Pre-analysis Plan for The Impact of Site Specific Soil Fertility Recommendations: Experimental Evidence from Malawi

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September 12, 2024

Abstract

Raising agricultural productivity among smallholder farmers in Sub-Saharan Africa is widely recognized as an important component of inclusive wealth creation and structural transformation. Central to this endeavor will be the adoption of sustainable soil and land management to improve the sustainability, resilience and productivity of agriculture. As such, government advise farmers to increase soil productivity by embracing the use of fertilizers and implement proper soil health management practices. However, these recommendations mostly come in the form of blanket one-size-fits-all recommendations that ignore heterogeneity in soil characteristics that individual farmers face. Using a cluster randomize control trial, we evaluate the impact of a bundled intervention that involves offering farmers a soil test on a plot they select and, using the results of this soil test, provide them with tailored advise on soil management to attain a desired yield for a particular crop the farmer chooses to plant on the plot. Furthermore, we also explore resources constraints as a potential barrier to the adoption of site specific fertilizer blends by adding a subsidy.

keywords: inorganic fertilizer, soil test, decision support tools, agricultural extension, fertilizer subsidies.

O33, Q12,Q16

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1 Introduction

Raising agricultural productivity among smallholder farmers in Sub-Saharan Africa is widely recognized as an important component of inclusive wealth creation and structural transformation. Central to this endeavor will be the adoption of sustainable soil and land management to improve the sustainability, resilience and productivity of agriculture. The USAID Bureau for Resilience and Food Security (RFS) has led a partnership with the International Fertilizer Development Center (IFDC) and other partners to build a low-cost "Space to Place" (S2P) approach for developing and disseminating localized fertilizer guidance. The S2P approach revolves around the delivery of spatially appropriate soil fertility management recommendations, guided by digitized soil maps (Space) combined with farm(er)-level characteristics (Place), for effective agronomic and fertilizer recommendations that increase fertilizer use efficiency to maintain or surpass current productivity levels, and reduce fertilizer wastage.

IFPRI was tasked in 2023 to do a rigorous impact evaluation of the S2P approach. However, at the start of the project if quickly became clear that the S2P application was not going to be ready in the first operational year of the evaluation (during the 2024/25 growing season). A full and rigorous evaluation of the S2P approach was therefore deferred to the 2025/26 growing seasons and beyond. As such, we decided that the 2024/25 growing season could be used to generate learning to inform S2P's theory of change.

Building on recent rigorous impact evaluations, we decided to evaluate the impact of a bundled intervention that involves offering farmers a soil test on a plot they select and, using the results of this soil test, providing them with tailored advise on soil management to attain a desired yield for a particular crop the farmer chooses to plant on the plot. Furthermore, we also explore resources constraints as a potential barrier to the adoption of site specific fertilizer blends by adding a subsidy.

2 Motivation

Governments in developing countries are trying to increase adoption of Green Revolution technologies, seed of improved varieties and mineral fertilizer in particular, through agricultural extension advice. In general, these extension systems provide blanket recommendations. One important reason why farmers fail to adopt seemingly profitable yield improving technologies is heterogeneity in the farmer's ability and context. For instance, high transacting costs may make a technology unprofitable for a farmer even though on average the technology would be profitable (Suri, 2011). A similar argument can be made for soil—another key production factor in agricultural production (Arouna et al., 2021). Also here, differences in soil composition and nutrient content may mean that blanket fertilizer recommendations are sub-optimal.

Information and Communication Technologies (ICTs) provide an opportunity to deliver advisory services that are more tailored to the specific needs of farmers (Spielman et al., 2021). Numerous Site Specific Nutrient Management (SSNM) Decision Support Tools (DST) have been developed with the promise to reduce inefficiencies coming from grossly simplified recommendations, thereby raising the productivity and profitability from adopting improved inputs (Arouna et al., 2021).

However, decision support tools for tailored nutrient recommendations have generally fallen short of expectations. This is illustrated by the numerous apps and tools that are out there but fail to scale (Sida et al., 2023). Some of the reasons why such tools do not have more impact may be related to the following open questions:

- the issue of spatial resolution, or how site specific these tools really are. Many of the tools rely on models that predict soil composition and nutrients in fairly large areas. As such, it has been argued that, often, "...the numerous laboratory services and digital applications providing field-specific recommendations appear to promise more accuracy than soil analysis can realistically deliver" (Schut and Giller, 2020).

- just providing information: many of the apps implicitly assume that just providing farmers with information is sufficient for farmers to change behavior. An extension component, with a human intermediary, is missing.

- decision support tools often take a host of pre-conditions for granted, the most critical probably being the fact that the recommended blend of soil macro- and micro nutrients is available to the farmer at reasonable cost. Indeed, as we will see below, most RCTs that study the effectiveness of DSTs have at least one treatment arm that investigates the importance of a particular pre-condition (such as access to insurance, financial resources, or information).

3 Related literature

Recently, various studies have been done on site specific nutrient management recommendations. Below, we review some of the most relevant studies.

Beg, Islam, and Rahman (2024) is one of the few studies that has a treatment arm with a soil test (which is similar to one of the treatment arms in our study, see below). In particular, using rice farmers in Bangladesh as a case, they compare two types of site-specific fertilizer recommendations—community-level recommendations and plot-specific recommendations based on individual soil tests—and compare this to government provided recommendations. They find limited effects, except perhaps for a reduction in application error (difference between recommended quantity of a particular nutrient and quantity used). That is, some farmers were using more than the recommended TSP and as a result of the intervention cut back. Some even appear to over-react and stop using TSP altogether, leading to lower yield. They also find indications that farmers adapt seed use to match baseline fertilizer use. Another study with a soil test treatment are is Gars, Kishore, and Ward (2022), which shows that plot-level soil testing and tailored input recommendations changed farmers' fertilizer usage and increased the adoption of recommended practices, leading to improved yields.

Arouna et al. (2021) evaluate the effectiveness of a mobile application that provides personalized advice on rice nutrient management in Nigeria. In particular, they evaluate RiceAdvice, an Android-based application to provide personalized recommendations on nutrient management (type, quantity, and timing of fertilizer) in rice production. They find that the intervention increases yields by 7 percent. No soil tests are done. They also have a treatment that combines personalized advice with a grant that provides the recommended level of fertilizer. Here they estimate a treatment effect of 20 percent. They also found a 10% increase from the intervention on profit which increased to 23% when the intervention is combined with the grant. The mechanism behind the increase in yield and profitability seems to be a reallocation in the fertilizer mix, with farmers using less NPK and more Urea.

Ayalew, Chamberlin, and Newman (2022) evaluate the impact of targeted site-specific fertilizer blend recommendations to Ethiopian smallholder farmers on fertilizer usage, farm productivity, profits from maize production, and household welfare using a cluster randomized control trial. They also have a treatment arm that adds insurance to the recommendation. They find significant reduction of the application error, which in turn affects yields. In particular, they report a 13 percent increase in yield (437 on baseline yield of 3250 kg/ha) and a very similar increase in farmer profit.

Oyinbo et al. (2022) study maize in Nigeria. They study the impact of Site Specific Soil Nutrient Management extension advice through the Nutrient Expert tool. They have two treatment arms and one business-as-usual blanket recommendations control. T1 farmers who are exposed to SSNM information interventions on nutrient application rates and fertilizer management, and T2 farmers who are exposed to the same SSNM information and additional information on the variability of expected returns to fertilizer investment under different price scenarios. They find modest effects on yields and profits. See also Maertens et al. (2023).

4 Research Questions

Our research aims to look at a prototype S2P intervention, as well as assess the relative importance of two of the key components. It will also investigate the role of resources constraints as a potential enabling factor and look into peer learning. In particular, we will answer the following research questions:

1. Does the provision of site-specific soil nutrient information derived from a soil test and the recommendation of a specific fertilizer blend based on this information change outcomes of interest?

2. Does the provision of site-specific nutrient recommendations combined

with a subsidy to buy these nutrients at a local agro-dealer, change the outcomes of interest? This research question looks at the importance of cash/credit constraints in the effectiveness of S2P.

5 Treatment Protocols

In the first treatment, a random sample of farmers is visited by an enumerator accompanied by an agronaut and is offered the opportunity for a soil on a plot chosen by the farmer. The farmer is also asked what crop the farmer plans to cultivate on this plot, as well as the target yield that the farmer would like to get from the crop on that plot. This information is registered in a CAPI app, and an appointment is made at a later date when the farmer will visit the farmer to go the the plot and take the soil sample. The soil sample is then analyzed, which results in a soil report (see example in Appendix 1) that is provided to the farmer. The report indicates the soil's texture, pH level, cation exchange capacity, percentage organic matter, total nitrogen, carbon to nitrogen ratio, as well as the parts per million of available P, exchangeable K, calcium, magnesium, iron, manganese, boron, copper and zinc. Beyond the exact measurements each soil property is given a score on a 4-point Likert scale (very low, low, high, very high), with emojis, color coding and bar charts indicating where the soil is deficient and where the levels are sound. An extension worker (agronout) then discusses the soil report with the farmer to derive a recommended nutrient package specific to the crop the farmer wants to grow. The farmer is then informed where and how to obtain these nutrients (in the form of a particular fertilizer blend).

The second treatment consists of a subsidy that the farmer receives in the from of a voucher that can be redeemed at a nearby Farmer World agro-input shop. The subsidy is tied to T1 in that it will be specific for the recommended fertilizer blend. The value of the subsidy will be model on Malawi's Agricultural Input Program (AIP) which allows farmers to buy one bag of fertilizer at a reduced rate (30 percent of full price). In particular, our subsidy will be equal to 70 percent of the AIP fertilizer bag value minus the cost of the soil test. This will allow us to directly compare our bundle as an alternative to Malawi's AIP.

The study employs a randomized controlled trial (RCT) design involving 113 villages across four districts in Malawi (Lilongwe, Dowa, Ntchisi, and Mchinji). The villages are randomly assigned to one of three groups.

- The first group, Treatment 1 (T1), in this group receive a soil report based on a soil test conducted on a plot chosen by the farmer. This report includes key characteristics of the soil, along with a customized recommendation for a fertilizer blend tailored to the specific crop selected by the farmer.
- The second group, Treatment 2 (T2), builds on the T1 intervention by examining the importance of relaxing resource constraints as an enabling

factor. In addition to receiving the soil report and fertilizer recommendation as in T1, farmers in this group also receive a discount voucher to purchase the recommended fertilizer blend from a local agro-dealer.

- The third group serves as the control (C) and provides the counterfactual for comparison. Farmers in this group receive a soil test, but instead of a site-specific fertilizer recommendation, they are provided with a blanket fertilizer recommendation that does not account for the specific conditions of their plots.

In the first treatment, a random sample of farmers is visited by an enumerator accompanied by an agronaut and is offered the opportunity for a soil on a plot chosen by the farmer. The farmer is also asked what crop the farmer plans to cultivate on this plot, as well as the target yield that the farmer would like to get from the crop on that plot. This information is registered in a CAPI app, and an appointment is made at a later date when the farmer will visit the farmer to go the the plot and take the soil sample. The soil sample is then analyzed, which results in a soil report (see example in Appendix 1) that is provided to the farmer. The report indicates the soil's texture, pH level, cation exchange capacity, percentage organic matter, total nitrogen, carbon to nitrogen ratio, as well as the parts per million of available P, exchangeable K, calcium, magnesium, iron, manganese, boron, copper and zinc. Beyond the exact measurements each soil property is given a score on a 4-point Likert scale (very low, low, high, very high), with emojis, color coding and bar charts indicating where the soil is deficient and where the levels are sound. An extension worker (agronaut) then discusses the soil report with the farmer to derive a recommended nutrient package specific to the crop the farmer wants to grow. The farmer is then informed where and how to obtain these nutrients (in the form of a particular fertilizer blend).

For the treatments, we cooperate with Meridian's Farmer Support Unit (FSU). This private-sector player offers farmers spectral soil tests and site- and crop-specific recommendations. The model underlying the test was calibrated on wet-chemistry analyses conducted on 22,000 samples from across Malawi. The tool is part of a private-sector business model in which FSU Meridian forms a recommendation for a package of nutrients, which is then supplied through their network of 400 agrodealers.

The sample for this study is drawn from a previous longitudinal study that involved 113 villages. This gives us the opportunity of leveraging two years' worth of data on Maize, Groundnut, and Soyabean growing famers for our study design and analysis. In doing so, we ensure that we do not lose external validity and generalizability as we are relying on a specific sample drawn for a different purpose. Since the sample for the previous study was selected using the same approach we would have applied for this study—randomly drawing districts, villages, and households within villages—we believe that using this sample does not compromise external validity.

Based on a thorough power and sample size calculation, we have determined that we will need to sample 16 households per village, resulting in a total of 1,808 households. Out of the 113 villages, 41 villages will be assigned to Treatment 1 (T1), another 42 villages to Treatment 2 (T2), and the remaining 30 villages to the control group (C). During the initial visit, farmers in all 113 villages will be offered a soil test. Those who accept the offer will be asked to select a plot of their choice for the soil test. Additionally, they will be asked to specify the crop for which they would like to receive recommendations, as well as their target yield. In making these selections, all farmers, regardless of treatment assignment, will be informed that there is a two-thirds chance they will receive the results of the soil test in time for the 2024/25 growing season.

The soil samples will be collected and tested by a private company called Meridian, whose core business involves the importation, blending, and distribution of fertilizer in Malawi, Mozambique, Zambia, and Zimbabwe. After the soil tests are conducted, the results will be communicated in a follow up visit to farmers in the randomly assigned T1 and T2 groups, along with nutrient management advice from private sector-trained extension agents, known as "agronauts." Farmers in the C group will also receive a follow-up visit in which blanket fertilizer recommendations will be provided instead of the soil test results to avoid contaminating the control group. Farmers in the control group will receive the results of the soil test along with the nutrient management advice as in the treated group during an end-line survey after the 2024/25 growing season.

We will visit farmers three times during the duration of this study between September 2024 and June 2025: first, when we visit them to collect soil samples; second, before the 2024/25 growing season to gather baseline data; and third, after the 2024/25 growing season to collect endline data. During the initial visit, we will begin by obtaining farmers' consent to participate in the study after providing them with complete information (see the attached consent letter). Farmers will then be asked to provide the location of the plot from which soil samples will be collected for testing. During the second visit, baseline data will be collected on key outcome indicators using the attached questionnaire, prior to implementing the interventions. During the third and final visit we will collect endline data on key outcome indicators as in the baseline.

We use openrouteservice to link sample villages to the nearest agro-dealer. We assume farmers go to agro-dealers by motorbike or bicycle.

6 Experimental Setup and Empirical Specifications

Households will be randomized at the village level following a parallel design with one control and two treatment arms. A first treatment arm will get the soil test and a recommendation based on this soil test which includes a recommended fertilizer blend. A second treatment is added incrementally on the first treatment. In this treatment arm, farmers get get the soil test and a recommendation based on this soil test, and also receive a voucher that partially subsides

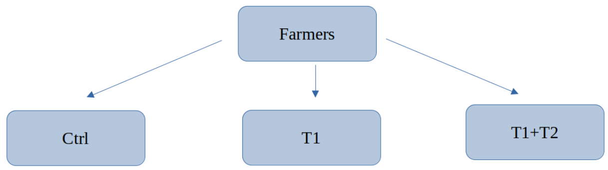


Figure 1: Experimental layout

the recommended fertilizer blend. The layout of the experiment is illustrated in Figure 1.

Due to the random assignment of participants to treatment and control groups, comparing outcome variable averages of treated and control participants provides unbiased estimates of the average treatment effects. We compare averages using OLS regression of the following form:

$$Y_i = \alpha + \beta_{T1} T1_j + \beta_{T2} T1_j T2_j + \varepsilon_i \tag{1}$$

where Y_i is the outcome of interest (agronomic practices, profits, return on investment, etc—see Section 8 below) of farmer i. $T1_i$ and $T2_i$ are treatment indicators at the village level that take the value of one if the farmer was located in a village that was allocated to the respective treatment group, and zero otherwise. The parameter estimate of β_{T1} is the treatment effect of the soil test treatment, β_{T2} is the incremental effect of adding the voucher to the combined treatment.[1]

For outcome families with more than one outcome (knowledge, adoption, input use, and effort), we compute outcome indices, which is a common way to account for multiple hypothesis testing. To do so, we follow Anderson (2008), where each index is computed as a weighted mean of the standardized values of the outcome variables. The weights are derived from the (inverse) covariance matrix, such that less weight is given to outcomes that are highly correlated with each other. For these indices, signs of outcomes were switched where necessary so that the positive direction always indicates a "better" outcome.

[1] To estimate β_{T1}, we will also estimate an alternative specification that boosts power by exploiting the fact that farmers T2 is provided on top of T1 (that is, farmers in the second treatment arm also receive T1). To do so, we consider T2 as covariate and enter it in deviations from its mean in the following way (Lin, 2013):

$$Y_i = \alpha + \beta_{T1} T1_j + \beta_{T2} T1_j \left(T2_j - \overline{T2} \right) + \beta_C \left(T2_j - \overline{T2} \right) + \varepsilon_i \tag{2}$$

See also this blog post: https://blogs.worldbank.org/en/impactevaluations/what-should-you-do-experiments-factorial-designs

7 Statistical Power and Sample Size Determination

We will run a simulation analysis to determine sample size for the design presented in section 6. Simulation, which involves instructing a computer to conduct an experiment thousands of times and tallying the frequency of significant outcomes under specific assumptions, is a considerably more flexible and intuitive approach to conceptualizing power analysis.[2]

Power calculations require the choice of an outcome variable. Normally, this outcome is assumed to be normally distributed, with a particular mean and standard deviation. However, when simulation is used, it is possible to draw from an actual distribution of the outcome variable if data is available. The outcome we consider in this study for our power calculations is maize yield. As such, we draw random samples from farmer level data that was collected for a study on smallholder market participation in the central region of Malawi (De Weerdt et al., 2024). Using this data, we find that average yield is 2,574 kilogram per hectare (with standard deviation of 1145 kg per hectare).

Power is determined in the following way. We set the number of villages to the maximum, as this is a clustered design and we want to exploit inter-cluster variation to the maxim extent. We then search in two dimentions. First, we vary the share of villages that is allocated to the control (and equally divide the remaining villages to T1 and T2). In the second dimension, we vary the number of households that will be interviewed in each village. We model similar effects for T1 and T2 (a 13 percent increase over baseline yield). We run 1000 simulations and use 5 percent significance level and .8 is our target for power.

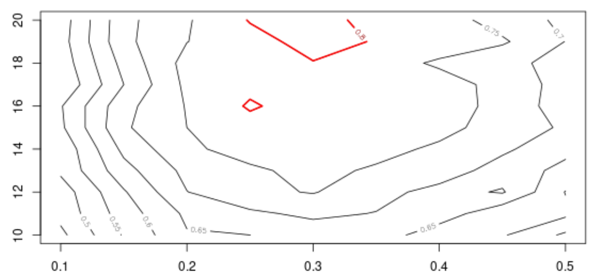
Figure 2(a) shows that when we allocate 25 percent of villages to the control group (and 75 percent to the treatments) and include about 16 households per village, we hit the 80 percent power level for the joint hypothesis that both β_{T1} and β_{T2} are significantly different from zero. However, to avoid that we are focusing on an isolated peak in the distribution, it seemed safer to move closer toward 30 percent in control (and hence 35 percent in T1 and 35 percent in T2) and aim for about 18 households per village. Figure 2(b) shows that at such a sample, we will get 85 to 90 percent power to identify a significant effect on T1. Figure 2(c) shows power to detect a significant difference between T1 and T2. Figure 2. From this, we conclude that we need about 30 percent in control (and hence 35 percent in T1 and 35 percent in T2) and aim for about 18 households per village.

8 Outcomes of interest

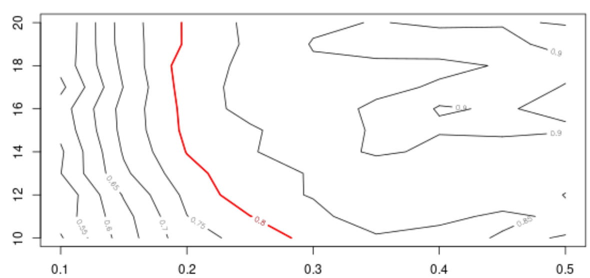
Our outcomes of interest are agricultural practices (with a particular focus on the use of recommended inputs and practices), yields, return on investment in

[2] See also this methods guide: https://egap.org/resource/10-things-to-know-about-statistical-power/

(a)



(b)



(c)

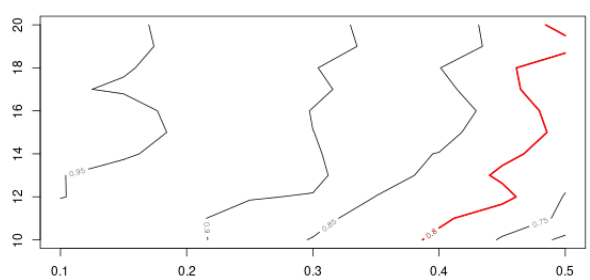


Figure 2: Power Plots

fertilizer, profitability of the crops and the return on investment for the subsidy.

- use of inorganic fertilizer on the plot on which the soil test was done. In particular, we will make sure we cover the 4 Rs (4 Rs: source, place, timing and rate)
- use of organic fertilizer on the plot on which the soil test was done (quantity)
- labour use on main plot
- yield on main plot (gps and subjectively measured plot area, estimated yield in bags and in kg)
- complementary input use and costs (seed used, chemical used)
- complementary agronomic practices, in particular those that also adress soil health
- a range of outcomes at the farm household level (crop mix, overall profits)

Outcome: Amount of fertilizer used by type, application error (gap from recommended rate, Yield, Farm revenue, Farm expenditure. We need to make sure that we also ask all questions needed to generate a recommendation via the fertilizer optimizer app.

Outcome: Fertilizer adoption, Amount of fertilizer used, Yield, profit.

Outcome: Fertilizer adoption rates, Yield, Profit.

Outcome: Fertilizer application rates, fertilizer management practices, maize yields, and revenues

We will also test for balance on fifteen pre-specified variables. First, we will use data previously collected to assess balance on the following five variables that are unlikely to be affected by the treatments: farmer's age (in years), sex of farmer, household size, land area for crop production (acres), and whether the household had difficulty in meeting food needs in the year preceding the survey. As this data was collected in May and June 2022, we can already establish balance at this point. Results are in Table 1. The table shows not a single significant difference for the five outcomes for pairwise comparisons between the different treatment groups. Joint tests of orthogonality confirm that we have good balance judged by these five outcome variables that were collected before the treatment administration.

Second, while we do not plan to do a dedicated baseline, we will collect data on some background characteristics on the previous season a few weeks after treatment administration. This will include wheter the household was and AIP receipient in the previous season, total land size use for cultiviation, number of crops grown, We also include five variables from among the outcomes of interest to test balance at baseline, in particular: use of organic fertilizer (yes/no), use of Urea (kg), yield, profit, crop in previous season was legume

Table 1: Balance table

	mean ctrl	T1	T2	nobs
Household head age (years)	42.434	1.158	-0.022	2007
	(14.76)	(0.867)	(0.901)	
Household head is male (1=yes)	0.781	0.012	0.01	2034
	(0.414)	(0.025)	(0.025)	
Household size (number)	4.902	0.129	0.159	2032
	(1.927)	(0.125)	(0.135)	
Land area (ha)	0.999	0.011	0.007	2033
	(0.627)	(0.053)	(0.051)	
Had difficulties feeding familiy in last year (1=yes)	0.276	0.041	0	2034
	(0.447)	(0.037)	(0.038)	
F-test C/T1 (p-value)	1.348	(0.241)		
F-test T1/T2 (p-value)	0.462	(0.805)		

Note: First column reports control group means (and standard deviations below); second column shows different between control and T1 (and standard errors clustered at the village level below); third column shows different between T1 and T2 (and standard errors clustered at the village level below). F-test test for joint significance in a regression with treatment status on the left hand side (T1/C or T2/T1). Likelihood ratio test is derived from a multinomial model where the left hand side has three levels (C,T1,T2).

9 Timeline

Soil tests will be done in September 2024. Treatment administration (+ baseline data collection) will happen once results from the soil tests are available, which should be after about 2 weeks. In April 2025, endline data will be collected.

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