
p-value			(.1130)

Note. For cols. 1 and 2, standard deviations are shown in parentheses; col. 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 the household level for regressions with plot-level variables are shown in parentheses. The number of observations in col. 3 is the total sample size. The long survey that collected costs and profits at baseline was conducted with a subsample, indicated by the lower number of observations. The joint test used a χ^2 test to estimate whether the coefficients are jointly significant.

C. *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

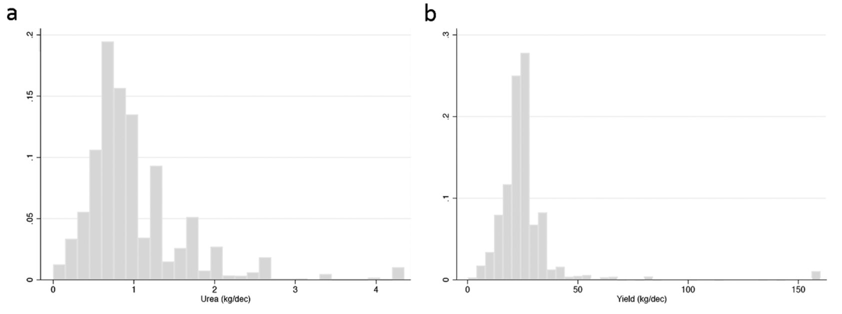

Figure 1. Urea (*a*) and yield (*b*) at baseline. A color version of this figure is available online.

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; they were also able to show the LCC to enumerators. About 75% of the treatment group state they received an 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 have failed to explain how the LCC works to

TABLE 2
TAKE-UP AND STATED USE OF LEAF COLOR CHARTS (LCCS)

	Received LCC (1)	Attended Training (2)	Used LCC (3)	Could Show LCC (4)
Treatment	.682***	.529***	.489***	.579***
	(.018)	(.020)	(.020)	(.019)
Age (years)	.000	.001	.001	−.000
	(.001)	(.001)	(.001)	(.001)
Schooling (years)	−.006***	−.006**	−.005**	−.004*
	(.002)	(.003)	(.003)	(.003)
Total plot area	.000	.000	.001**	.000*
	(.000)	(.000)	(.000)	(.000)
Income (nonagricultural)	.000	.000	.000	.000
	(.000)	(.000)	(.000)	(.000)
Mean of control group	.0788	.0604	.0604	.0723
Observations	1,526	1,526	1,526	1,526

Note. Dependent variables are dummy variables with a value of 1 if farmers say they have received a leaf color chart, attended the training, and used the chart and if they can show the chart to the enumerator, respectively; otherwise, they take a value of 0. Robust standard errors are shown in parentheses. All regressions include strata fixed effects.
* $p < .10$.
** $p < .05$.
*** $p < .01$.

the farmer—56% of the treatment farmers stated that they used the LCC compared with 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 that 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.

D. 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

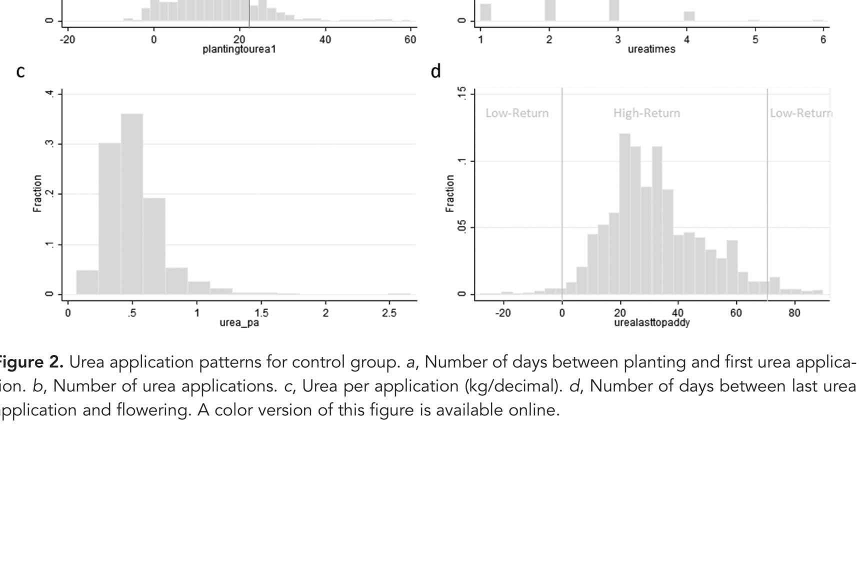

Figure 2. Urea application patterns for control group. *a*, Number of days between planting and first urea application. *b*, Number of urea applications. *c*, Urea per application (kg/decimal). *d*, Number of days between last urea application and flowering. A color version of this figure is available online.

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 kilograms per decimal at each application with a longer right tail (driven by farmers who apply only once).[27] The recommended amount of 0.27 kilograms per decimal 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 urea fewer than three times. A small proportion of farmers apply it 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 Institute estimates that most farmers using the LCC would apply urea four times instead of the recommended three applications, farmers are not explicitly instructed to apply more frequently but rather to allow the leaf colors to indicate whether 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 3 weeks postplanting 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, but the average quantity of urea (0.52 kg/decimal) per application is significantly higher than the quantity recommended during the training (0.27 kg/decimal). Last, yield would increase if treatment farmers can improve the timing of urea application to match the period when crop demand for nitrogen

[27] Figure A5 shows separate histograms for control farmers with two total applications and three total applications per season. Even for farmers who apply thrice or more frequently, average application is 0.44 kg/decimal, about 1.6 times the recommended application.

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.

E. 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 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:

$$y_{ph} = \alpha_0 + \alpha_1 \text{Treatment}_h + \rho X_h + \delta Z_{ph} + \gamma_s + \epsilon_{ph}, \tag{1}$$

where 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 nonagricultural 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.[28]

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-differences estimator:

$$\begin{aligned} y_{pht} = {} & \beta_0 + \beta_1 \text{Treatment}_h + \beta_2 \text{Post}_t + \beta_3 \text{Treatment}_h \times \text{Post}_t \\ & + \rho X_{ht} + \delta Z_{pht} + \gamma_s + \epsilon_{pht}, \end{aligned} \tag{2}$$

where y_{pht} is the outcome for plot p of household h at time t; and 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 right-hand side:

[28] 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.

$$y_{ph}^{\text{endline}} = \phi_0 + \phi_1 \text{Treatment}_h + \phi_2 y_{ph}^{\text{baseline}} + \rho X_h + \delta Z_{ph} + \gamma_s + \epsilon_{ph}. \quad (3)$$

IV. Results

In this section, we present the main findings of this study. In section IV.A, we estimate whether we observe any changes in urea application timing due to the intervention. In section IV.B, we present the treatment effects on urea and yields as well as treatment effects on revenue, costs, and profits.

A. Treatment Effects on Timing, Frequency, and Quantity of Urea Applications

In this section, we identify changes in urea application by farmers, as discussed above.[29] 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 the 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).[30] 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 21 days after planting or later. The table shows that farmers in the treatment group are much more likely to have waited until 21 days to start urea application compared with 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 the 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 (a decline of 0.9 percentage points), although a very small proportion of control farmers apply this late. The

[29] We present this section with the caveat that the data on timing was collected for a subsample 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.

[30] We use the Stata code implemented by Jones, Molitor, and Reif (2018).

TABLE 3

CHANGES IN BEHAVIOR IN USING UREA

	Change in Timing			Change in Frequency			Change in Quantity		
	Applied First Urea after 21 Days (1)	Applied Urea after Flowering (2)	Mean Interval between Applications (3)	Times Urea Applied (4)	Times Urea Applied High-Return Period (5)	Times Urea Applied Low-Return Period (6)	Urea per Application (7)	Urea per Application High-Return Period (8)	Urea per Application Low-Return Period (9)
Treatment	.040***	−.009***	−.551*	.020	.047*	−.027	−.011	−.007	−.030***
	(.014)	(.003)	(.295)	(.028)	(.029)	(.026)	(.009)	(.015)	(.012)
Adjusted *p*-value	[.042]	[.068]	[.294]	[.677]	[.340]	[.615]	[.532]	[.677]	[.068]
Control mean	.119	.0132	20.75	2.419	1.250	1.169	.508	.423	.496
Observations	3,541	3,541	3,107	3,541	3,541	3,541	3,541	3,541	3,541

Note. 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 of 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. Mean interval between applications is given in days; changes in quantity are expressed in kilograms per decimal. Standard errors, shown in parentheses, are clustered at the household level. All regressions include strata fixed effects. We report family-wise *p*-values in brackets that account for the nine possible outcomes being tested.

* $p < .10$.

*** $p < .01$.

mean interval between urea applications overall, in column 3, declines by 0.55 days (significant at the 10% level), which is likely due to the delay in start time.

Columns 4–6 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 in columns 5 and 6, respectively.[31] 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 7–9 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 with the control group.

In 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 after planting shift their application to after the 21-day period, as recommended in the LCC training. The distribution of number of applications at 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 whether the effects on timing of first application are driven by the choice for cutoff, we present the treatment effects on timing of first application varying the cutoff 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 time line of urea application (intervals measured in days) are shown in table A8.

As discussed in section III.D, 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 previous 7 days. The results are shown in table A9. We compute Tobit estimates, since the

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

variables are highly censored at zero and also report estimates of ordinary least squares in table A10. The dependent variable in column 1 is the number of days during the previous week that the farmer visited his fields. The other dependent variables are total number of minutes spent in the previous 7 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 as 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 provide suggestive evidence that the intervention increases the frequency of urea applications in the high-return period and the frequency of field visits.[32]

B. *Treatment Effects on Total Urea Use and Yield*

Table 4 shows the intent-to-treat effects of the intervention on urea used and yields attained by farmers. Controls for age and years of education of the farmer, nonagricultural 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 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 (col. 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).[33] 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 1,739 in revenue (US$22.3). The effect

[32] 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.

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

TABLE 4
FULL SAMPLE: TREATMENT EFFECTS ON UREA AND YIELD

	Urea		Yield	
	(1)	(2)	(3)	(4)
Treatment × Post	−.079**	−.089**	1.757**	1.352
	(.034)	(.041)	(.849)	(.941)
Treatment	.001		−1.035	
	(.025)		(.759)	
Post	.084***	.088***	−3.238***	−2.932***
	(.026)	(.031)	(.697)	(.787)
Controls	Yes	Yes	Yes	Yes
Household fixed effects	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

Note. 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. Urea and yield are in kilograms per decimal; 100 decimals = 1 acre.
** $p < .05$.
*** $p < .01$.

is not precise with household fixed effects, but standard errors could be magnified in this specification due to the structure of the data.[34]

In the appendix, we present effects using alternate specifications. Estimates using the log of urea per decimal and the log 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 the 1% level), while yield increases by 3.8% but not statistically significantly. 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 forms 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 kilograms per decimal at the household level. The coefficient on yield is positive and significant in the difference-in-differences specification at the household level but not in the 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 nonfertilizer inputs are available only at baseline for the long survey sample of farmers, so we estimate two sets of regressions. Columns 1–3 of table 5 show the difference-in-differences

[34] Figure 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, AND PROFITS

	Long Survey Sample			Full Sample		
	Revenue (1)	Total Cost (2)	Profit (3)	Revenue (4)	Total Cost (5)	Profit (6)
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

Note. Controls variables include age, schooling, total plot area cultivated, nonagricultural income, and rice variety. Standard errors, clustered at the household level, are shown in parentheses. All regressions include strata fixed effects. All dependent variables are in takas per decimal; 100 decimals = 1 acre.
** $p < .05$.
*** $p < .01$.

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 4–6.

For the long survey sample, revenue increases by Tk 34.4 per decimal (significant at the 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 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 the 5% level); total cost and profits are higher, but the estimated effects are not statistically significant.[35] In the appendix, we also present the regressions using an ANCOVA specification and household-level data, and we find very similar effects (tables A14 and A15).[36]

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.

[35] 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 with 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.

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

Since the effect on yield is nonnegative and even positive in some specifications, we can rule out a decrease in yield despite significant reductions in urea usage. We take the yield effects as suggestive evidence that productivity improved, plausibly due to a shift in urea application to the high-return period. Treatment farmers may improve the timing of urea use and 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 whether farmers use the LCC effectively, but 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.

We also test for nonlinearities 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 table A17.

V. Cost-Effectiveness of Intervention

A. 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 the Philippines and indirect fees. Other expenses for the intervention included honoraria 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 farmer for the LCC intervention is approximately US$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 US$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, which is lower than the total intervention cost per farmer (including the fixed costs of training).

The cost-effectiveness is much higher when we consider the fact that the costs are a one-time expense; the LCC is durable and can be used by the farmer for multiple seasons. Moreover, these estimates show returns during the *boro*

TABLE 6
COST-BENEFIT ANALYSIS OF PROGRAM

Costs:	
1,000 LCCs[1]	1,100
Training and 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
Savings in urea for mean farmer (.079 kg/decimal urea saved × 66 decimals of land × US$.459/kg)	2.39
Cost-effectiveness (benefits/costs) per season	.92
If LCC cost is over two seasons	1.84
If LCC cost is over three seasons	2.76

Note. We use the difference-in-differences estimates of treatment effects of urea from table 4. The world price of urea was US$0.459/kg in 2012–13 (Huang, Gulati, and Gregory 2017). We use an exchange rate of US$1 = Tk 78 to convert returns to dollars. LCC = leaf color chart.
[1] Includes cost of importing 1,000 LCC from the Philippines, including shipping (US$1,000) and bank and agent fees (US$100).
[2] Includes honorarium for Department of Agricultural Extension trainers, refreshments during training, transport of LCCs, additional training costs for Center for Development Innovation and Practices staff, and printing.

season, but the LCC can also be used during the *aman* season (the alternate rice planting season, which lasts from April–May until November–December). We provide the estimates of urea savings if the LCC is used for two or three seasons. Dividing the LCC intervention cost over multiple seasons, we find that each dollar spent on the intervention generates a return of US$1.84 due to urea savings over two seasons and US$2.76 over three seasons.[37]

Using the average treatment effect of 8% urea savings and annual consumption and prices from the Bangladesh Ministry of Agriculture, we estimate that a total of 180,000 metric tons of urea, worth US$80 million, or 14% of the agricultural input subsidy budget, could be saved during the 2012–13 season (GAIN 2013).[38] Under the subsidy provided during that period, the government

[37] 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 (BIHS; Ahmed 2013) from 2011–12 to obtain a measure of farming labor wages. The average male daily wage for farmwork from the BIHS community survey based on 50 village surveys is Tk 209.8. The modal number of hours worked per day for agricultural workers is eight, amounting to an hourly wage of Tk 26. 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 that the intervention increases labor time by 19.5 minutes per season. Based on the hourly wage, the cost of this time is Tk 8.5, or US$0.11, per farmer per season. This lowers the return of the intervention to US$2.28 per season, implying that each dollar spent on the intervention results in a gain of US$0.88 over one season through urea savings (accounting for labor cost) and US$2.64 over three seasons.

[38] The total consumption in Bangladesh is 2,247,000 metric tons, and the price is US$0.459/kilogram or US$459/ton in 2012–13 (Huang, Gulati, and Gregory 2017).

pays 49% of the cost of urea consumed, which implies savings of US$40 million of the urea subsidy cost (or 7% of the input subsidy budget) to the government of Bangladesh.[39]

B. Socioenvironmental Cost Averted due to Urea Reduction

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

Urea application affects the environment through emissions of greenhouse gases in two ways: (1) emissions of nitrous oxide (N_2O) from additions of nitrogen to land due to deposition and leaching and (2) 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 and 1.03 kilograms, 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 kilograms of CO_2 emissions avoided due to LCC usage by one farmer. Using a social cost of CO_2 of US$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 US$0.32 per farmer over one season. Thus, the environmental cost savings alone can make up for the variable cost of the LCC (US$1.1, excluding the fixed training costs) in less than four seasons. These benefits will accrue as more farmers utilize better

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

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 tons of, or US$11 million in, CO_2 emissions.

VI. 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. Through a field experiment in this study, 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 using it. 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 suboptimal use of inputs (Marenya and Barrett 2007; Jack 2013; 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, Fischer, and Schoar (2014) conduct a field experiment with microentrepreneurs 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 that urea savings can be achieved without compromising productivity. We also underscore the significance of the timing of urea application, as well as the quantity of urea applied. 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.

Appendix

A1. Sample Selection

The CDIP selected 20 of their branch offices to participate in the study, and we selected approximately 100 farmers from villages covered by each branch. Within each branch, approximately one-third of the sample was drawn from CDIP microfinance clients, and the remaining two-thirds were drawn from farmers residing in villages with a CDIP school.[40] The second group of farmers may or may not be directly connected with the CDIP.[41] For the first subsample, we randomly selected four microfinance groups from the list provided by the CDIP for each branch and then randomly selected 10 rice farmers from each group. For the second subsample, two villages were selected by the CDIP in each branch. We conducted a census of farmers in those villages and then randomly selected 30 rice farmers from each village.[42] To be included in the study, the farmer had to meet the following criteria: (1) agree to participate, (2) have cultivated rice in the 2012 *boro* season, (3) expect to cultivate rice in 2013 at the time of the survey, 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 the CDIP based on the above criteria. 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.

A2. Nonlinearities: 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

[40] 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.

[41] The sample is drawn this way for logistical purposes, based on preferences stated by the CDIP.

[42] The number of villages or microcredit groups in each branch sometimes varied based on availability of CDIP staff.

time preferences, cognition, or income in section A2.1. We test heterogeneity with respect to baseline urea and usage in section A2.2.

A2.1. Treatment Effects by Patience, Cognition, and 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 is important and as the LCC encourages farmers to check their fields regularly, the treatment effects may vary by time preferences or the level of patience of the primary farmer. An LCC is an easy-to-use tool, and instructions to use the LCC in this intervention were simplified as much as possible; however, the ability to use the tool correctly may still depend on the cognitive abilities of the primary farmer. Finally, treatment effects may vary by the level of baseline household income if poverty acts as a constraint on whether farmers choose to take up this tool.

At the endline survey, farmers were asked a series of standard questions to determine their time preferences. For the first set of questions, farmers were asked to choose between (hypothetically) receiving Tk 1,000 today or 1 month later; if they stated they would prefer to receive the money today, they were asked what they would prefer in a choice between Tk 1,000 today or Tk 1,100 1 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 Tk 100,000) 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.[43] We use both as measures of cognition. Ideally, these data would have been collected at baseline. However, because time preferences or cognition are unlikely to change due to treatment, 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 nonagricultural household income. To do so, we estimate the following for each of these measures:

$$\begin{aligned} y_{pht} = {} & \beta_0 + \beta_1 \text{Treatment}_h + \beta_2 \text{Post}_t + \beta_3 \text{Treatment}_h \times \text{Post}_{ht} + \beta_4 C_h \\ & + \beta_5 C_h \times \text{Treatment}_h + \beta_5 C_h \times \text{Post}_h + \beta_6 C_h \times \text{Treatment} \times \text{Post}_h \\ & + \rho X_{ht} + \delta Z_{pht} + \gamma_s + \epsilon_{pht}, \end{aligned} \tag{4}$$

[43] Fifteen 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.

where C_h is an individual or household characteristic, such as time preference and cognition of primary farmer or nonagricultural 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 because 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 to use.[44] Treatment effects do not differ by baseline nonagricultural 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.

A2.2. 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.

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

A3. Supplementary Figures

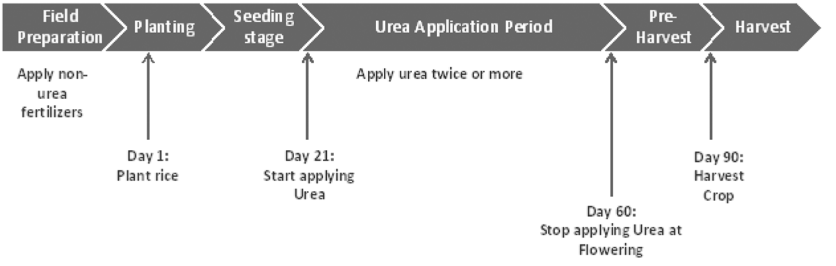

Figure A1. Stylized time line for rice cultivation during bora season. A color version of this figure is available online.

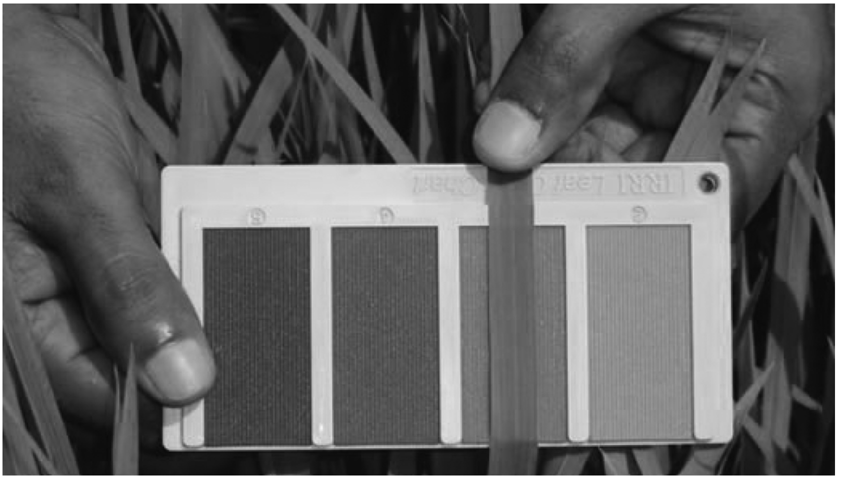

Figure A2. A leaf color chart. A color version of this figure is available online.

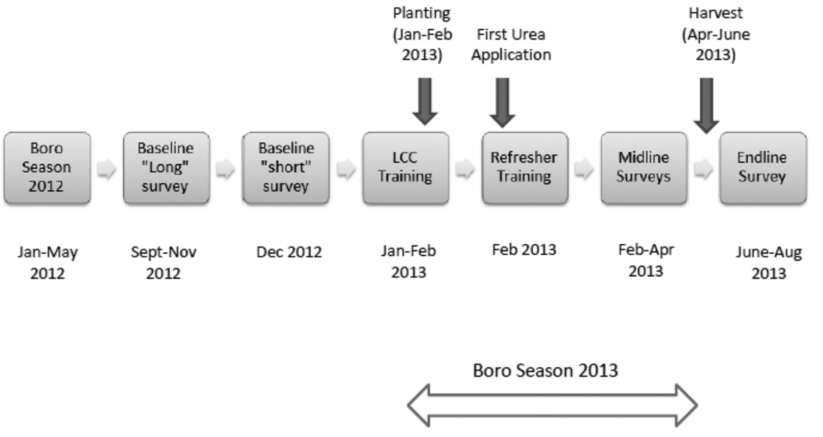

Figure A3. Time line of study. LCC = leaf color chart. A color version of this figure is available online.

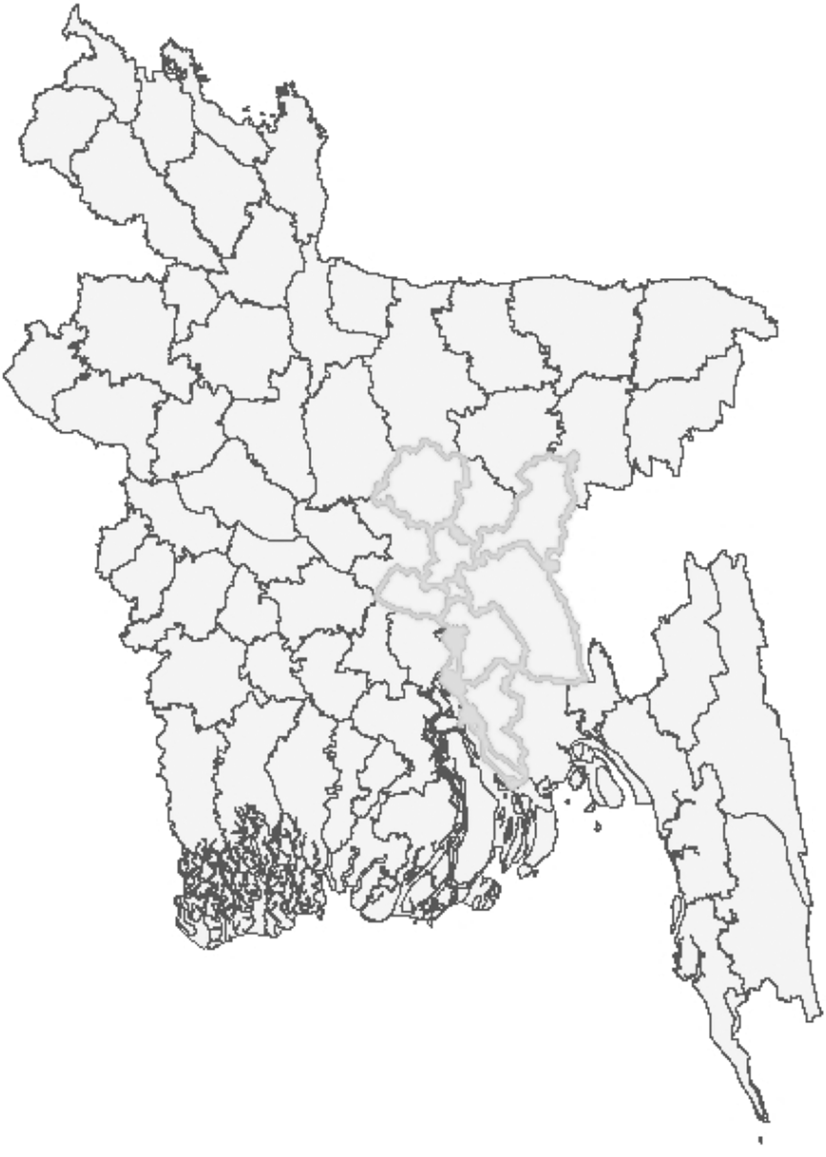

Figure A4. Study areas (districts) in Bangladesh. A color version of this figure is available online.

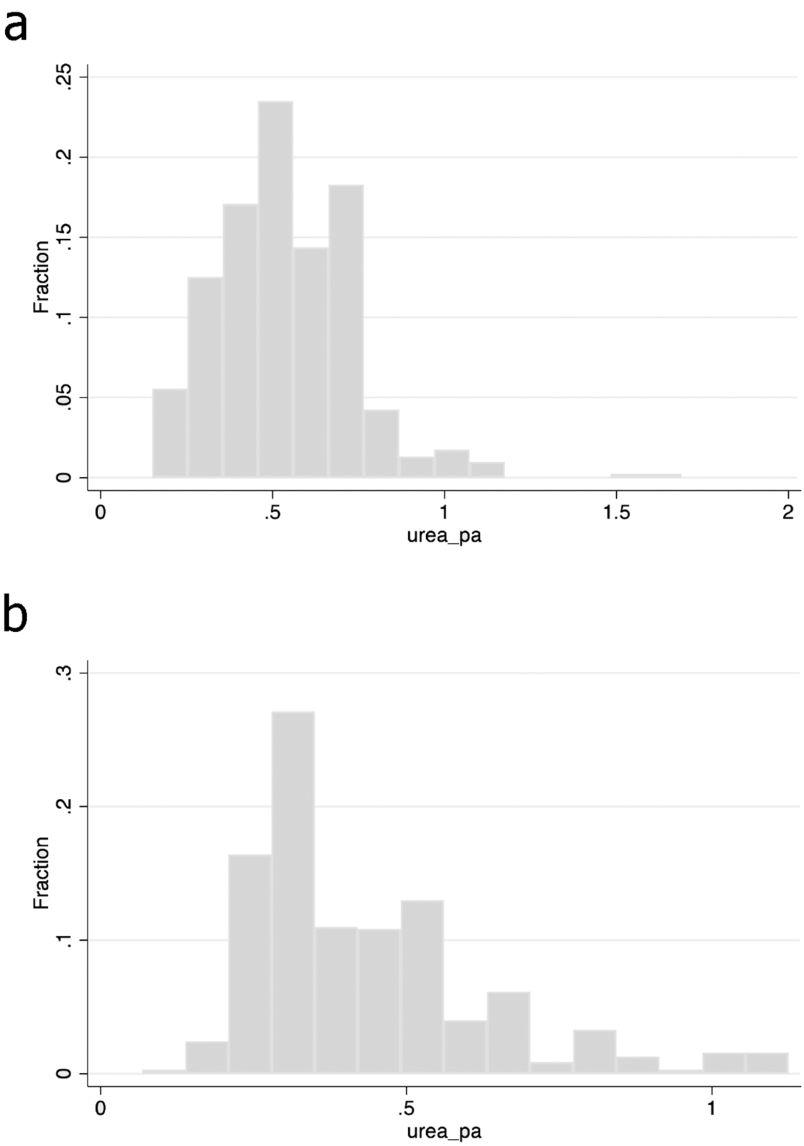

Figure A5. Urea per application by number of total applications. *a*, Two applications per season (kg/decimal). *b*, Three applications per season (kg/decimal). A color version of this figure is available online.

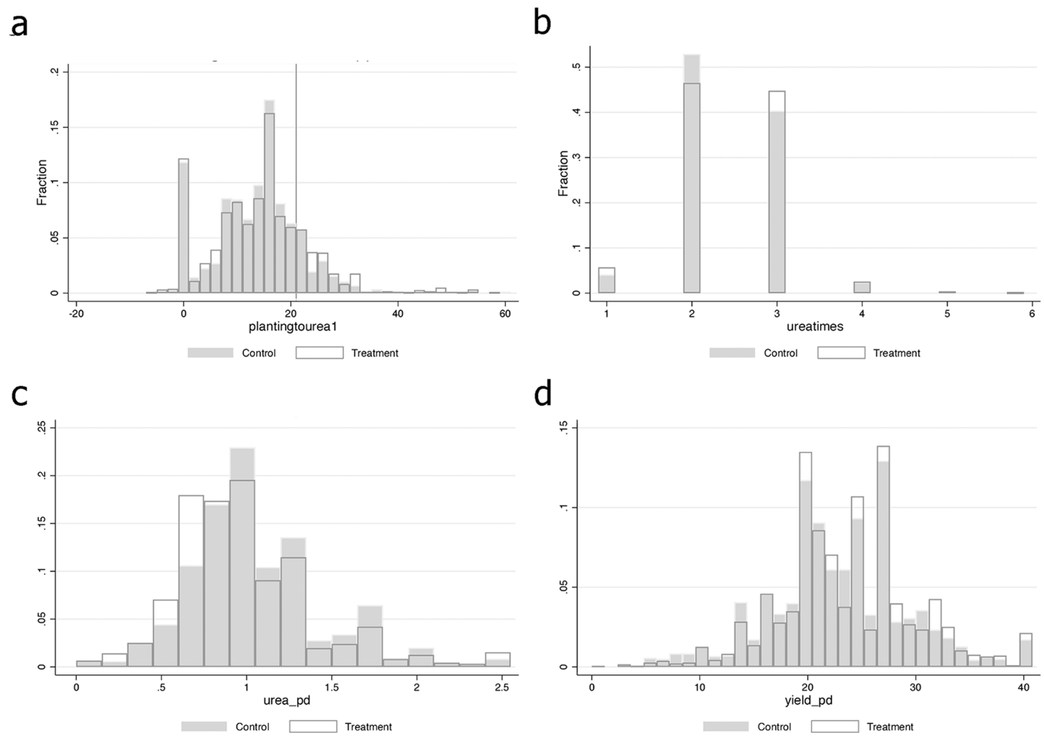

Figure A6. Urea application and yield for treatment and control group. *a*, Number of days between planting and first urea application. *b*, Number of urea applications. *c*, Urea (kg/decimal). *d*, Yield (kg/decimal). A color version of this figure is available online.

A4. Supplementary Tables

TABLE A1

INSTRUCTIONS FOR USING LEAF COLOR CHART (LCC)

1.	Check leaf color with LCC every 10 days, from 21 days after planting until flowering; if urea is not needed on day you check with LCC, check back again in 5 days
2.	Every time you check leaf color with LCC, pick 10 healthy leaf samples; walk diagonally across field from one end to other to pick 10 bunches
3.	From each bunch of leaves, select the topmost fully developed leaf and place on LCC to match color; compare in shade of your body
4.	If six or more of the 10 samples are light in color (i.e., match first two panels of LCC), apply 9 kg of urea for every 33 decimals of land; check leaf color with LCC again in 10 days
5.	If urea is not needed on day you measure (i.e., four or fewer of the 10 leaf samples are light), check leaf color again in 5 days with LCC to see whether urea is needed

TABLE A2

DESCRIPTIVE STATISTICS FOR DISTRICTS IN STUDY AREA

District	Population in Rural Areas (%)	Population in Agriculture (%)	Average Rural Household Size	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

Sources. Bangladesh Bureau of Statistics (http://www.sid.gov.bd/). Urbanization and literacy rate data for each district come from community reports from the 2011 Bangladesh Population and Housing Census. Population in rural areas was computed from total rural population and total population for each district using the same source. Population in agriculture was computed from total population and total population in agriculture data from the 2010 Statistical Yearbook of Bangladesh.

TABLE A3

SURVEY TYPES, SAMPLES, AND OUTCOMES

Survey Type	Survey Detail	Sample	Outcomes
Baseline	Long survey	1,440	Urea, yield, inputs, profits
Baseline	Short survey	605	Urea, yield
Midline	Time use survey 1	1,080	Time use
Midline	Time use survey 2	1,080	Time use
Midline	Urea use survey	1,569	Urea application timing
Endline	Long survey	1,549	Urea, yield, inputs, profits

Note. Urea use and endline surveys were intended for all baseline households involved in rice cultivation in the 2012–13 *boro* 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 follow-up data collection rounds and table A6 for additional balance checks.

TABLE A4

HOUSEHOLD AND PLOT CHARACTERISTICS ACROSS SAMPLES

	Summary Statistics		Difference
	No Midline (1)	Midline Time Use (2)	(Col. 2 − Col. 1) (3)
	A. Farmer and 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)	
Nonagricultural 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	1,080	2,045
	B. Plot-Level Variables: All Households		
Plot area (decimals)	30.92	28.40	***
	(23.12)	(20.76)	
Urea used (yes/no)	.999	.999	
	(.03)	(.04)	
Urea (kg/decimal)	.945	1.067	***
	(.64)	(.66)	
Yield (kg/decimal)	25.51	25.91	
	(17.81)	(17.92)	
Observations	2,034	2,482	4,516
	C. 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	3,388

Note. For cols. 1 and 2, standard deviations are shown in parentheses. The number of observations in col. 3 is the total sample size. The long survey that collected costs and profits at baseline was conducted with a subsample, indicated by the lower number of observations.

** $p < .05$.

*** $p < .01$.

TABLE A5
ATTRITION BY TREATMENT

	Endline Survey (1)	Midline Time Use (2)	Midline Urea Use (3)
Treatment	.006	−.014	−.000
	(.018)	(.017)	(.014)
Constant	−.004	.009	.000
	(.142)	(.134)	(.115)
Observations	2,025	2,025	2,025

Note. The dependent variable indicates households not included in each group. Regressions include strata fixed effects. Standard errors are in parentheses.

TABLE A6

RANDOMIZATION CHECKS AFTER ATTRITION: DIFFERENCES AT BASELINE FOR MIDLINE AND ENDLINE SAMPLES

	Individual/Household-Level Variables				Plot-Level Variables						
	Age (1)	Schooling (2)	Nonagricultural Income (3)	Total Plot Area (4)	Plot Size (5)	Urea (6)	Yield (7)	Revenue (8)	Total Cost (9)	Profit (10)	χ^2 Test (11)
	A. Midline (Time Use) Sample										
Treatment	.006	−.163	−521.520	−.327	.865	−.010	−.956	−5.675	−9.178	3.977	.67
	(.744)	(.268)	(661.530)	(2.188)	(.929)	(.028)	(.847)	(10.825)	(10.794)	(13.563)	(.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	
	B. Endline Sample										
Treatment	.361	−.172	−797.780	1.594	1.237	−.006	−1.291	−23.644*	−18.369*	−4.293	2.41
	(.629)	(.213)	(549.472)	(2.126)	(.869)	(.027)	(.801)	(12.115)	(9.413)	(13.387)	(.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	

Note. Reported are the coefficient of the treatment for regressions of each dependent variable on treatment and strata fixed effects for the midline time-use surveys. Age and schooling are in years, income is in takas, plot area and size are in decimals, urea and yield are in kilograms per decimal, and revenue, cost, and profit are in takas per decimal. Robust standard errors for regressions with individual- and household-level variables and standard errors, clustered at the household level for regressions with plot-level variables, are shown in parentheses. The joint test used a χ^2 test to estimate whether the coefficients are jointly significant.

* $p < .10$.

TABLE A7

TIMING OF INITIAL UREA APPLICATION

	In Third Week (1)	After 18 Days (2)	After 19 Days (3)	After 20 Days (4)	After 22 Days (5)	After 23 Days (6)	After 24 Days (7)
Treatment	.035*	.035*	.043**	.037**	.038***	.031**	.021*
	(.018)	(.018)	(.018)	(.016)	(.013)	(.013)	(.012)
Observations	3,541	3,541	3,541	3,541	3,541	3,541	3,541
R^2	.342	.342	.335	.357	.334	.356	.334
Means (control group)	.220	.220	.189	.157	.0990	.0887	.0794

Note. Control variables include age, schooling, nonagricultural income, and total plot area. Standard errors, shown in parentheses, are clustered at the household level. All regressions include strata fixed effects.
* $p < .10$.
** $p < .05$.
*** $p < .01$.

TABLE A8

CHANGES IN UREA APPLICATION INTERVALS DURING THE SEASON

	Days from Planting to First Application (1)	Days between First and Second Applications (2)	Days between Second and Third Applications (3)	Days between Third and Fourth Applications (4)	Days between Fifth and Sixth Applications (5)	Days from Last Application to Flowering (6)
Treatment	.435	−.598**	.164	.489	.930	−.346
	(.372)	(.298)	(.527)	(1.030)	(4.699)	(.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

Note. Control variables include age, schooling, nonagricultural income, and total plot area. Standard errors, shown in parentheses, are clustered at the household level. All regressions include strata fixed effects.
** $p < .05$.

TABLE A9

TOBIT ESTIMATES OF TIME USE BY FARMERS (7-DAY RECALL)

	No. of Times in Field (1)	Fertilizer Application (2)	Weeding (3)	Pesticide Application (4)	Other Activities (5)	All Activities (6)	All Activities Excluding Fertilizer Application (7)
Treatment	.134*	7.949	10.047	9.245	2.200	19.930	18.503
	(.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

Note. Values reflect Tobit estimates of treatment effects on time use by farmers using data from rounds 2 and 4 of the midline surveys. The dependent variables in cols. 2–5 are total time spent in minutes during the previous 7 days on different agricultural activities. Control variables include age, schooling, total plot area cultivated, and nonagricultural income. Standard errors, clustered at the household level, are shown in parentheses. All regressions control for survey round and strata fixed effects.
* $p < .10$.

TABLE A10
ORDINARY LEAST SQUARES ESTIMATES OF TIME USE BY FARMERS (7-DAY RECALL)

	No. of Times in Field (1)	Fertilizer Application (2)	Weeding (3)	Pesticide Application (4)	Other Activities (5)	All Activities (6)	All Activities Excluding Fertilizer Application (7)
Treatment	.112	3.921	5.827	.786	1.349	11.883*	7.962
	(.071)	(3.436)	(4.554)	(.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

Note. Data are from rounds 2 and 4 of the midline surveys. The dependent variables in cols. 2–5 are total time spent in minutes during the previous 7 days on different agricultural activities. Control variables include age, schooling, total plot area cultivated, and nonagricultural income. Standard errors, clustered at the household level, are shown in parentheses. All regressions control for survey round and strata fixed effects.
* $p < .10$.

TABLE A11
FULL SAMPLE: TREATMENT EFFECTS ON UREA AND YIELD (LOGS)

	Log Urea			Log Yield		
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment × Post	−.113***	−.120***	−.126***	.041	.038	.032
	(.033)	(.033)	(.039)	(.025)	(.025)	(.029)
Treatment	.031	.034		−.010	−.007	
	(.023)	(.023)		(.019)	(.019)	
Post	.169**	.199***	.198***	−.054***	−.042**	−.040*
	(.024)	(.025)	(.029)	(.019)	(.019)	(.023)
Controls	No	Yes	Yes	No	Yes	Yes
Household fixed effects	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

Note. 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.
* $p < .10$.
** $p < .05$.
*** $p < .01$.

TABLE A12
FULL SAMPLE: TREATMENT EFFECTS ON UREA AND YIELD (ANCOVA SPECIFICATION)

	Urea (Kg/Decimal)			Yield (Kg/Decimal)		
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment	−.070***	−.073***	−.079***	.560**	.577**	.029**
	(.018)	(.018)	(.019)	(.260)	(.256)	(.013)
Urea (baseline)	.032	.030	.026			
	(.020)	(.019)	(.020)			
Yield (baseline)				.079	.025	−.012
				(.432)	(.414)	(.030)
Controls	No	Yes	Yes	No	Yes	Yes
Mean at baseline	1.011	1.011	1.011	25.73	25.73	25.73

TABLE A12 (*Continued*)

	Urea (Kg/Decimal)			Yield (Kg/Decimal)		
	(1)	(2)	(3)	(4)	(5)	(6)
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

Note. The dependent variable is the natural logarithm of urea in col. 3 and of yield in col. 6. Control variables include lagged dependent variable (i.e., urea or yield from baseline) 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.
** $p < .05$.
*** $p < .01$.

TABLE A13
REVENUE, COST, AND PROFITS: PRICE DATA FROM VILLAGE STORES

	Long Survey Sample			Full Sample		
	Revenue (1)	Total Cost (2)	Profit (3)	Revenue (4)	Total Cost (5)	Profit (6)
Treatment × Post	34.412**	20.126	14.286			
	(15.454)	(19.145)	(21.563)			
Treatment	−19.615	−22.176	2.561	10.035**	.950	9.999
Post	(13.164)	(14.693)	(16.529)	(4.626)	(10.657)	(11.482)
	−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

Note. Controls variables include age, schooling, total plot area cultivated, nonagricultural income, and rice variety. Standard errors, clustered at the household level, are shown in parentheses. All regressions include strata fixed effects. All dependent variables are in takas per decimal; 100 decimals = 1 acre.
** $p < .05$.
*** $p < .01$.

TABLE A14
REVENUE, COST, AND PROFITS (ANCOVA SPECIFICATION)

	Long Survey Sample			Full Sample		
	Revenue (1)	Total Cost (2)	Profit (3)	Revenue (4)	Total Cost (5)	Profit (6)
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	.000	.006	.036	.000	.006	.036
	(.023)	(.032)	(.026)	(.022)	(.033)	(.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

Note. Controls variables include age, schooling, total plot area cultivated, nonagricultural 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 a baseline measure in cols. 4–6. All dependent variables are in takas per decimal; 100 decimals = 1 acre.
* $p < .10$.
** $p < .05$.

TABLE A15

TREATMENT EFFECTS IN HOUSEHOLD SPECIFICATION

	Urea (Kg/Decimal) (1)	Yield (Kg/Decimal) (2)	Revenue (Tk/Decimal) (3)	Cost (Tk/Decimal) (4)	Profit (Tk/Decimal) (5)
	A. Difference-in-Differences Specification				
Treatment × Post	−.079**	1.434*	19.259*	5.947	13.179
	(.031)	(.762)	(10.769)	(11.943)	(13.203)
Treatment	.010	−.868*	−10.561	−3.304	−7.135
	(.021)	(.514)	(7.270)	(8.062)	(8.913)
Post	.101***	−1.672***	115.284***	132.087***	−17.065*
	(.022)	(.542)	(7.665)	(8.501)	(9.398)
Observations	3,406	3,406	3,406	3,406	3,406
	B. ANCOVA Specification				
Treatment	−.081***	.398	6.145	3.175	2.895
	(.018)	(.253)	(4.483)	(11.030)	(11.719)
Baseline dependent variable	.053***	.007	.005	−.015	.043
	(.019)	(.010)	(.019)	(.053)	(.043)
Observations	1,535	1,535	1,535	1,535	1,535

Note. Controls variables include age, schooling, total plot area cultivated, nonagricultural 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.

* $p < .10$.

** $p < .05$.

*** $p < .01$.

TABLE A16

COSTS BREAKDOWN (LONG SURVEY SAMPLE)

	Fertilizers (1)	Manure (2)	Pesticides (3)	Other Expenses (4)	Labor (5)
Treatment × Post	6.771	.840	.882	7.151*	−2.560
	(6.836)	(1.204)	(1.148)	(3.769)	(5.401)
Treatment	−7.810	.488	−.719	−4.834	.322
	(6.502)	(.450)	(.632)	(3.073)	(3.563)
Post	9.759*	−.456	−2.680***	2.241	13.737***
	(5.282)	(.516)	(.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

Note. Controls variables include age, schooling, total plot area cultivated, nonagricultural income, and rice variety. Standard errors, clustered at the household level, are shown in parentheses. All regressions include strata fixed effects. All costs are in takas per decimal; 100 decimals = 1 acre.

* $p < .10$.

*** $p < .01$.

TABLE A17

TREATMENT EFFECTS BY TIME PREFERENCES, COGNITION, AND BASELINE HOUSEHOLD INCOME

	Urea (1)	Yield (2)	Urea (3)	Yield (4)	Urea (5)	Yield (6)	Urea (7)	Yield (8)	Urea (9)	Yield (10)
Time preference (low stakes) × Treatment × Post	.026	.706								
	(.021)	(.443)								
Time preference (high stakes) × Treatment × Post			−.015	.077						
			(.021)	(.494)						
Math score × Treatment × Post					−.010	−.263				
					(.030)	(.799)				
Raven's score × Treatment × Post							.051	.654		
							(.036)	(1.086)		
Nonagricultural income × Treatment × Post									.002	−.039
									(.003)	(.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

Note. Controls include age, schooling, total plot area cultivated, and rice variety. Regressions in cols. 1–6 also control for nonagricultural income. Coefficients not shown for the variables Treatment, Post, and Treatment × Post, the specific characteristic variable in each column, and 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 and Raven's scores measure the number of correct answers and range from 0 to 7 and 0 to 8, respectively. Nonagricultural income is the reported month's nonagricultural income in 1,000 takas per month as reported at the baseline survey. Urea and yield are in kilograms per decimal; 100 decimals = 1 acre.

TABLE A18

SOCIOENVIRONMENTAL COST OF UREA AVERTED BY LEAF COLOR CHART

Average urea savings (.079 kg/decimal saved per farmer × average plot size of 66)	5.16
$N_2O - N$ emissions saved from management of soil with N:	
N savings per farmer (based on urea N content of 46%)	2.37
$N_2O - N$ emissions saved (based on N_2O emission factor of 1%)[a]	.0237
CO_2 equivalent of $N_2O - N$ emissions saved[b]	7.02
CO_2 emissions saved from urea application:	
CO_2 emissions saved per farmer (based on CO_2 default emission factor of 20% of urea applied)	1.03
CO_2 equivalent of total greenhouse gas emissions saved (kg)	8.06
Value of greenhouse gas emission averted (US$; based on social cost of CO_2 of US$40/ton)[c]	.290
Total value of greenhouse gas emission averted across all farmers (US$)	322

[a] Intergovernmental Panel on Climate Change (Eggelston et al. 2006) linear Tier 1 default rate.
[b] Global warming potential of N_2O (in CO_2 equivalents) of 296.
[c] Interagency Working Group on the Social Cost of Carbon (2013).

TABLE A19
TREATMENT EFFECTS BY BASELINE UREA AND YIELD

	Urea (1)	Yield (2)	Ln(Yield) (3)
Baseline urea × Treatment	−.021		
	(.034)		
Baseline yield × Treatment		.035	.002*
		(.022)	(.001)
Treatment	−.051	.377	.018
	(.037)	(.288)	(.015)
Observations	3,632	3,632	3,632

Note. Control variables include lagged dependent variable (i.e., urea or yield from baseline) 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.
* $p < .10$.

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