

Profitability of Fertilizer: Experimental Evidence from Female Rice Farmers in Mali[†]

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Intensified use of agricultural inputs, particularly fertilizer, is a possible route to improved agricultural productivity. Field trials of these technologies show substantial increases in yields, but typically are done on highly monitored experimental plots rather than by farmers themselves.

Returns to a certain technology might be quite different on real-world farms than on experimental farms, particularly when farmers must reoptimize multiple inputs in response to a new technology. Suri (2011) argues that not all farmers benefit from fertilizer use, despite there being high average returns. Behavioral biases may also prevent farmers from realizing their intentions to use fertilizer (Duflo, Kremer, and Robinson 2011). We use a simple field experiment to provide free fertilizer to women rice farmers in southern Mali to measure how farmers choose to use the fertilizer, what changes they make to their agricultural practices, and the profitability of this set of changes.

Rice is an important crop in the study area. It is almost exclusively farmed on women-controlled plots. The technology is low-input intensive and is “broadcast” farmed on nonirrigated flood plains: seeds are literally scattered loosely into a plot, rather than small plants transplanted

TABLE 1—FERTILIZER USAGE WORLDWIDE ON RICE

	Fertilizer kg/ha	Yield kg/ha
World	134	3,703
Africa	19	2,164
Asia	140	3,777
North America	184	6,615
Latin America	90	3,083
Western Europe	279	5,902

Notes: Fertilizer usage as of 2002. Rice yield based on 1994–1996 data.

Source: FAOStat and FAO (1996).

from nurseries to rows in the plot. The rice production is mostly used for own consumption. Fertilizer is recommended by local agricultural extension agents and believed to substantially increase yields (Government of Mali 2009). Nevertheless, only about 30 percent of women use fertilizer, even with government price subsidies of around 33–43 percent (depending on the specific fertilizer).

As shown in Table 1, Africa’s fertilizer rates and yields are lower than any other region’s. The women in our sample in southern Mali are above the average for fertilizer usage for Africa, using about 38 kg/ha of fertilizer, but they achieve yields of only around 1,600 kg/ha. In contrast, the irrigated zone within Mali has fertilizer per hectare rates of about 113 kg/ha and achieves yields of about 4,500 kg/ha. A similar, if even larger, gap exists between Africa and the rest of the world for other cereal crops such as maize.

Our experiment had two treatment groups: those who received the full recommended quantity of fertilizer per hectare, and those who received half of the recommended quantity per hectare. We find that treatment increased the likelihood that women used fertilizer and increased the quantity of fertilizer used on their plots. They also report using more complementary inputs such as labor and

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TABLE 2—QUANTITIES AND VALUE OF FERTILIZER TRANSFERRED BY TREATMENT TYPE

	Half		Full	
	Mean	SD	Mean	SD
Quantity of fertilizer (kg)	32.09	21.77	65.71	45.04
Value of fertilizer (FCFA)	8,022.54	5,442.93	16,427.24	11,259.78
Quantity of fertilizer per ha (kg)	156.04	37.36	308.20	80.49
Farmers	123		135	

herbicides. From a methodological perspective, this highlights a challenge in measuring the returns to a given input. In this case, farmers change other complementary inputs making it difficult to isolate the returns to fertilizer. This is a general and familiar point: a discrete change in the price or availability of one input may induce agents to reoptimize in potentially many dimensions; it is not, in general, possible to isolate the technical returns to varying that input alone. Instead, we are able to estimate the returns to a policy of fertilizer distribution. This basic tension between measuring returns to a specific input and determining the impact of a policy plagues most empirical studies in this literature.

As a consequence of the increased input use, rice output increases by 31 percent on average, an increase we measure with statistical precision. However, we do not measure any increase in agricultural profits. The point estimate of the effect of this increased input intensity on profits is very close to zero, but the precision of the estimates is low. The confidence interval includes the estimates of the most profitable quantity of fertilizer examined by Duflo, Kremer, and Robinson (2008). However, the noise of the estimates in a real world environment highlights a potential constraint on farmers' fertilizer use: it may simply be difficult to learn about the returns to fertilizer for a particular farmer, given their land quality and other inputs, when the signal is weak and there are large fluctuations in profits due to other shocks.

I. Research Design and Data

The fertilizer experiment was conducted in 23 villages in the district of Bougouni of southern Mali. In spring 2010, we conducted a census of female farmers in the selected villages, randomly sampled one woman per household, and conducted a baseline survey. Detailed information was collected on agricultural activities, other economic activities, assets, consumption, expenditures, etc. Of the 416 respondents who were successfully interviewed, 383 cultivated rice in the agricultural season prior to the survey. These 383 women constitute our sample frame for the experiment.

Women were randomly assigned to one of two treatment cells or a control group: (i) 135 received the total recommended quantity per hectare, (ii) 123 received half of the recommended quantity per hectare, and (iii) 125 were in the control group and received no fertilizer.¹ We contacted various research institutes and extension agents within Mali to determine the treatment content.² The recommended level of fertilizer is roughly in line with the quantity of fertilizer used in North America and Western Europe. The half treatment is comparable to levels used in Asia for rice. We used our GPS measures of rice plot areas to determine individual farmers' plot sizes; the average rice plot is small, 0.22 of a hectare. Table 2 shows the mean transfers made, with the full treatment receiving on average 308.20 kg per hectare, and the half treatment receiving on average 156.20 kg per hectare.³

¹ Randomization was done using a rerandomization routine that stratified by village and guaranteed that for all of the following variables the *p*-values for the comparisons of means between any of the three groups were larger than 0.5: whether or not there was an extended household, use of fertilizer, use of plow, and an agricultural asset index. These baseline characteristics are included as controls in all regressions shown in Tables 3 and 4.

² As a result of their advice we defined 200 kg of grain fertilizer (Complexe céréale, a particular type of NPK) and 100 kg of urea per hectare as the full treatment amount. The original recommended amounts, consistent with Mali's agricultural subsidy program (Druilhe and Barreiro-Hurlé 2012), were 100 kg of diammonium phosphate (DAP) and 150 kg of urea. However, DAP was not available—a frequent problem—in the project area, so the local extension office recommended an alternative composition with fertilizer which was available.

³ There is variation in the amounts received per hectare since for logistical reasons we put plot sizes into buckets

In late May 2010, we bagged and labeled the two fertilizer types and sent teams to the villages to distribute the fertilizer to the women in the treatment groups. We also provided a short, 30-minute explanation of how to use the fertilizer. No further training or monitoring was provided. A few months later, in August 2010, we conducted a first follow-up survey that focused on use of inputs. We conducted a second follow-up survey immediately after the harvest in December 2010. We were able to collect follow-up data for 378 primary respondents (out of 383).

The experimental design differs from that of Duflo, Kremer, and Robinson (2008) from Kenya in three main ways. First, in the Kenya experiment, each farmer divided a given plot into sections, applying fertilizer on some parts and not on others. Second, extension agents from the partner Kenya NGO helped farmers apply the fertilizer, monitored farmers, and assisted with harvest through crop cutting (which also lends itself to more precise measures of output). Third, in the Kenya experiment, other inputs were not formally measured.⁴ In our experiment, women farmers were provided just the fertilizer and a short training on fertilizer. We returned months later to measure input use halfway through the agricultural cycle, and then finally after the harvest to measure output.

We thus report treatment effects from a policy of fertilizer distribution done without one-on-one monitoring nor extensive training. This design also reveals farmer choices when their endowments of fertilizer are exogenously increased. Farmers may adjust their behavior in response to the delivery of fertilizer in a variety of ways, such as transferring to others, storing, selling, as well as adjusting complementary inputs and effort.

(i.e., less than 1,500 square meters, between 1,500 and 2,500 square meters, etc.) and provided the same quantity of fertilizer for all individuals in the same bucket and treatment group.

⁴ In some of the trials, though, farmers were asked about the time spent weeding, and farmers reported weeding similar amounts on all segments of their plots. Dividing up one parcel into several parts, along with the instructions provided by the research team to not otherwise adjust their farming practices and the extension agents' monitoring, may have made farmers less likely to change other inputs.

II. Results

We investigate the effects of the fertilizer transfers on input usage, output, and profits. Given that treatment assignment was random, the empirical strategy is straightforward. We estimate the following regression specification:

$$y_{ijt} = \beta_0 + \beta_1 \text{half}_{ijt} + \beta_2 \text{full}_{ijt} \\ + \beta_3 y_{ij(t-1)} + \beta_4 x_{ij(t-1)} + \delta_j + \varepsilon_{ijt},$$

where i represents farmers, j represents villages, and t represents time (two time periods, before and after). The coefficients of interest are β_1 and β_2 , capturing the effect of the half and full treatment, respectively. $y_{ij(t-1)}$ is the lagged dependent variable, $x_{ij(t-1)}$ is the vector of baseline variables used in the randomization routine, and δ_j are village indicators since we stratified the randomization by village.⁵ In Table A1 of the online Appendix, we show tests for orthogonality of assignment to treatment and a set of input and outcome variables. For zero out of nine variables are we able to reject the null hypothesis of equality at the 10 percent level.

A. Inputs

Table 3 looks at the impacts on inputs used on rice plots. All columns are estimates of the above specification where the dependent variable is identified in the column heading. Column 1 shows that treatment had a huge effect on the likelihood of usage: in control, 32 percent of women used fertilizer, whereas the two treatments had almost perfect compliance, generating treatment effects of 64 percentage points (standard error = 0.04) for both the half and full treatments. The provision of fertilizer also dramatically increased the quantity of fertilizer used. The control group on average used 13 kg of fertilizer, while the half treatment group used 21 kg more (standard error = 4.10) and the full treatment group used 33 kg more (standard error = 4.05). In the half treatment, the women used up most or all of the fertilizer given to them. The women in the full treatment used

⁵ In addition, a dummy variable is included indicating if the value of the outcome variable is missing at baseline.

TABLE 3—INPUTS (WOMEN, RICE PLOTS)

	Input use			Input expenses				
	Use of fertilizer (1)	Fertilizer quantity used (Kg) (2)	Family labor (days) (3)	Fertilizer expenses (FCFA) (4)	Herbicides (FCFA) (5)	Expenses on hired labor (FCFA) (6)	Total input expenses (excl. fertilizer) (FCFA) (7)	Total inputs (incl. value of fertilizer used) (FCFA) (8)
Treatment (half)	0.64*** (0.04)	21.28*** (4.10)	2.84 (4.32)	-2,412.91*** (536.70)	1,012.54* (533.73)	1,075.15* (602.21)	1,705.06 (1,139.86)	7,061.32*** (1,641.05)
Treatment (full)	0.64*** (0.04)	32.91*** (4.05)	-4.73 (4.27)	-3,011.97*** (532.16)	999.8* (527.71)	2,353.15*** (594.93)	3,003.96*** (1,130.02)	11,450.61*** (1,627.02)
<i>p</i> -value: half = 1/2 × full	0.00	0.17	0.16	0.05	0.27	0.85	0.84	0.35
Observations	378	378	378	377	378	378	377	377
Mean of control	0.32	13.17	59.76	3,585.16	3,855.24	2,967.74	9,685.77	12,993.70
SD of control	0.47	28.08	37.11	7,871.52	4,942.22	3,632.80	10,000.33	14,399.81

Notes: Standard errors are in parentheses. Column 1 is a linear probability model, while columns 2–8 show OLS estimates where the dependent variable is identified in the column heading. Also included in all specifications is the lagged dependent variable, an indicator for when the baseline value is missing, village fixed effects, and the control variables used in the randomization routine (whether or not there is an extended household, use of fertilizer, use of plow, and an agricultural asset index). The dependent variable in 7 is the sum of those in 5 and 6, and expenses on seeds, plowing, rental of carts, manure, and chemicals other than fertilizer and herbicides such as, e.g., insecticides and pesticides. *p*-value: half = 1/2* full reports the *p*-value of a Wald test that the impact of the half treatment is 1/2 the size of the full treatment. The mean and standard deviation of control are values of the column heading variable at endline in only control villages.

***Significant at the 1 percent level.

**Significant at the 5 percent level.

*Significant at the 10 percent level.

about 70 percent⁶ of the fertilizer given to them, suggesting some fertilizer was either stored, sold or shared with other household members.⁷ This strong response of fertilizer use on women's plots to grants of fertilizer to women has important implications for our understanding of the economic organization of Malian households, and for the analysis of agricultural input and financial markets. Our focus in this paper, however, is on the impact of this increased fertilizer use on complementary inputs and on output.

⁶ The full treatment group used on average 46 kg of fertilizer, compared to an average of 66 kg given to women in that treatment group.

⁷ We asked about interhousehold sales and transfers of fertilizer in the first follow-up survey. Only three treatment households reported either selling or giving fertilizer to other households. We therefore believe that most of the unused fertilizer was used by other household members or stored. We did not observe an increase in fertilizer use on men's plots or other women's plots in 2010. However, men's plots are much larger on average than women's plots so it would be very difficult to detect a small, in relative terms, increase in fertilizer used.

We observe no change in the amount of family labor applied to women's rice plots (Table 3, column 3). We find that a portion of the fertilizer grants replaces cash expenditure on fertilizer (Table 3, column 4): women in the half treatment spent 2,413 CFA francs (FCFA) less on fertilizer (standard error = 537), and those in the full treatment spent 3,012 FCFA less (standard error = 532).

Other inputs were crowded in from the free fertilizer distribution. For herbicides (Table 3, column 5), we find about a 1,000 FCFA increase (standard error = 530 FCFA) for both treatment groups, and expenses on hired labor increased, but less so: 1,075 FCFA (standard error = 602) for the half treatment group and 2,353 FCFA (standard error = 595) for the full treatment group.⁸

The total input expenses, excluding fertilizer and family labor, increased significantly

⁸ We did not observe changes in expenses on other inputs such as seeds and plowing.

TABLE 4—OUTPUT (WOMEN, RICE PLOTS)

	Value output (FCFA) (1)	Profits (FCFA) (2)	Profits (subtracting value of family labor) (FCFA) (3)	Profits (subtracting fertilizer costs only) (FCFA) (4)
Treatment (half)	5,952.23* (3,549.27)	-1,101.05 (3,253.79)	-2,446.13 (3,193.44)	593.56 (3,277.51)
Treatment (full)	1,1045.78*** (3,504.60)	-115.82 (3,226.97)	1,458.83 (3,167.06)	2,936.29 (3,237.35)
p-value: half = 1/2 × full	0.89	0.71	0.25	0.76
Obs.	372	371	371	372
Mean of control	3,5919.50	2,2971.13	-1,220.54	32,649.88
SD of control	31,406.16	28,880.84	27573.59	29,660.41

Notes: Standard errors are in parentheses. All columns show OLS estimates where the dependent variable is identified in the column heading. Also included in all specifications is the lagged dependent variable, an indicator for when the baseline value is missing, village fixed effects, and the control variables used in the randomization routine (whether or not there is an extended household, use of fertilizer, use of plow, and an agricultural asset index). Family labor is valued at 400 FCFA per day in column 3. The mean and standard deviation of control are values of the column heading variable at end-line in only control villages.

- ***Significant at the 1 percent level.
- **Significant at the 5 percent level.
- *Significant at the 10 percent level.

for the full treatment group (1,705 FCFA, standard error = 1,140 for the half treatment; 3,004 FCFA, standard error = 1,130 for the full treatment). All in, column 8 shows how the provision of fertilizer, and women’s subsequent decisions on how to use the fertilizer and other inputs, affected total inputs. Total inputs, including the value of fertilizer used but excluding family labor, increased substantially, almost as much as the transferred amounts (8,023 FCFA transferred versus 7,061 FCFA increased inputs for the half treatment; 16,427 FCFA transferred versus 11,451 FCFA increased inputs for the full treatment).

B. Output and Profits

The increases in input usage led to a considerable increase in the value of output, as shown

in column 1 of Table 4. Output is valued at producer prices at the time of harvest, to avoid confounding a potential increase in profits from increased output with the returns to storage. The increase in output is 5,952 FCFA (standard error = 3549) in the half treatment group and 11,046 FCFA (standard error = 3505) in the full treatment group, compared to a control group mean of 35,920 FCFA, an increase of 17 percent and 31 percent, respectively.

However, columns 2–4 show that we cannot detect an increase in profits. Column 2 estimates a small but negative impact on profits (-1,101 FCFA, standard error = 3,254; -116 FCFA, standard error = 3,227, for the half and full treatments, respectively), calculated as the value of output minus the value of inputs other than family labor. We can then think of this definition of profits as including the family’s wages for their labor plus the firm’s profits. Column 3 also removes the value of family labor from profits.⁹ Subsequently, average profits in the control group are very low, and even negative on average. Column 4 uses a version of profits calculated as the value of output minus the value of just fertilizer in order to be comparable to that used by Duflo, Kremer, and Robinson (2008), which overestimates the impact on profits because other purchased inputs increased due to treatment. In all three cases, we cannot reject the null of no increase in profits. The confidence interval is large. A simple return on investment calculation, dividing the change in profits from the full treatment, as measured in column 2 of Table 4, by the change in inputs from the full treatment (column 9 of Table 3), has a 90 percent confidence interval ranging from -0.48 to 0.46. Therefore, the rates of returns of the most profitable amounts of fertilizer in Duflo, Kremer, and Robinson (2008) are contained in our confidence interval.

The large confidence interval of course partially reflects measurement error in the survey. But it also highlights that there is substantial variability in profits. For the full treatment, the

⁹ We value family labor at a rate of 400 FCFA per day. As in most places in West Africa, labor markets are relatively thin, and it is challenging to price family labor. This figure is based off of average wages paid to women laborers participating in work groups, which is the closest type of hired labor to family labor we observe in rural labor markets in southern Mali.

upper bound of the 95 percent confidence interval of the treatment effect on profits, as measured in column 2, is still only 0.2 of a standard deviation. If the signal on the profitability of fertilizer is weak relative to the noise resulting from weather variability, it will be hard for farmers to learn about how much—if any—fertilizer is optimal for them to use on their particular plot of land given other possible constraints they face on inputs (including labor, for example). Note that the experiment induced a large increase in the quantity of fertilizer used. A smaller increase in fertilizer, as would be more typical for farmers experimenting, would be even harder to detect.¹⁰

III. Conclusion

An experiment providing fertilizer grants to women rice farmers in Mali found that, first, women who received fertilizer increased both the quantity of fertilizer they used on their plots and complementary inputs such as herbicides and hired labor. This highlights that farmers respond to an increase in one input by reoptimizing other inputs, making it challenging to isolate the returns to any one input. Second, while the increase in inputs led to a significantly higher level of output, we find no evidence that profits increased. Our results suggest that fertilizer's impact on profits is small compared to other sources of variation. This may make it difficult

for farmers to observe the impact of fertilizer on their plots, and accordingly this affects their ability to learn about the returns to fertilizer and could affect their decision to adopt even in the absence of credit constraints.

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¹⁰ We also investigated treatment effect heterogeneity along the dimension of farmer experience/skill. As shown in the online Appendix, we do not find evidence of treatment effect heterogeneity on output nor profits.