Can information improve investment?
Effects of site-specific soil recommendations on fertilizer demand

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Abstract

This paper studies the effects of providing smallholder farmers with plot-specific soil quality information and fertilizer recommendations on investment and technology adoption. Low use of mineral fertilizers by farmers in Sub-Saharan Africa contributes to low crop yields, high rates of food insecurity, and persistent poverty. A possible explanation as yet unexplored in the literature for persistently low adoption rates: the presence of hyper-local variation in soil quality means that blanket fertilizer recommendations set by governments may be unsuitable for many farmers. We use a randomized control trial to test the effects of plot-specific recommendations with and without a concomitant easing of farmer liquidity constraints. We find evidence of agronomically important within-village variation in soil nutrient deficiencies and we find that government recommendations are not relevant for the majority of farmers in our sample. Results demonstrate that the combination of liquidity and information is key to resolving plot-specific soil nutrient limitations; information alone does not change investment and provision of vouchers without information leads farmers to purchase the most common fertilizer in the market. Results from a production function analysis show that application of mineral fertilizer to address plot-specific nutrient limitations leads to large maize yield increases. Our research suggests that substantive crop yield increases in the region will require a targeted approach that addresses sub-regional soil constraints to crop production and makes efficient use of environmental and economic resources.

Keywords: site-specific information, soil quality, fertilizer, RCT, difference-in-differences

1. Introduction

Poor soil quality and limited use of mineral fertilizers contribute to low agricultural productivity and pervasive poverty and high malnutrition in much of rural Sub-Saharan

Africa (Sanchez 2002; Minten and Barrett 2008; Sanchez and Swaminathan 2005).[1] Farmers in Sub-Saharan Africa are among the least likely to use mineral fertilizer in the world (World Bank 2014) despite evidence that mineral fertilizer application increases crop yields and economic returns (IFDC, 2006).[2]

Duflo et al (2008) show that fertilizer increases productivity on small farms, but in places such as our study area where few small farmers report ever having used fertilizer, farmers may not be well informed about benefits of fertilizer on their farms. A more likely mechanism through which lack of information may constrain use of fertilizer is heterogeneity of benefits. Evidence indicates that significant variation in soil quality induces heterogeneity in economic returns to fertilizer use (Suri 2011), with fertilizer application substantially less profitable on more depleted soils (Marenya and Barrett, 2009). Otsuka and Larson (2013 Ch 13) argue that local variation in soil quality has impeded the adoption of Green Revolution technologies because knowledge sharing is difficult when the experience of neighboring farmers may not be relevant (Munshi 2004), and/or because farmers do not know what mineral fertilizers are best suited to their own plots.

A large literature addresses small farmers' ability to afford fertilizer, and in particular, the effect of fertilizer subsidies on agricultural productivity (Chibwana et. al, 2014; Ricker-Gilbert and Jayne, 2011). A prevalent objection to subsidies among economists is that they distort incentives. If farmers are perfectly rational and fertilizer is divisible, so liquidity does not constrain purchases, subsidies should result in overuse of fertilizer. However, fertilizer often is not perfectly divisible. In our study area it comes in bags of 50 and 25 kilograms.[3] In this case, a liquidity constraint alone or a liquidity constraint combined with the kind of limited rationality discussed in Duflo at al (2011) may prevent farmers from purchasing fertilizer.

Our study makes a two-fold contribution to the literature. First, we use a randomized control trial to test the effect that information about plot-specific soil deficiencies and recommended fertilizer type and amount has on small farmers' use of fertilizer and crop yields. Second, we test the effect of the provision of this plot-specific information in the presence of liquidity constraints and when fertilizer subsidies alleviate the constraint. The information about soil deficiencies and recommended fertilizer, which is specific to a farmer's plot of land, may seem more relevant and therefore convincing to farmers, especially in the context of sub-Saharan agriculture, than do general recommendations for fertilizer use disseminated by the extension services.[4]

To our knowledge, this is the first study to provide information to farmers about plot-

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[1] After decades of stasis, in part due to soil nutrient depletion following years of insufficient organic and inorganic fertilizer applications (Sanchez 2002), cereal yields have recently begun to increase in some areas, particularly in countries such as Malawi and Tanzania where governments have instituted programs subsidizing mineral fertilizer and hybrid seed for smallholder farmers (Denning et al. 2009, Sanchez et al. 2009).

[2] Some research has found evidence that the value cost ratio for maize is low (Kihara et al. 2016). Nziguheba et al (2010) show varying returns

[3] The bags can be opened to sell smaller amounts but this strategy is costly since fertilizer quality can be compromised once the bag is opened.

[4] A few studies suggest that information which is specific to individuals is more likely to change behavior than is general information in other contexts as well (Madajewicz et al 2007).

specific soil deficiencies and associated fertilizer recommendations. We randomize the assignment of individual farmers within villages among three treatment groups and a control group. Farmers in the first treatment group receive information about types and amounts of fertilizer to best address deficiencies on what they designate to be their main maize growing plot. Farmers in the second treatment group receive a voucher, which covers the cost of enough fertilizer to cover a 0.5-acre plot. The voucher addresses the liquidity constraint, that farmers may not have sufficient cash to purchase fertilizer regardless of whether they know what kind they should buy and how much. Farmers in the third treatment group receive both the plot-specific information and the input voucher. Farmers in the control group receive neither information nor a voucher. The study also includes control villages in which no farmers received treatment, which enables us to test for spillover effects.

First, we find evidence of important variation in soil deficiencies across farms. The plot-specific recommendations provide a unique service that clearly addresses an information constraint among the smallholder maize farmers. The soil limitations in evidence in our sample do not correspond to government mineral fertilizer recommendations for maize growers in the region, which are appropriate for only 0.5 percent of the farmers in our sample,[5] Our results indicate that national regional-level fertilizer recommendations are not serving the needs of many small farmers.

Second, farmers who were provided with plot-specific information in combination with input vouchers acted on the information, purchasing fertilizers related to their soil's specific nutrient deficiency. Farmers provided only vouchers were more likely to purchase urea, the most well known and most commonly used mineral fertilizer. Our results suggest that information can help close farm-specific nutrient deficiency gaps.

Specifically, we find that providing plot-specific information together with the inputs voucher significantly increases farmer application of mineral fertilizer on maize by 11.73 kg per acre and increases maize yields by 173.72 kg per acre on farmers' main maize plots, an increase from 0.148 and 430.87 kg per acre, respectively, at the baseline mean. The voucher alone increases application of fertilizer more modestly by 4.64 kg per acre. The evidence that the increases in fertilizer application in the group that receive vouchers only result in higher yields is weak, most likely because these farmers are not applying the type of fertilizer that addresses the nutrient deficiencies in their soil. Information alone has no effect on application of fertilizer or on yields relative to the control group.

The results indicate that plot-specific information enables farmers to increase productivity over and above simply relaxing the liquidity constraint, and farmers are willing to use the information to guide their production decisions even in the short term. We show that farmers who receive plot-specific information choose different fertilizers than do farmers who receive only vouchers. Farmers who received the information and vouchers applied more of the mineral fertilizer types recommended to them, which were distinct from the government recommendation for the area. Farmers who received only vouchers were more likely to increase the amount of the generally recommended fertilizer as well as organic fertilizer and compost. The use of vouchers to invest in organic fertilizer and compost

[5] These results are consistent with Tjernstrom (2015), who finds considerable within and between village variability in soil quality measurements in Western and Central Kenya.

suggests that farmers are not convinced that the generally recommended fertilizer is profitable. Our results suggest that farmers are correct based on an estimation of a production function for maize. The farmers are not likely to be unaware of the general recommendations. We reminded all farmers, including the control groups, about these recommendations at the beginning of our intervention.

Our results also support the hypothesis that farmers face liquidity constraints, which effectively prevent them from putting information to use. An alternative interpretation of the results is that farmers who received information but not a voucher did not purchase fertilizer in the hope that the project would offer them vouchers in order to induce them to purchase fertilizer, since farmers were aware of what the other groups in the experiment received. The team explained that the intervention would only occur once, but farmers may not have perceived that communication to be credible.

We investigate whether the information had spillover effects, as it may if farmers whose plots neighbor those of information recipients use the information to tailor their own fertilizer applications. We find no evidence of spillover effects in the first two years after the information is made available to farmers. Farmers who own neighboring plots may not perceive the information as being useful to them, since it is plot-specific. In fact, about half of farmers received the same recommendation as their closest neighbor in our data. Liquidity constraints may prevent them from using the information. Moreover, non-treated farmers may be waiting for evidence of productivity increases on treatment plots to determine if they should use the information or not.

The paper is structured as follows. The next section provides background on the soil testing, region, and study design. Section 3 explains the design and implementation of the experiment. Section 4 presents the data and identification strategy. Section 5 presents descriptive results while section 6 presents the main results of the paper. In section 7 we explain the results and in section 8 we perform several robustness checks.

2. Context

The site of the study is Morogoro Rural, one of the six districts of Tanzania's Morogoro region. The region is a high producer and consumer of maize, we will focus on maize, but is characterized by chronically low inputs use. According to the 2007 Tanzania Agricultural Census, 98 percent of households in Morogoro grew maize on at least one plot and less than one percent reported using any fertilizer. Resulting maize yields in Morogoro averaged about 1.4 t/ha between 1994-2001 (Paavola 2008), far below the 6 to 7 t/ha achieved with applications of 70-100 kg N/ha (Folberth et al. 2013).

Farmers in the United States, Canada, and other affluent countries can pay for sophisticated soil testing and employ high-cost technologies to address variations in soil quality. These technologies include GPS-equipped tractors to distribute fertilizer inputs adjusted according to within field variability, with high accuracy across farm acerage. In contrast, few soil testing services are available to farmers in Sub-Saharan Africa (SSA) and the costs of those that do exist are prohibitive to small farmers. Only a few farmers throughout SSA, and very few small-scale farmers, know the nutrient status of their soils or their specific soil-mediated production constraints, despite national and regional efforts to advocate for the crop-yield effects and profitability of mineral fertilizer application. For example, recent research shows for land under cultivation in SSA perhaps as much as 20% does not respond to applications of standard fertilizers (containing nitrogen, phosphorus, and potassium), suggesting that underlying soil constraints to production may be related to pH, micronutrients, or other biological factors (Vanlauwe et al. 2010, Zingore et al. 2007). In the absence of testing, farmers have largely relied on observed crop yields as an indication of soil quality. However, research by Berazneva et al. (2018) finds a poor correlation among farmer-reported subjective assessments of soil quality, actual yields, and lab-based measures.

Nor can farmers in the region currently rely on national and regional government recommendations for mineral fertilizer application. In many parts of SSA, such recommendations are made at relatively high levels of aggregation (Tittonell et al. 2008), with governments often promulgating one recommendation for an entire region or country. Duflo *et al*. (2008) find that many farmers in Kenya receive recommendations for fertilizer application rates that do not match the needs of the soils they cultivate. While uniform recommendations can have some success in improving yields broadly, additional progress will likely require targeted approaches that address specific soil constraints to crop production and make efficient use of environmental and economic resources.

Several field-level test kits have been developed in recent years to address the issues of accessibility and affordability of soil testing for small-scale farmers in SSA. One of these test kits is SoilDoc, a rapid on-farm soil diagnostic kit that combines in-field measurements of essential soil physical and chemical parameters with information communications technology (ICT) to provide farm-specific management recommendations.

3. The experiment

We randomly selected 50 villages in the Morogoro Rural district in Tanzania that were accessible by vehicle and known to grow maize. We designated 20 randomly selected villages where we randomized treatment status at the individual farmer level. In each village, we randomly selected 40 farmers to participate in the study, whom we randomly allocated into one of four groups: a) 10 farmers received plot-specific fertilizer recommendations for the 2016 growing season (group T_1); b) 10 farmers received plot-specific information for the 2016 growing season and a voucher worth approximately 40 USD with which they could purchase any input available from selected agro-input dealers (group T_2); c) 10 farmers received vouchers worth approximately 40 USD that they could redeem for any input from pre-specified agro-input dealers (group T_3); d) 10 farmers served as control (group C_1). In each of the remaining 30 villages, we surveyed 10 farmers who received no treatment, in order to measure potential spillover effects (C_2).

In each of the 50 villages, we obtained lists of all maize-farming households from the village leaders. We selected only those maize farmers for the study who a) had not participated in Tanzania's National Agricultural Input Voucher Scheme (NAIVS) in the last three years; and b) planned to cultivate a plot of maize in the 2016 growing season on which they also cultivated maize in the 2014 season.

Between September and November 2014, a team of soil scientists and agronomists from Sokoine University of Agriculture (SUA) collected soil samples from each farmer in the study, both treatment and control farmers in both treatment and control villages. The team sampled the soil from the plot that each farmer identified as his or her main maize plot. This is the plot where the farmer cultivated maize during the 2014 rainy season as well as the plot on which the farmer intended to grow maize during the 2016 long rainy season. A farmer's main plot was defined as the plot a farmer considered to be most important to their household's livelihood (in terms of food security and income generation).

The soil fertility parameters analyzed by SoilDoc include soil pH, biologically active soil organic matter, electrical conductivity (indicative of general fertility as well as salinity issues) and extractable macronutrients (nitrate-N, sulfate-S, phosphate-P, and potassium-K). We also assessed soil physical properties such as surface sealing strength, compaction, and aggregate stability (a property that integrates biological, chemical and physical conditions). The soil tests used followed the SoilDoc kit protocol, described in more detail in Appendix 1.

Communication of the plot-specific fertilizer recommendations based on the soil analysis and voucher distribution took place between December 2015 and January 2016, before the long rains season planting. A team of agronomists held meetings with all participating farmers in each village. During this meeting, they explained the project and process to all farmers, both treatment and control. The team told those farmers who did not receive plot-specific recommendations for the 2016 growing season that they would receive them in time for the 2017-growing season. The team reviewed the standard, regional-level recommendations provided by the government -- 60 kg urea and 40 kg DAP per acre[6]. This was done out of concern that farmers who did not receive SoilDoc recommendations would not purchase any inputs because they did not know what to apply. Indeed, during the second baseline survey, which we carried out before we began the intervention, only 3.7% farmers reported knowing the regional recommendations.

The SUA agronomists met separately with each farmer who received a plot-specific recommendation to explain their results. Appendix 2 shows an example of recommendations for a farmer whose soil was depleted in nitrogen, phosphorus and sulfur (NPS). We provided recommendations for both one acre and half of an acre so that farmers could more easily understand which fertilizers and which quantities to purchase and apply for plots of different sizes.

In order to observe the effect of information, we removed differences in transactional costs associated with purchasing inputs by bringing inputs to the farmers. An agro-input dealer agreed to travel to each of the 50 villages and spend six hours in each village to give farmers the opportunity to purchase any input. During the meeting in which the agronomists provided the recommendations, the team notified all farmers that an agro-input dealer would be visiting their village. One week before the input dealer arrived in a village, the dealer notified the village leader who communicated information about the visit to village

[6] In the field, we modified the government recommendations to one 50 kg bag of urea and one 50 kg bag of DAP per acre to facilitate the purchase of fertilizers which are most commonly found in 50 kg bags.

members. All farmers who were selected to participate in the project, including the control farmers, could purchase inputs from the dealer during the dealer's visit.

Farmers who received a voucher could purchase any agricultural input in any amount that the dealer carried. The value of the voucher, 80,000 Tz Shillings, was sufficient to cover 0.5 acres of maize using the standard, regional government recommendations. Instead of redeeming the voucher for inputs they could also redeem the voucher for cash for 85% of the value of the voucher. If they purchased inputs that were less than the value of the voucher, they could redeem 85% of the remainder of the value of the voucher for cash. The team explained these rules to farmers at the village meeting and wrote them on the voucher coupons given to farmers, shown in Appendix 3. Farmers who did not receive a voucher, received an information card, as shown in Appendix 4, which provided information about the availability of inputs from the agro-dealer.

4. Data and Identification

We asked all farmers who were selected for the study a set of baseline questions in August 2014, including modules on demographics, household and dwelling characteristics, on-farm decision making, credit, savings and assets, risk preferences, plot map and details, organic and inorganic input use, pesticides/herbicide use, improved seeds use, labor and learning. We conducted a second baseline survey in August 2015 asking farmers about their 2014 harvest on their main maize plots, total quantities of maize sold, stored and consumed, as well as their expectations about returns from fertilizers. The second baseline was conducted after it was realized that the 2014 yields on farmers' main maize plot had not been collected. After the treatment, which occurred between December 2015 and January 2016, we conducted an endline survey in August 2016. All surveys took place at the same time of the year, August, after harvest of the long rains maize crop.

Of the 50 villages first randomly selected, it was discovered after baseline that three control villages did not in fact grow maize, so were dropped from the study. In total, we surveyed 1,050 households in the first baseline survey, as some randomly selected farmers to participate in the study were not found the day of the survey. Farmers atritted out of the study over time: some farmers could not be found, some passed away or moved, while others were unwilling to participate in the study. From the original 1,050 surveyed, a total of 806 farmers participated in each round of the survey, representing an overall attrition rate of 23 %. However, not all rounds of data are used in each subsequent analysis. Between the first baseline and the soils analysis, we have an attrition rate of 4%. We have an attrition rate of 20% between the baseline and the second baseline. Finally, we have an attrition rate of 6% between the baseline and the endline surveys.

Most importantly for our analysis, table 1 shows that the attrition rate among treatment groups and controls is similar. The attrition rate is only statistically significant at the 1% level for the control villages and the treatment groups and control farmers in treatment villages for the second baseline.

We are interested in estimating the effects of providing farmers with plot-specific fertilizer recommendations and/or vouchers on farmers' use of fertilizers and crop yields.

We estimate the average treatment effect of the intervention on our outcomes of interest with the following first differences estimation:

$$\Delta y_i \;=\; \alpha_0 + \sum_{i=1}^{3} \beta_i T_i + \sum_{i=1}^{2} \delta_i C_i + \varepsilon_i \quad (1)$$

where Δy_i are the outcomes of interest differences between 2014 and 2016 (defined further below), T_i are the different treatments (groups T_1- T_3 as defined above) and C_i are the control farmers (groups C1 - C2 as defined above). Parameters $\alpha_0, \beta_i, \delta_i$ are estimated with β_i being the main parameters of interest.

We estimate the effect of the treatments on maize yields and fertilizer use overall (on all plots) as well as the effect on only their main maize plots. Because approximately 5% of farmers defined their main maize plots in 2016 differently than they had in 2014, we estimate the effect of whether farmers changed practices on their main maize plots as defined both in 2014 and 2016.

5. Descriptives

Table 2 shows that treatment and control households are mostly balanced among the treatment groups, except for the following variables: whether the household is headed by a female, the size of the 2014 main maize plot, and whether the main maize plot soils are deficient in phosphorus and potassium. While these differences are statistically significant, they are not economically or agronomically significant, thereby concluding that the randomization was successful.

6. Results

6.1 Fertilizer Use

Table 3 shows the first treatment effects estimation analyzing effects on farmers' per acre fertilizer use across all farm plots (Column 1), on maize (2) and on crops other than maize (3). Farmers receiving recommendations and vouchers increased their fertilizer use by approximately 10.1 kg/acre on maize and farmers receiving only vouchers increased their use by approximately 4.4 kg/acre on maize, a significant increase from 0.147 kg/acre applied at the baseline mean. Farmers who only received recommendations, however, did not significantly change their fertilizer use during the 2016 season (Row 1). Farmers seem to have concentrated the applications onto maize; point estimates are smaller for the treatment effects on per acre fertilizer use across all plots (Column 1) and we see no effects on application to non-maize crops (Column 4).

Treatment effects on fertilizer application are stronger when we focus on farmers' main maize plots; these are the plots whose soils were tested and which the recommendations reference. Table 4 shows the effects on fertilizer use on farmers' 2014 main maize plot.[7] Our analysis shows that farmers with multiple maize plots concentrated application on their main maize plot. In other words, fertilizer use did not significantly increase on maize plots other than farmers' main maize plots.

6.2 Spillover effects

Control farmers in treatment villages could benefit from the information or resources neighboring farmers received. Indeed, there is evidence of information sharing and learning from neighbors (Conley and Udry). To test for spillover effects of information and resources (fertilizers and/or cash) provided to farmers who did not receive any soil recommendations or vouchers but who lived in villages where other farmers did receive these treatments, we estimate equation (1) but control for farmers found in control villages. Table 5 presents results from specifications in which we test for differences in outcomes between farmers in control villages and control farmers in treatment villages. Results from these specifications show that there is no significant difference among control farmers in treatment or control villages, i.e., we find no evidence of near-term spillovers in information or resources. For this reason, tables 3 and 4 and all subsequent tables group control farmers together, whether they were in treatment or control villages.

6.3 Site specific soil recommendations

We have a special interest in the value of the information; that is, does information about plot-specific nutrient limitations lead farmers to invest in fertilizers relevant to their plots rather than just purchasing urea? What is the value of the soil information on the type of fertilizer that farmers purchase and apply? Can information help close plot-specific soil nutrient deficiencies? Farmers received plot-specific recommendations about their particular nutrient limitations but could choose among a range of fertilizers for purchase and application. Does the content of the information received matter or do recommendations solely serve as reminders to farmers to apply government-recommended fertilizers? We answer these questions by studying farmer purchase and application of ammonium sulfate (SA). Sulfur is widely deficient in the region's soils; 95% of soils in our sample were found to be below critical levels of sulfur. However, sulfur is not included in the fertilizers recommended by the government in this region.

Table 6 shows that farmers who received vouchers and recommendations applied on average approximately 2.3 kg/acre of SA on their 2016 main maize plots (since no farmers applied any SA in 2014). These results indicate that farmers are in fact responding to the information given and that the recommendations given do not just act as reminders to apply any fertilizer.

6.4 Yields

Of particular interest is testing whether the increase in use of fertilizers affected total yields. All survey rounds took place at the end of the harvest season in August 2014, 2015 and 2016. We asked farmers to report total maize harvested from the entire farm and total maize harvested from their main maize plot. Self-reported yields are notoriously noisy, though we

[7] 95% of farmers did not change their primary maize plot between 2014 and 2016. Table A4 in the appendix runs the same analysis as Table 7 but accounts for farmers who reported having changed their main maize plot between 2014 and 2016.

nonetheless report the estimations here, in Table 7. We find that yields increased on main maize plots for farmers receiving recommendations and vouchers and vouchers only. Consistent with the result on differential treatment impacts on fertilizer application, maize yields in the recommendations and voucher group were higher than in the voucher only group: an increase of 173-175 kg/acre and 100-103 kg/acre, respectively, up from 431 kg/acre at the baseline mean. These results are not robust to the cross-sectional estimation, however (the last two columns of table 7).

7. Explaining the results

7.1 Soil analysis results

The soil lab analysis results in table 8 show that the soils in Morogoro are broadly deficient in several nutrients: simultaneous deficiency in both nitrogen and sulfur is most common (NS limited), with 63.5% of farmers in our sample being in this category. Government fertilizer recommendations for the region recommend urea and DAP, tailored to address deficiencies in nitrogen and phosphorus (NP limited). Yet, interestingly, nitrogen and phosphorus together are seldom limiting for farmers in our sample, with only 0.7% of farmers showing deficiencies in these two nutrients alone.

Given the high rate of farmers being NS limited, we are interested in knowing to what degree soil management recommendations are spatially correlated. Could soil sampling be carried out at the village level or district level in lieu of farmer specific plots? To begin examining these questions, we look at the proportion of farmers who share the same recommendation as their nearest main neighbor that also participated in the study. We find that 55.3% of farmers share the same fertilizer recommendation as their nearest neighbor. That share does not vary much with the 2nd to 5th nearest neighbor: 57.7% (57.1%) (54.6%) (55.3%) of farmers share the same fertilizer recommendation as their 2nd (3rd) (4th) (5th) nearest neighbor.

7.2 Fertilizer Purchases

With a single exception, only farmers receiving vouchers purchased fertilizer from the designated agro-input dealer (Table 9). No farmers in the information-only group purchased any fertilizer or seed from the agro-input dealers who visited the village. A total of 64 farmers reported supplementing their input purchases from the project input dealer with fertilizer purchased from nearby suppliers or Morogoro.

Table 10 shows that farmers who received information and a voucher (T_3) purchased approximately 26 kg urea and 12.5 kg SA. Three farmers requested cash and purchased no inputs, while 183 farmers received the remainder of the value of their voucher in cash at 21,807 Tz Shillings, on average.

Farmers who received only a voucher without information (T_1) purchased on average 8.7 kg urea, 0.9 kg SA, 0.13 kg DAP and 0.04 kg seeds. The majority of farmers in T_1 – 121 out of 198 farmers – redeemed the voucher for cash at a value of 68,000 TZ Shillings.

In total, 238 farmers purchased some quantity of fertilizer from the agro-dealer. Of those who purchased fertilizer, 79% applied some mineral fertilizer on their 2014 main maize plot while the others did not. Of the 746 who did not purchase fertilizer from the agro dealer, 51 or approximately 7% still reported applying fertilizer.

7.3 Organic fertilizer application

We also examine whether the different treatments affect the application of organic fertilizer application on maize. Table 11 shows that farmers receiving vouchers did apply more organic fertilizers such as manure or compost on maize on their farms and main maize plots. (Why might this be??? Or do we omit this result?)

7.4 Fertilizer application and underlying soil type

We also examine whether fertilizer application and yields vary with farmers' underlying soil deficiencies. In table 12, we see that farmers who received recommendations and vouchers with S (P)-limited soils applied 11.6 (8.3) kg/acre more fertilizer yielding an increase of 191.6 (72.5) kg/acre.

7.5 Yields & production function

To study the effect of the information given to farmers relative to the standard, regional fertilizer recommendations for Morogoro, we estimate a production function to quantify the effect of ammonium sulfate on yields. We estimate the production function using two stage least squares, and we use the assignment to the recommendations and voucher treatment and voucher only treatment as instrumental variables for those farmers who applied any SA (information plus voucher) and those farmers who only applied urea (voucher only). We estimate:

$$y_i = \alpha_0 + \beta_0 \hat{f}_i + \boldsymbol{\Gamma_0' X_i} + \varepsilon_i \quad (2)$$
$$\hat{f}_i = \alpha_1 + \Gamma_1' X_i + \Lambda' Z_i + \nu_i \quad (3)$$

where y_i are farmer-reported log yields per acre, f_i are dummy variables indicating whether farmers applied specific fertilizers SA or urea only, and X is a matrix of controls including rainfall, pH, total acres farmed, whether the farmer applied improved seeds or organic fertilizers, and household characteristics. We use the assignment to treatment group recommendations and voucher and voucher only as instrumental variables for those farmers who applied any SA and those farmers who only applied urea, Z_i, in equation 3. Unobserved factors are represented by ε_i and ν_i.

Table 13 shows the results from the production function estimation (the first stage results for column 1 are shown in Appendix 6, Table A2). Farmers who applied any SA increased yields by approximately 450-500%. Farmers who only applied urea, did not have statistically higher yields. Results make agronomic sense: rainfall in February and March – the months around planting – increase yields, while soils with a pH above 6 decrease yields. Farmers with more acres of maize had lower yields, as did farmers in the lower wealth tiers, as estimated by an asset index.

8. Robustness

We test the robustness of the effects by estimating the cross-sectional effects of the treatments on 2016 outcomes. Tables 15 and 16 show the cross-sectional results: fertilizer application on farmers' main maize plot defined in 2014 and 2016, respectively. The results are slightly higher and more statistically significant than the panel estimation, but quantitatively similar.

The total number of observations varies across tables 3-12. Not all variables were recorded for each household, either because the household refused to answer or because we lost a household to attrition. We repeated the analysis in tables 3-12 using the set of observations that contained all variables and found the results consistent with those reported here (available from the corresponding author by request).

9. Discussion

The preceding analysis has shown that farmers who received both recommendations and a voucher increased their use of fertilizers and they increased their use by a factor that was more than two times the increase among those who received vouchers only. Moreover, farmers who only received recommendations did not increase their purchase or use of fertilizers. Increases in fertilizer use led to strong maize yield increases, especially for farmers who purchased fertilizers specific to their plot's nutrient deficiencies.

Results indicate that while site-specific fertilizer recommendations are useful to farmers, financial constraints limit farmers from making such input investments. Two primary mechanisms that may help explain why farmers choose not to invest in inputs without subsidization: the profitability of maize and the uncertainty surrounding fertilizer use.

Before the treatment in 2015 we elicited farmer's expected yield increase from applying 25 kg of fertilizer on their main maize plot in three hypothetical seasons: a bad season, a good season and an average season. The difference between a farmer's expected yields in a bad season versus an average season is approximately three-fold. Farmers expect yields to double in a good season (see table X). These expected returns on yields are slightly lower than the returns observed in this study. For an average application of 4.6 kg (table 3), farmers obtain approximately 100 kg in return (table 13), or approximately a 500 kg increase in yields for 25 kg of fertilizer.

Regardless of the quality of the season, we find that on average, farmers expected the addition of 25 kg of fertilizer to their main maize plot would lead to an increase in approximately 300 - 400 kg of maize, see Figure 2.

Given the range of maize prices observed in 2014 and 2016 (table 18), an expected increase of 300 kg would be worth 105,000 TZ Sh in 2014 and 135,000 TZ Sh in 2016 given the median prices. Given the cost of 25 kg of urea was 35,000 TZ Sh in 2016, applying fertilizer would seem profitable. However, these back-of-the-envelope calculations fail to account for the wide variation in both expected and realized yields from applying fertilizer as well as the highly varying prices at which farmers sell maize. Furthermore, this estimation does not account for the transaction costs associated with procuring fertilizer nor the possible variation in fertilizer quality. As shown in the production function estimation, the application of SA in addition to urea leads to a particularly strong increase in yields for these farmers. So while on average the application of fertilizer does appear profitable, the uncertainty in expected yield gains and maize prices likely are a major impediment to farmer investments of inputs like fertilizer.

10. Conclusion

In this study, we have found that site-specific soil fertilizer management recommendations have the potential to increase yields by addressing heterogeneous soil nutrient deficiencies. However, farmers only act on the information and purchase fertilizers if they received a fertilizer voucher/subsidy. In other words, farmers who only received recommendations did not act on the information.

Further work needs to be undertaken to understand what specific factors deter farmers from making the decision to invest in fertilizers. Do farmers lack the resources to do so? Or does the high uncertainty in maize prices, the cost of fertilizer and the unpredictability of rainfall deter farmers? The findings of this study suggest that combining fertilizer subsidy programs with soil testing has the potential to increase the returns to fertilizer use.

11. References

Chapoto A, Kabaghe C, Jayne T, Mason N Burke W and Shipekesa A (2011). "Mountains of maize, persistent poverty". *Food Security Research Project*: Michigan State University.

Chibwana C, Fisher M and Shively G (2012). "Cropland allocation effects of agricultural input subsidies in Malawi". *World Development* 40(1): 124-133.

Denning G, Kabambe P, Sanchez P, Malik A, Flor R, Harawa R, Nkhoma P, Zamba C, Banda C, Magombo C, Keating M, Wangila J and Sachs J (2009). "Input subsidies to improve smallholder maize productivity in Malawi: toward an African Green Revolution" *Plos Biology* 7(1): 1-9.

Dercon S and Christiaensen L (2011). "Consumption risk, technology adoption and poverty traps: evidence from Ethiopia." *Journal of Development Economics* 96(2): 159-173.

Dorward, A., and E. Chirwa. 2011. "The Malawi Agricultural Input Subsidy Programme: 2005/06 to 2008/09". *International Journal of Agricultural Sustainability* 9:1:232-247.

Duflo E, Kremer M and Robinson J (2008). "How high are rates of return to fertilizer? Evidence from field experiments in Kenya". *American Economic Review* 98(2): 482-488.

Duflo E, Kremer M and Robinson J (2011). "Nudging Farmers to Use Fertilizer: Theory and Experimental Evidence from Kenya", *American Economic Review* 101(6): 2350-2390.

Fabregas R, Kremer M, Robinson J and Schilbach F (2013). "The Market for local agricultural information." Columbia University Development Economics Seminar, December 10, 2013.

Folberth C, Yang H, Gaiser T, Abbaspour K and Schulin R (2013). "Modeling maize yield responses to improvement in nutrient, water and cultivar inputs in sub-Saharan Africa." *Agricultural Systems* 119: 22-34.

Foltz J, Aldana U and Laris P (2011). "The Sahel's Silent Maize Revolution: Analyzing Maize Productivity in Mali at the farm-level". *NBER Working Paper*.

Gregory D and Bumb B (2006). "Factors Affecting Supply of Fertilizer in sub-Saharan Africa." World Bank Discussion Paper No. 25.

Holden and Lunduka (2012). "Do fertilizer subsidies crowd out organic manures? The case of Malawi." *Agricultural Economics* 43: 303-314.

IFDC (International Fertilizer Development Center), 2006. IFDC Report 31, 1.

Jayne T, Mather D, Mason N, Ricker-Gilbert J (2013). "How do fertilizer subsidy programs affect total fertilizer use in sub-Saharan Africa? Crowding out, diversion, and benefit/cost assessments." *Agricultural Economics* 44(6): 687-703.

Jayne T and Rashid S (2013). "Input subsidy programs in sub-Saharan Africa: a synthesis of recent evidence." *Agricultural Economics* 44(6): 547-562.

Kelly V, Crawford E and Ricker-Gilbert J. (2011). "The New Generation of African Fertilizer Subsidies: Panacea or Pandora's Box?" *USAID and MSU Policy Synthesis Paper.*

Kihara J., Huising J., Nziguheba G., Waswa B.S., Njorogeg S., Kabambe V., Iwuafor E., Kibunja C., Esilaba A.O., Coulibaly A. (2016) "Maize response to macronutrients and potential for profitability in sub-Saharan Africa"

Marenya P and Barrett C (2009a). "State-conditional fertilizer yield response on Western Kenyan Farms". *American Journal of Agricultural Economics* 92(4): 991-1006.

Marenya P and Barrett C (2009b). "Soil quality and fertilizer use rates among smallholder farmers in western Kenya". *Agricultural Economics* 40(5): 561-572.

Morris, M., V.A. Kelly, R.J. Kopicki and D. Byerlee. 2007. *Fertilizer Use in African Agriculture: Lessons Learned and Good Practice Guidelines.* Washington: World Bank.

Nakasone E, Torero M and Mintent B (2013). "The power of information: the ICT revolution in agricultural development." Working paper.

Nziguheba, G., Palm, C. A., Berhe, T., Denning, G., Dicko, A., Diouf, O., et al. (2010). *The African Green Revolution: Results from the Millennium Villages Project.* Rome: FAO.

Paavola J (2008). "Livelihoods, vulnerability and adaptation to climage change in Morogoro, Tanzania." Environmental Science & Policy 11: 642-654.

Poulton, C., J. Kydd, and A. Doward. 2006. "Increasing Fertilizer Use in Africa: What Have We Learned?" Discussion Paper No. 25, Wash- ington DC: World Bank.

Ricker-Gilbert J, Jayne T and Chirwa E (2011). "Subsidies and crowding out: a double-hurdle model of fertilizer demand in Malawi." *American Journal of Agricultural Economics* 93(1) 26-42.

Ricker-Gilbert J, Jayne T and Chirwa E (2011). "Subsidies and crowding out: a double-hurdle model of fertilizer demand in Malawi." *American Journal of Agricultural Economics* 93(1) 26-42.

Sanchez P, Denning G and Nziguheba G (2009). "The African Green Revolution Moves Forward." *Food Security* 1:37–44.

Sanchez P (2002). "Soil Fertility and Hunger in Africa." *Science* 295: 2019-2020.

Sanchez P and Swaminathan M (2005). "Hunger in Africa: The link between unhealthy people and unhealthy soils." *The Lancet* 365: 442-444.

Sirrine D, Shennan C and Sirrine J (2010). "Comparing agroforestry systems' ex ante adoption potential and ex post adoption: on-farm participatory research from southern Malawi." *Agroforestry Systems* 79:253–266.

Suri T (2009). "Selection and Comparative Advantage in Technology Adoption". NBER Working Paper 15346.

Tittonell, P., B. Vanlauwe, M. Corbeels, and K. E. Giller (2008): "Yield gaps, nutrient use efficiencies and response to fertilisers by maize across heterogeneous small- holder farms of western Kenya," *Plant and Soil*, 313, 19–37.

Vanlauwe B, Bationo A, Chianu J, Giller KE, Merckx R, Mokwunye U, Ohiokpehai O, Pypers P, Tabo R, Shepherd K, Smaling E, Woomer PL, Sanginga N (2010). "Integrated soilfertility management: Operational definition and consequences for implementation anddissemination." *Outlook on Agriculture* 39: 17-24.

Zingore S, Murwira H, Delve R, Giller K (2007). "Soil type, management history and current resource allocation: three dimensions regulating variability in crop productivity on African smallholder farms." *Field Crops Research* 101: 296-305.

Figures

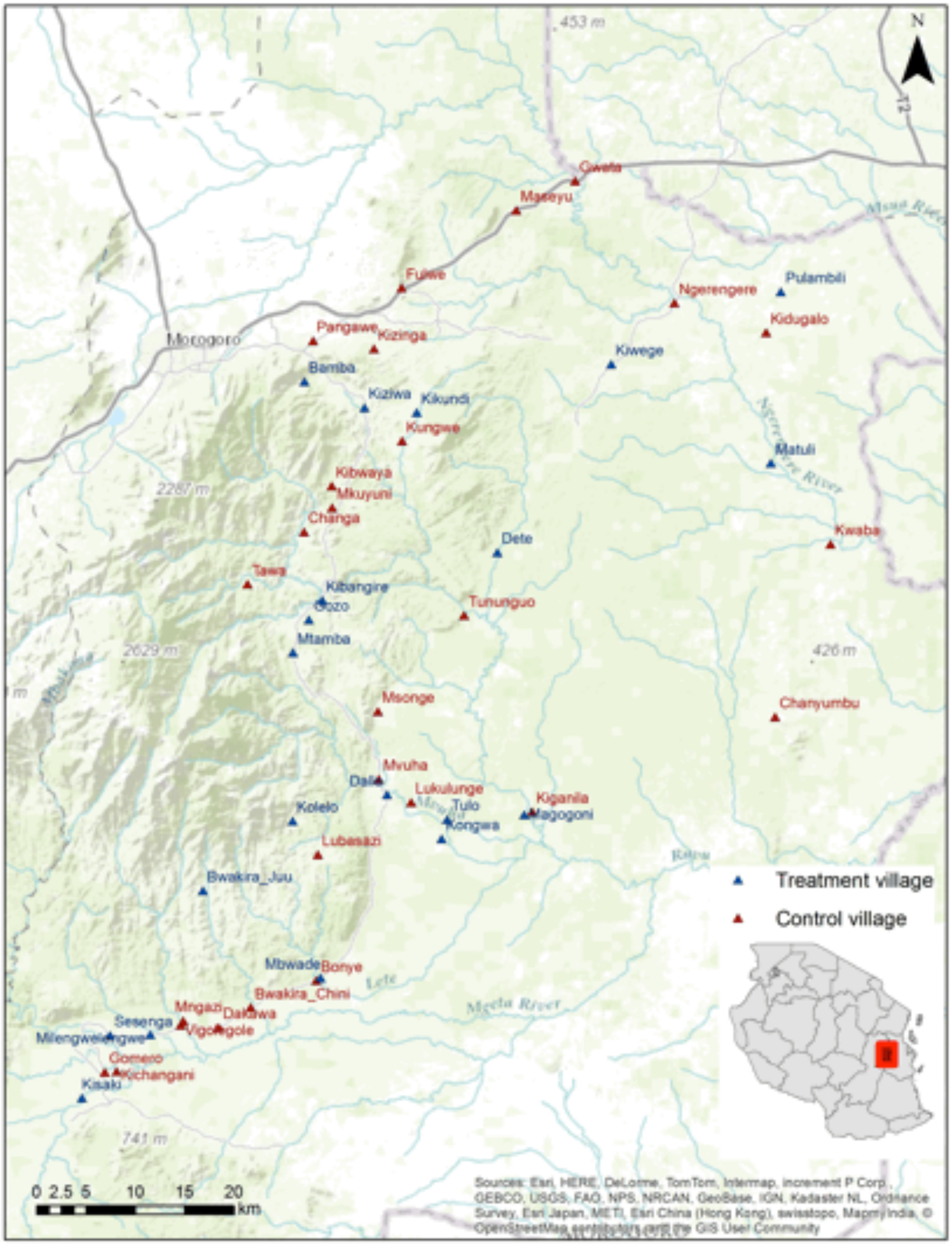


Figure 1. Spatial distribution of the control and treatment fields and villages in Morogoro Rural district

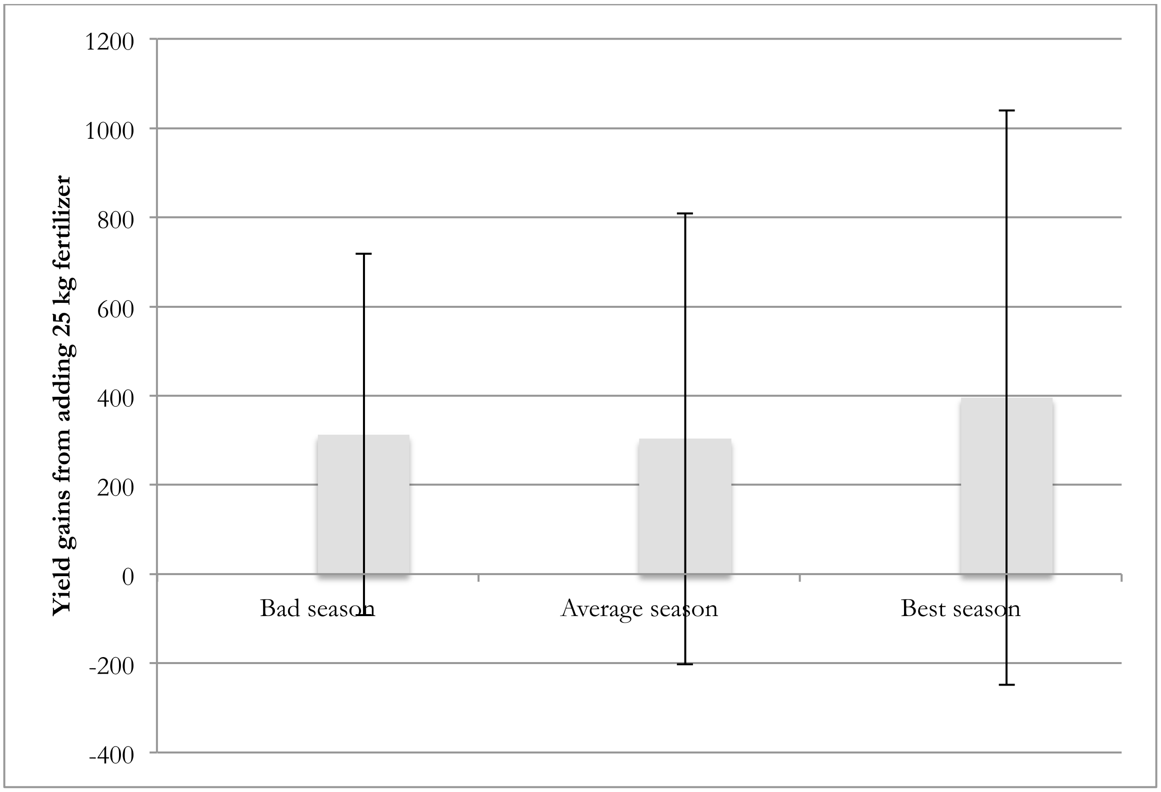


Figure 2. Expected gains from applying 25 kg fertilizer to farmer's main maize plots

Tables

	Baseline Aug. 2014	Soil Analysis Sep. - No. 2014		Second Baseline Aug. 2015		Endline Aug. 2016	
	n	n	%	n	%	n	%
Control	190	181	4.7%	147	22.6%	179	5.8%
Voucher	198	188	5.1%	155	21.7%	187	5.6%
Recommendations	191	188	1.6%	138	27.7%	177	7.3%
Recommendations+voucher	203	198	2.5%	157	22.7%	190	6.4%
Control village	268	252	6.0%	244	9.0%	251	6.3%
Total (n)	1050	1007		841		984	

Table 1. Total number of participating farmers during each round

			Voucher		Recommendations		Recommendations + Voucher		F-test
Baseline covariates	*n*	*sample mean*	*Coeff.*	*p-value*	*Coeff.*	*p-value*	*Coeff.*	*p-value*	*p-value*
Household characteristics									
Completed elementary school	1,050	0.685	0.018	0.651	0.028	0.489	-0.014	0.721	0.801
Dependency ratio	987	1.588	-0.168	0.132	-0.074	0.509	-0.140	0.212	0.397
Household is headed by a female (D)	1,050	0.168	-0.022	0.483	-0.003	0.917	**0.061**	**0.051**	0.121
Household head is close to village chair (D)	1,050	0.314	-0.017	0.663	-0.001	0.986	-0.040	0.312	0.764
Household asset index	1,050	0.000	-0.207	0.219	-0.052	0.762	-0.203	0.226	0.501
Land tenure									
Total land owned (acres) in 2014	1,050	5.214	0.046	0.929	0.234	0.658	-0.289	0.576	0.864
Total acres farmed in 2014	1,050	4.453	0.044	0.908	0.377	0.335	-0.287	0.453	0.547
Share of land under maize cultivation	1,050	0.566	-0.005	0.022	-0.022	0.023	-0.006	0.022	0.33
2014 Input use									
Inorganic fertilizers applied on maize on 2014 MM plot (D = 1, yes)	1,050	0.008	0.004	0.632	0.004	0.601	-0.002	0.825	0.890
Inorganic fertilizers applied on maize on 2014 main maize plot (kg/acre)	1,045	0.148	**0.434**	**0.044**	0.244	0.263	-0.003	0.988	0.170
Inorganic fertilizers applied on maize (all farm) (D = 1, yes)	1,050	0.008	0.004	0.632	0.004	0.601	-0.002	0.825	0.890
Inorganic fertilizers applied on maize on entire farm (kg/acre)	1,050	0.147	**0.431**	**0.044**	0.240	0.268	-0.003	0.988	0.172
Size of 2014 MM plot (acres)	1,050	2.552	-0.142	0.550	**0.453**	**0.060**	-0.082	0.727	0.140
Size of 2014 MM plot cultivated with maize (acres)	1,050	1.949	0.042	0.780	0.171	0.264	-0.131	0.380	0.402
Used maize improved seeds on 2014 MM plot	1,050	0.188	-0.029	0.381	-0.023	0.497	-0.019	0.573	0.800
Yields									
Maize yields on entire farm (kg/acre)	1,050	462.05	34.604	0.342	-9.645	0.794	35.706	0.322	0.567
Maize yields on 2014 MM (kg/acre)	829	430.87	-28.586	0.530	-37.865	0.427	28.524	0.529	0.610
2014 Soil charactersitics									
Soil is phosphorus limited	1,007	0.272	**0.097**	**0.013**	**0.065**	**0.094**	**0.126**	**0.001**	**0.004**
Soil is potassium limited	1,007	0.109	-0.045	0.101	0.008	0.755	0.038	0.156	**0.074**
Soil is sulphur limited	1,007	0.953	-0.011	0.554	-0.032	0.081	-0.009	0.639	0.382

Table 2. Sample balance test

Notes: Columns 3-8 report the coefficients and p-values from OLS regressions of the indicated baseline covariate on each treatment group indicator. Column 9 reports the p-value from a joint test of statistical significance of all treatment indicators.

Table 3: Treatment effects on entire farm fertilizer application

	(1) Kg fertilizer per acre on all farm	(2) Kg fertilizer per acre on maize	(3) Kg fertilizer per acre on crops other than maize
Recommendations (T_1)	-7.137	-13.675	-0.310
	(6.671)	(13.428)	(0.231)
Recommendations + vouchers (T_2)	3.150*	10.125***	-1.880
	(1.568)	(1.451)	(2.686)
Vouchers (T_3)	3.397**	4.434***	0.154
	(1.345)	(1.430)	(0.172)
Constant	0.387***	0.701**	0.006
	(0.134)	(0.281)	(0.068)
Observations	981	981	981
Adjusted R^2	0.005	0.006	-0.001

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4: Treatment effects on 2014 main maize plot fertilizer application

	(1) Kg fertilizer per acre on 2014 main maize plot	(2) Kg fertilizer per acre on maize on 2014 main maize plot	(3) Kg fertilizer per acre on crops other than maize on 2014 main maize plot
Recommendations (T_1)	-14.410	-14.496	0.000
	(14.857)	(14.852)	(0.000)
Recommendations + vouchers (T_2)	7.886**	11.731***	0.233
	(3.627)	(1.888)	(0.232)
Vouchers (T_3)	4.453***	4.635***	0.172
	(1.590)	(1.636)	(0.169)
Constant	0.425**	0.511**	-0.000
	(0.176)	(0.215)	(0.000)
Observations	881	881	881
Adjusted R^2	0.004	0.006	0.000

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5: Spillover effects of fertilizer application on maize plot

	(1) Kg fertilizer per acre on maize	(2) Kg fertilizer per acre on maize	(3) Kg fertilizer per acre on maize on 2014 main maize plot	(4) Kg fertilizer per acre on maize on 2014 main maize plot
Recommendations (T_1)	-15.322	-15.134	-14.492	-14.304
	(15.328)	(15.350)	(14.852)	(14.873)
Recommendations + vouchers (T_2)	10.423***	10.611***	11.735***	11.923***
	(1.541)	(1.510)	(1.888)	(1.862)
Vouchers (T_3)	4.770***	4.958***	4.639***	4.827***
	(1.525)	(1.535)	(1.637)	(1.647)
Control in Trt Villages (D)		0.462		0.462
		(0.478)		(0.478)
Constant	0.507**	0.319	0.507**	0.319
	(0.213)	(0.190)	(0.213)	(0.190)
Observations	884	884	884	884
Adjusted R^2	0.006	0.005	0.006	0.005

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6: Treatment effects on main maize plot of SA application

	(1) 2016 SA kg fertilizer per acre on maize	(2) 2016 SA kg fertilizer per acre on maize on 2016 main maize plot	(3) 2016 SA kg fertilizer per acre on maize on 2014 main maize plot
Recommendations (T_1)	0.034	0.034	0.034
	(0.201)	(0.201)	(0.201)
Recommendations + vouchers (T_2)	2.286***	2.330***	2.256***
	(0.795)	(0.802)	(0.796)
Vouchers (T_3)	0.013	0.013	0.013
	(0.184)	(0.184)	(0.184)
Constant	0.137	0.137	0.137
	(0.096)	(0.096)	(0.096)
Observations	839	839	839
Adjusted R^2	0.045	0.047	0.044

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 7: Yields

	(1) Kg maize yields on entire farm (kg per acre)	(2) Kg maize yields on 2014 MM plot (kg per acre)	(3) Maize yields on 2014/2016 main maize plot	(4) 2016 maize yields on 2014 main maize plot	(5) 2016 maize yields on 2016 main maize plot
Recommendations (T_1)	3.291	3.177	5.450	-25.290	-23.018
	(50.924)	(55.767)	(55.923)	(39.337)	(39.432)
Recommendations + vouchers (T_2)	81.257	173.715***	175.100***	72.962	74.347
	(70.015)	(62.517)	(62.806)	(51.211)	(51.513)
Vouchers (T_3)	-50.629	103.446*	100.770*	-2.517	-5.193
	(64.658)	(59.498)	(59.424)	(45.950)	(45.282)
Constant	-187.013***	-172.797***	-172.128***	296.624***	297.293***
	(38.874)	(42.313)	(42.463)	(33.192)	(33.256)
Observations	716	716	716	716	716
Adjusted R^2	0.003	0.017	0.017	0.003	0.003

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

	Control	Voucher	Recommendations	Recommendations+ voucher	Control villages	Total
N only limited	0.6%	0.6%	1.2%	0.6%	0.6%	3.6%
NP limited	0.1%	0.3%	0.0%	0.1%	0.2%	0.7%
NK limited	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%
NS limited	10.0%	11.6%	11.0%	11.3%	19.5%	63.5%
NPK limited	0.0%	0.0%	0.1%	0.1%	0.0%	0.2%
NPS limited	5.2%	5.0%	4.3%	4.8%	2.2%	21.4%
NKS limited	1.0%	0.6%	1.2%	0.9%	1.9%	5.6%
NPKS limited	1.1%	0.6%	0.9%	1.8%	0.6%	5.0%

Table 8. Farmer nutrient deficiencies per treatment group (% of total soil samples, n= 1,007)

	Voucher (T1)	Recommendation (T2)	Recommendation+voucher (T3)	Control (T4)	Control village (T5)
Urea (D)	5.9%	0.0%	17.8%	0.0%	0.1%
SA (D)	0.7%	0.0%	9.4%	0.0%	0.0%
DAP (D)	0.1%	0.0%	0.0%	0.0%	0.0%

Table 9. Fertilizer purchases reported by agro-input dealer (in % of total farmers in the sample, n = 1,050)

Table 10: Treatment effects on entire farm fertilizer application

	(1) UREA (Kg)	(2) SA (Kg)	(3) DAP (Kg)
Recommendations (T_1)	-0.109	-0.000	0.000
	(0.109)	(.)	(0.000)
Recommendations + vouchers (T_2)	25.827***	12.438***	0.000
	(1.161)	(1.755)	(0.000)
Vouchers (T_3)	8.729***	0.884**	0.126
	(2.046)	(0.373)	(0.125)
Constant	0.109	0.000	-0.000
	(0.109)	(.)	(0.000)
Observations	1050	1050	1050
R^2	0.616	0.390	0.004

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 11: Treatment effects on organic fertilizer use

	Applied any organic fertilizers on maize	Applied any organic fertilizers on maize on 2014 MM plot	Proportion of land on which organic fertilizers were applied on maize	Proportion of land on which organic fertilizers were applied on maize on 2014 MM
Trt: recommendations (D)	-0.007	-0.025	-0.026	-0.036
	(0.055)	(0.053)	(0.055)	(0.053)
Trt: recommendations + vouchers (D)	0.044	0.047	0.054	0.053
	(0.048)	(0.048)	(0.049)	(0.048)
Trt: vouchers (D)	0.160***	0.157***	0.157***	0.156***
	(0.042)	(0.041)	(0.041)	(0.040)
Constant	0.035	0.032	0.023	0.026
	(0.028)	(0.027)	(0.029)	(0.027)
Observations	817	817	817	817

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 12: Treatment effects on fertilizer by Soil Type use

	(1) P-limited: Kg fertilizer per acre on maize on 2014 MM plot	(2) P-limited: Kg maize yields on 2014 MM plot (kg per acre)	(3) S-limited: Kg fertilizer per acre on maize on 2014 MM plot	(4) S-limited: Kg maize yields on 2014 MM plot (kg per acre)
Recommendations (T_1)	0.490	-74.810	1.236	-31.126
	(0.291)	(45.025)	(0.969)	(56.750)
Recommendations + vouchers (T_2)	8.301***	72.545	11.621***	191.562***
	(2.992)	(84.865)	(2.090)	(63.173)
Vouchers (T_3)	4.465**	-35.575	4.608**	133.534**
	(1.914)	(94.083)	(1.767)	(60.939)
Constant	-0.032	-140.093***	0.581**	-183.633***
	(0.032)	(36.157)	(0.233)	(41.472)
Observations	235	185	809	664
R^2	0.091	0.019	0.079	0.032

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 14: Production function (log kg per acre)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Applied SA (1=yes)	4.809**	4.859**	4.947**	4.788**	4.915**	4.410**	4.368**	4.534**
	(2.267)	(2.261)	(2.319)	(2.273)	(2.375)	(2.175)	(2.145)	(2.200)
Applied only urea (1=yes)	-0.933	-1.067	-1.140	-1.095	-1.146	-1.086	-1.074	-1.138
	(0.921)	(0.911)	(0.951)	(0.935)	(1.000)	(0.904)	(0.898)	(0.916)
Cummulated rainfall in Febrary and March (mm)		0.019***	0.017***	0.016***	0.016***	0.016***	0.016***	0.016***
		(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
NPS deficient (1=yes)			0.093	0.109	0.120	0.099	0.096	0.111
			(0.185)	(0.183)	(0.191)	(0.175)	(0.173)	(0.177)
NKS or NPKS deficient (1=yes)			-0.256	-0.282	-0.278	-0.260	-0.254	-0.270
			(0.194)	(0.190)	(0.194)	(0.183)	(0.184)	(0.186)
pH is limiting (1=yes)			-0.481**	-0.442**	-0.430**	-0.408**	-0.403*	-0.381*
			(0.210)	(0.208)	(0.215)	(0.207)	(0.208)	(0.213)
Total acres maize cultivated				-0.107**	-0.108**	-0.171***	-0.172***	-0.176***
				(0.043)	(0.043)	(0.046)	(0.046)	(0.047)
Farmer applied organic fertilizer (1=yes)					0.022	0.036	0.035	0.048
					(0.155)	(0.150)	(0.149)	(0.152)
Farmer applied improved seeds (1=yes)					0.058	-0.022	-0.022	-0.027
					(0.134)	(0.127)	(0.128)	(0.129)
No education (D)						-0.283	-0.287	-0.269
						(0.179)	(0.178)	(0.181)
Dependency ratio						0.024	0.025	0.027
						(0.047)	(0.047)	(0.047)
Household is headed by a female (D)						-0.215	-0.216	-0.225
						(0.168)	(0.169)	(0.172)
Poorest quartile						-0.409**	-0.415**	-0.406**
						(0.164)	(0.162)	(0.165)
2nd quartile						-0.294*	-0.295*	-0.288*
						(0.152)	(0.151)	(0.154)
3rd quartile						-0.051	-0.055	-0.047
						(0.155)	(0.154)	(0.156)
Land owned (acres)						0.012	0.012	0.012
						(0.008)	(0.008)	(0.008)
Household head is close to village chair (D)							-0.067	-0.078
							(0.122)	(0.124)
Household head is the village chair							0.472	0.475
							(1.368)	(1.386)
Farmer categorizes soil quality as poor								-0.301
								(0.234)
Farmer categorizes soil quality as fair								0.030
								(0.122)
Constant	5.318***	1.842**	2.226**	2.594***	2.527***	2.753***	2.791***	2.840***
	(0.082)	(0.864)	(0.901)	(0.895)	(0.915)	(0.893)	(0.888)	(0.901)
Observations	702	702	702	702	702	702	702	702

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 15: Cross-section treatment effects on 2014 main maize plot of fertilizer

	2016 fertilizer per acre (kg/acre) on main maize plot	2016 fertilizer per acre (kg/acre) on maize on 2014 MM plot	2016 fertilizer per acre (kg/acre) on crops other than maize on 2014 MM plot
Trt: recommendations (D)	1.684 (1.124)	1.599 (1.142)	0.000 (0.000)
Trt: recommendations + vouchers (D)	10.703*** (1.726)	11.659*** (1.886)	0.231 (0.231)
Trt: vouchers (D)	4.935*** (1.598)	5.095*** (1.623)	0.171 (0.168)
Constant	0.450** (0.173)	0.536** (0.212)	-0.000 (0.000)
Observations	886	886	886

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 16: Cross-section treatment effects on 2016 main maize plot of fertilizer

	2016 fertilizer per acre (kg/acre) on 2016 main maize plot	2016 fertilizer per acre (kg/acre) on maize on 2016 main maize plot	2016 fertilizer per acre (kg/acre) on crops other than maize on 2016 MM plot
Trt: recommendations (D)	1.427 (1.146)	1.328 (1.158)	-0.000 (.)
Trt: recommendations + vouchers (D)	10.581*** (1.689)	11.894*** (1.793)	0.220 (0.217)
Trt: vouchers (D)	5.221*** (1.589)	5.276*** (1.618)	0.173 (0.170)
Constant	0.707** (0.300)	0.807** (0.308)	0.000 (.)
Observations	895	895	895

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

	Obs	Mean	Std. Dev.	Min	Max
Bad season	925	348	475	0	2,800
Bad season + 25 kg fertilizer	936	657	677	0	3,800
Average season	944	1,185	1,053	100	6,000
Average season + 25 kg fertilizer	944	1,489	1,273	140	7,700
Best season	945	1,922	1,730	160	9,800
Best season + 25 kg fertilizer	944	2,319	1,929	180	11,200

Table 17. Farmer subjective expectation of yields and fertilizer use on main maize plot

	Obs	Mean	Median	Std. Dev.	Min	Max
2014 maize price per kg	191	462	350	751	75	6,750
2016 maize price per kg	93	478	450	316	64	3,125

Table 18. Maize prices at which farmers sold to traders or others in 2014 and 2016

Appendix 1

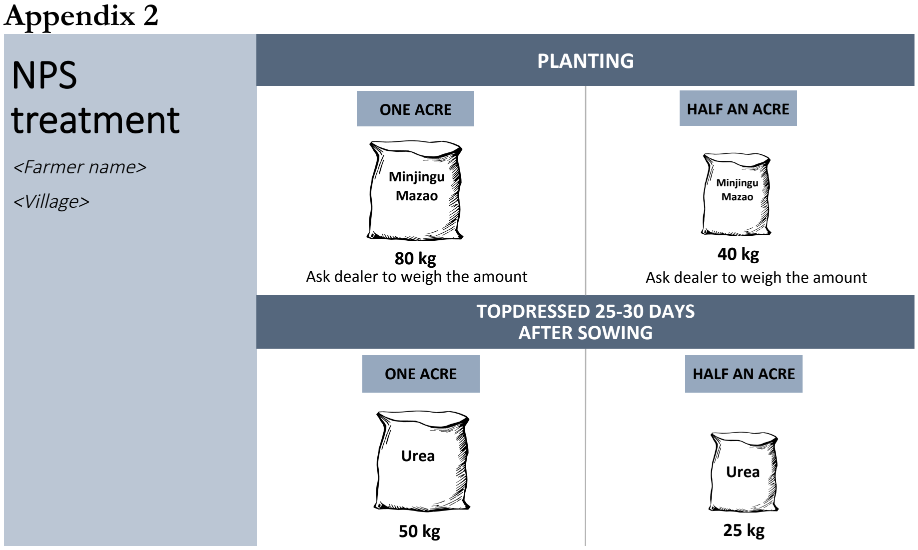
SoilDoc

A team of researchers and collaborators at Columbia University's Agriculture and Food Security Center has worked to address this gap by developing a lab-in-a-box, a rapid on-farm soil diagnostic kit. The kit combines in-field measurements of essential soil physical and chemical parameters with information communications technology (ICT) to provide farm-specific management recommendations. The tool, also known as SoilDoc, has been validated and calibrated with standard wet chemistry procedures.

SoilDoc is a portable, on–farm soil testing kit coupled with an android system that provides farmer tailored soil and crop management recommendations including inorganic and organic inputs and soil conservation practices. Recommendations are provided in near real time. In addition to measuring soil fertility parameters including soil pH, biologically active soil organic matter, electrical conductivity (indicative of general fertility as well as salinity issues) and extractable macronutrients nitrate-N, sulfate-S, phosphate-P, and potassium-K, the kit also has the capacity to test certain nutrients in the sap of growing crops, e.g., nitrogen, phosphorus, sulfur and potassium.

Trained extension workers can assess these various soil constraints in-situ with farmers' participation, they can then make recommendations based on their expertise and can also transmit the field results with an android phone or tablet to a central operating system that will send soil management recommendations based on the results. The results are sent via SMS and are communicated to farmers in near real time. This way, farmers are advised on which nutrients to apply on their fields or which other soil management practices are needed to address the soil constraints. SoilDoc uses state-of-the-art battery-powered instruments similar to those used in wet-chemistry labs. Current results from SoilDoc correlate highly with laboratory methods.

Appendix 2



Recommendation for a farmer deficient in N, P and S (English).

Appendix 3

FERTILIZER VOUCHER

VALUE: 80,000 TZS

This voucher can be used to do ONE of the following:

- **Purchase fertilizers only**
  You may redeem this voucher to purchase any type of fertilizer (Urea, AS, DAP, MOP, SOP, Yara Mila Tobacco, and Minjingu Mazao) worth up to **80,000** TZS. Spending **80,000** TZS does not require any contribution of cash from you. You can contribute your own money to increase the amount bought if you wish.
- **Receive cash only**
  You may redeem this voucher for 68,000 TZS cash.
- **Purchase fertilizers and receive cash**
  You may decide to only use part of this voucher to purchase fertilizers and then receive 85% of the balance remaining on the voucher as cash.

<<Dealer>> will be in your village during the month of December 2015 or January 2016 to deliver inputs. Your village extension worker will contact you with the exact delivery date. Failure to be present during this date will render this voucher void. If you are not the recipient printed on this voucher, you *must* present the National ID Card of the recipient printed on this voucher in order to receive fertilizers. This voucher must be submitted to the <<dealer>> to receive the requested fertilizers.

RECIPIENT:
Name: <<Respondent name>> ID Number: <<Respondent ID>> Village:__________

REDEEMED:
Date: __________________ Recipient Signature:______________

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If <<dealer>> runs out of fertilizer supply, <<dealer>> is required to return to your village within 1 day of the original delivery date

Appendix 4

FERTILIZER INFORMATION CARD

This **information card** is to inform you that <<dealer>> will be in your village during the month of December 2015 or January 2016 to deliver fertilizers. The available fertilizers include Urea, AS, DAP, MOP, SOP, Yara Mila Tobacco, and Minjingu Mazao. Your village extension worker will contact you with the exact delivery date.

Please note that this information card does not have monetary value but *must* be presented to <<dealer>> to receive requested fertilizers If you are not the recipient printed on this information card, you *must* present the National ID Card of the recipient printed on this information card in order to receive fertilizers.

RECIPIENT:

Name: <<Respondent name>> ID Number: <<Respondent ID>> Village: <<Treatment village>> Date presented: _______

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If <<dealer>> runs out of fertilizer supply, <<dealer>> is required to return to your village within 1 day of the original delivery date

Appendix 5

Table A1: Treatment effects on maize, not on main maize plot

	Fertilizer per acre (kg/acre) on maize crop NOT on MM plot
Trt: recommendations (D)	-0.831
	(0.562)
Trt: recommendations + vouchers (D)	-1.385
	(0.950)
Trt: vouchers (D)	-0.158
	(0.115)
Constant	-0.000
	(.)
Observations	890

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Appendix 6

Table A2: First stage

	Applied SA (1=yes)	Applied only urea (1=yes)
Trt: recomendations + vouchers (D)	0.094***	0.214***
	(0.015)	(0.028)
Trt: vouchers (D)	0.000	0.153***
	(0.015)	(0.029)
Constant	0.007	0.030**
	(0.007)	(0.014)
Observations	702	702

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$