Pre-analysis plan (27.01.2026)

1. Trial title

Adopting technology under climate stress: Evidence from randomized soil tests and fertilizer recommendations

2. Country

Ghana

3. Status

On-going

4. Keywords

Agriculture, soil testing, nutrient management, weather shocks, climate change adaptation, extension services, digital platform, Ghana

5. Abstract

Agricultural productivity in Sub-Saharan Africa remains low compared to other areas of the world; explained by multiple factors, including input and output market frictions, credit and liquidity constraints as well as knowledge gaps. Limited access to information and knowledge about adequate soil management practices is likely to play an important role, but previous evidence on the impact of nutrient deficiency information and recommendations on fertilizer use and practices is mixed and often comes from areas where farmers are overapplying fertilizer. Our study adds to the evidence on the effectiveness of management practice interventions by implementing a randomized controlled trial (RCT) in which we provide soil test information and farm-specific fertilizer recommendations. The RCT is conducted in Northern Ghana with predominantly female soybean farmers. The intervention thus targets a relatively vulnerable group in a poor context with very low baseline fertilizer use. Further, the intervention is implemented in the context of a severe drought that exhibited considerable spatial heterogeneity in the study area.

We study the impacts of soil and nutrient management information on farmers' input management practices, their knowledge thereof, and fertilizer allocation across crops. We assess potential sources of heterogeneous effects, including past exposure to the drought, initial farming knowledge, confidence and practices, distance to urban areas as well as the local availability of inputs. Our treatment consists of an information session for the farmers, wherein they are informed about the nutrient deficiencies on their farm as indicated by a soil test as well as adequate fertilizer quantities, timing, and application practices. The soil tests were conducted and administered by WamiAgro Ltd., an agricultural platform, and Sesi Technologies, an agri-tech company. Half of our farmer sample was randomly assigned to receive the soil test and recommendations on top of the information and market services, termed "Nutrient management". Apart from this, the treatment and control group receive

weather information and guidance on farming practices from WamiAgro, as well as the option to sell their soybeans via the platform [1].

We will analyze the effects of the intervention on nutrient management knowledge and practices, fertilizer application, crop choice and land use, labor demand at planting and, accordingly, input costs. The hypothesized impact of the intervention is that it will enhance farmers' understanding of their soil health and, by recognizing nutrient deficiencies, enable them to adjust their fertilizer selection and application. For example, our information treatment may improve farmers' knowledge of correct fertilizer application distances and timing. We also expect improvements in self-reported soil quality (conditional on fertilizer application) and changes in fertilizer expenses (conditional on the type of management response). Further, we expect higher labor demand at the land preparation and planting phase (again conditional on the type of management response).

We hypothesize that exposure to the recent drought makes farmers less likely or more hesitant to implement fertilizer recommendations. We also expect responses to vary with expectations about future drought occurrence, farm and household characteristics (such as farm size, gender, age, education and experience), distance to urban areas, risk attitudes, credit use, confidence in own farming abilities, local availability of inputs and prices. We explore heterogeneity along these dimensions by interacting the treatment with each of these characteristics (one-by-one).

6. Trial start date

June 12, 2024

7. Intervention start date

May 2025

8. Intervention end date

February 2026

9. Trial end date

July 2026

[1] Initially, the experimental design foresaw a 2x2 design. Farmers were randomly assigned to a control group, a “Soil test” group, a “Credit” group, and a “Soil test + Credit” group. The original design could not be implemented due to a drought in 2024 and financial constraints on the side of our implementing partner in 2025. All groups could sell their produce to WamiAgro, used by 24% of farmers at baseline. All groups could also obtain information services (e.g., regarding the weather forecast, crop epidemics and pests) from WamiAgro, used by 38% of farmers at baseline.

10. Outcomes

Our first baseline gathered data on the 2023 agricultural season and a second baseline in January/February 2025 gathered data on the 2024 agricultural season, while the follow-up surveys in January/February and July 2026 will focus on the 2025 season and the planting phase of 2026.

We will assess the impact of the interventions on several intermediate outcomes, focusing on the uptake of soil testing and comprehension of nutrient deficiencies and recommendations. We will also measure fertilizer use and assess changes in soil and fertilizer management practices in the follow-up survey conducted via phone. In addition, we collect data on shock coping measures and adaptation strategies to weather shocks and climate change. These were collected during the second baseline and will be elicited again during the first follow-up survey. We may conduct further follow-up surveys to study the effects of the treatment on yields, agricultural productivity, inputs, profits and household welfare.

1. <u>Intermediate outcomes</u>

<u>1.1 Soil test take-up, recall and understanding</u>

- Take-up:
  - Has the respondent ever heard about soil tests?
  - Has the respondent ever tested his/her soil?
  - Has the respondent ever gotten information about soil tests conducted on other farmer's plots?
  - Did the respondent receive any consultation based on the soil test?
- Understanding:
  - Farmer's self-reported understanding of soil test results/recommendations
- Recall of soil test consultation:
  - Does the respondent remember any information about the nitrogen level of soil?
  - Does the respondent remember any information about the potassium level of soil?
  - Does the respondent remember any information about the phosphorus level of soil?
  - Does the respondent remember any information about the fertilizers that were recommended to him/her?
- Soil fertility:
  - How does the respondent rate the fertility of his/her soil? Self-reported soil fertility is a subjective rating based on a 5-point scale ranging from very low to very high.
- Subjective confidence:
  - Confidence about amount of fertilizer (Likert scale from 1 to 5)
  - Confidence about type of fertilizer (Likert scale from 1 to 5)
  - Confidence about general fertilizer application knowledge (Likert scale from 1 to 5)
  - Confidence about general farming ability for soybean (Likert scale 1 to 5)
- Knowledge of soil health and nutrient requirements:
  - Knowledge of optimal timing for phosphorus fertilizer application
  - Respondent can name visible sign of nitrogen deficiency on soybean plant
  - Respondent can name visible sign of phosphorus deficiency on soybean plant
  - Respondent can name visible sign of potassium deficiency on soybean plant
  - Respondent knows which fertilizers to apply when nitrogen is low
  - Respondent knows which fertilizers to apply when phosphorus is low

    - Respondent knows which fertilizers to apply when potassium is low
    - Respondent knows general recommendation for fertilizer application distance to seeds
- Knowledge of input types and costs
    - Respondent has heard of Triple Super Phosphate (TSP)
    - Respondent knows price of one 50 kg bag of TSP
    - Respondent has heard of inoculants
    - Respondent knows price of one sachet of inoculants (100g)

<u>1.2 Input usage and changes in soil management</u>

- Input usage:
    - Fertilizer
        - Has the respondent applied any fertilizer on his/her soybean acres? (for soybean acres and for other crops separately) (extensive margin)
        - Quantity used on soybean acres (for soybean acres and for other crops separately) (intensive margin)
        - Costs (for soybean acres and for other crops separately)
        - Source of the fertilizer (self-made/manure or purchased)
        - Timing of fertilizer purchase
        - Timing of fertilizer application
        - Type of fertilizer used
    - Pesticides (insecticides, weedicides, herbicides, molukticides, fungicides, akarisides, nematicides)
        - Has the respondent applied any pesticides on his/her soybean acres?
        - Costs (for soybean acres)

<u>1.3 Labor demand</u>

- Demand for agricultural labor for land preparation/planting and harvesting/threshing (separately):
    - Number of workers hired
    - Number of female workers hired
    - Number of youth workers (under age 35) hired
    - Daily wage/payment arrangement
    - Days each laborer worked on average
- Family labor on farm
    - Average days per week farming soybean
    - Average days per week farming other crops
    - Average hours per day farming soybean
    - Average hours per day farming other crops
    - Number of household members helping on farm during harvesting/threshing
    - Number of days per week household members helped during harvesting/threshing

<u>1.4 Agricultural production of soybeans</u>

- Yield and sales:
    - Number of acres cultivated with soybean

    - Total soybean harvest
    - Quantity sold
    - Types of buyers of soybean harvest
    - Price per unit of soybeans sold (by type of buyer)
    - Post-harvest losses
    - Quantity consumed
    - Quantity stored
- Self-reported revenues and profits

2. Ultimate outcomes

2.1 Shocks and strategies

- Shock occurrences
    - Ex-post strategies used to cope with any household shock
    - Changes in asset holdings (household, agricultural and livestock assets)
- Perceptions and ex-ante adaptation strategies
    - Perceived risk of another drought or flood in the next twelve months
    - Ex-ante adaptation strategies to cope with future drought in the next twelve months
    - Ex-ante adaptation strategies to cope with future drought or flood in the next ten to 15 years
- Adaptation strategies implemented within last 12 months
    - Strategies implemented to reduce effects of potential drought
    - Strategies implemented to reduce effects of potential flood
    - Strategies implemented to reduce effects of frequent extreme weather conditions (climate change)

2.2 Household income, welfare and financial inclusion

- Economic resilience
    - How much was the income from other crops the respondent sold?
    - Did the respondent engage in other non-farm activities?
    - Respondent's personal income from non-farm activities and paid agricultural labor last month
    - What has been the most (second most and third most) important income source for the household since last survey?
    - Did the household receive any remittances since the last survey on a regular basis?
    - HH was in financial distress anytime since the last survey? (financial distress: unable to fulfil usual daily expenditures)
    - Since the last survey, was there a time when, because of lack of money or other resources the household ran out of food?

- Subjective well-being: where do they locate their household on the 5 steps going from 1=poor to 5=rich
- Subjective relative well-being: where do they locate their neighbors on the 5 steps going from 1=poor to 5=rich

Heterogeneity analysis

We analyze heterogenous impacts for the following characteristics:

- Farm size
- Gender
- Educational level
- Age
- Experience (years cultivating soybeans)
- Risk attitudes
- Having taken out a loan in the previous twelve months
- Baseline confidence in fertilizer type and amount applied
- Experiencing a more vs. less severe drought in the past two years (self-reported and satellite data-based)
- Perceived risk of another drought in the next twelve months
- Distance to nearest town
- Availability of fertilizers
- Local price of fertilizers

11. Experimental design

Sampling

Our sample consists of smallholder farmers who either previously collaborated with WamiAgro or became new clients in 2024, prior to the start of the trial. We included only those communities that had reported to WamiAgro that they would be farming soybeans in 2024. The platform selected 17 communities based on these eligibility criteria. Each community comprises between one and 14 farmer groups, and a random subset of farmers was selected from each group.

Due to the planting phase already commencing in five communities in the Northern region before the baseline survey could be conducted in June, these communities were replaced with five others in the North East region, ensuring an equivalent number of farmers per group. In total, 1,363 farmers were surveyed for the baseline.

Regions (Districts) and communities

- Northern Region (Zabzugu)
    - Zabzugu (including Nakohigu)
    - Tindang
    - Gor-Tanei
    - Kukpalgu
- Savannah Region (Sawla-Tuna-Kalba, West Gonja)
    - Tuna
    - Larabanga
    - Alhassan Kura Damongo
- Upper West Region (Sissala West, Wa)
    - Jeffisi

  - Busa
  - Goripie
  - Bihee
- North East Region (Chereponi)
  - Jakpa
  - Kpenchi
  - Nawari
  - Ando Ngamanu
  - Cherekpegri
  - Famisha

Timeline

Activity	**Timeline**
Baseline Survey	*Jun 24*
Services provided to all farmers (WamiAgro): Info Market	2024 Jul-Oct Oct/Nov
2nd Baseline Survey	*Jan/Feb 25*
Services provided to all farmers (WamiAgro): Soils tested Info Market	2025 May Jun-Oct Oct/Nov
Follow-up Survey I	*Jan/Feb 26*
Intervention: Nutrient Management	 Jan/Feb 26 (after survey)
Follow-up Survey II (phone)	*Jul 26*

Randomization procedure

The original 17 communities were divided into five strata based on the number of registered farmers in each community. The random assignment into four groups was then done within each stratum. The random assignment was based on a 2x2 design, which is why communities were initially into three treatment groups ("Soil test", "Soil test + Credit", "Credit") and the control group. Within each treatment group and the control group, the number of farmers to be interviewed was determined so that the number of farmers drawn per group was inversely proportional to the number of farmer groups in each treatment and control group. Since the credit intervention was not implemented, we only compare the two groups that received the soil tests and will receive the nutrient management information (formerly "Soil test" and "Soil test + Credit" group) with the two groups that did not ("Credit" and the control group). Eight communities belong to the "Nutrient management" group and nine communities belong to the control group.

The randomization had been done before the five communities had to be replaced. The random assignment was then transferred from the "old" to "new communities" with only very minor adjustment to the number of sampled farmers per group. Overall, more farmers were sampled to prevent a loss in power in case of attrition.

Details on services

This study evaluates the effectiveness of an information treatment based on soil test results. In the treatment group ("Nutrient management"), each smallholder receives information on their soil's nutrient composition and crop-specific input recommendations. Our intervention is an information session for the farmers, wherein they are informed about their nutrient deficiencies as well as adequate fertilizer quantities, timing, and application practices. The information session is primarily designed by the researchers, with the help of WamiAgro and Sesi Technologies and provided to each farmer individually. The implementation in the field is done by our research team and enumerators. The session is planned to last about 10 min. General advice provided comes from WamiAgro, Sesi Technologies and publicly available information from the Ministry of Food and Agriculture. Adjustments to the fertilizer recommendations were made due to certain fertilizer unavailability and adjustments based on agronomic advice from WamiAgro.

Farmers' soils were tested in May 2025 using a handheld soil testing device that measures pH, electrical conductivity, soil temperature and moisture on the spot. Nutrient deficiencies and fertilizer recommendations were calculated by Sesi Technologies using these measurements as well as satellite imagery. Sesi Technologies also took actual soil samples for a few farmers and had them tested in a lab to cross-validate the results. However, once the results were available only some farmers actually received the information from field officers and most of them without detailed information and appropriate instructions on how to adapt the fertilizer management. This has also been confirmed in qualitative interviews done with field officers of WamiAgro and farmers. Therefore, our "Nutrient management" treatment will provide a homogenous communication of the soil test results and recommendations, such that all farmers whose soil was tested, actually receive the information. The recommendations can still be considered as valid and useful. To stringently monitor prior information provision, we will systematically ask all farmers during the first follow-up survey how services are being delivered and whether and how farmers received their soil test results and fertilizer recommendations already during the 2025 agricultural season. We will assess heterogeneity in treatment impact, based on whether farmers have received the nutrient management information once or twice.

Both the treatment and control group receive the standard services offered by WamiAgro Ltd., which consist of information provision, training and granting smallholders access to international markets.

Spillovers

Given the design of our study, we do not expect significant spillover effects. The treatment and control group communities are geographically dispersed, which minimizes the likelihood of interaction between treated and untreated units. Furthermore, the treatment is highly specific and tailored to individual participants, further reducing the possibility of spillovers. These factors together suggest that any unintended influence of the treatment on control groups is likely to be minimal.

However, we cannot be certain to rule out spillover effects for communities that were assigned a different treatment status but are located within the same region and geographically relatively close to one another. Therefore, we will test whether knowledge of soil tests and nutrient deficiency management is higher in the control communities in our sample that are closer in distance to the treatment group. We can estimate this by incorporating the number of treated soybean farmers within a meaningful radius. This variable will be included both linearly and interacted with the treatment to examine whether spillover effects differ between treated and untreated farmers.

If we are able to conduct more follow-up surveys after July 2026, we will check for spillovers directly at the market level. If the treatment results in a substantial increase in soybean production among treated farmers, this could affect local soybean prices. An oversupply in treated regions might lead to a decrease in prices, which could spill over into adjacent markets, especially if these markets are closely linked. Conversely, if the treatment enhances the quality of soybeans, it could lead to price premiums that might influence market prices more broadly. While these impacts are plausible, their magnitude would depend on the scale of the treatment effects and the degree of market integration across regions. It is important to monitor these potential spillovers as they could have broader economic implications beyond the immediate scope of the study. In order to better understand any potential spillover effects, we will collect qualitative data via focus group discussions, interviewing farmer group leaders and field officers in the control and treatment group.

Model specification (ANCOVA)

The primary objective of this analysis is to estimate the effect of the intervention on the outcome variables measured after the intervention, controlling for baseline outcomes and other covariates. The use of an ANCOVA model allows us to increase statistical power and control for pre-treatment differences, whenever our data permits.

The standard ANCOVA model will be specified as follows:

$$Y_{ict} = \beta_0 + \beta_1 Treat_c + \lambda Y_{ic0} + X_{ict}'\gamma + \varepsilon_{ict}$$

Where Y_{ict} is the post-treatment outcome for farmer i in community c measured in survey wave t. $Treat_c$ is the treatment indicator equal to 1 if the community c received the "Nutrient management" treatment, and 0 otherwise. Y_{ic0} are the baseline outcomes. X_{ict} is a vector of control variables and ε_{ict} is the error term. The intervention was randomized at the community level. Therefore, we cluster the standard errors at the community level. We will calculate p-values using the wild cluster bootstrap-t procedure.

Covariates X_i:

- Age
- Gender
- Household head status
- Education
- Region
- Farm size
- Experience (years cultivating soya)

Multiple Hypothesis Testing

Given the large number of outcomes estimated in our study, there is an increased risk of falsely rejecting the null hypothesis due to multiple comparisons. To address this, we will control for the False Discovery Rate (FDR) using the Benjamini-Hochberg (1995) procedure. Specifically, sharpened q-values will be calculated within each domain for the groups of outcomes.

12. Was the treatment clustered?

Yes, by community.

13. Planned number of clusters
    17

14. Planned number of observations

At baseline, we interviewed 1,363 farmers. We had to drop four farmers from our sample who stated that they did not cultivate soybeans, nor were they planning to cultivate soybeans in the future and we had to drop one respondent who was the only one in their farmer group who cultivated soybeans. This reduces the number of farmers to 1,358. For the second baseline, 1,355 farmers could be re-interviewed. Two households had moved or migrated, and one household could not be contacted. We plan to interview the same farmers for two follow-up surveys, one in person and the other via phone. This will result in a total of 5,420 observations for outcomes measured in all four survey rounds. It will be 2,710 or 4,065 observations for most of the outcomes, measured in two or three rounds, respectively. Moreover, depending on available financial resources, we plan to conduct one or two additional short phone surveys. Overall, we anticipate an attrition rate of approximately 5% due to factors such as non-response, traveling, migration, and death. We will observe and document any kind of attrition carefully. We will analyze whether it is systematically related to the treatment status.

Power

Power calculations were performed using baseline data to estimate the Minimum Detectable Effect (MDE) with 80% power and a 5% significance level. While treatment was randomized at the community level (K=17), our primary power specifications utilize the K=78 farmer groups as the nested cluster unit to reflect the organizational structure of the intervention.

For our binary outcome, any fertilizer used, the baseline adoption rate in the control group is 15.13%, while the full-sample prevalence is 21.48% (yielding a pooled SD of 0.411). With a farm-group ICC of 0.29, the study is powered to detect an absolute increase of 15.14 percentage points. This corresponds to a standardized effect size of 0.37 standard deviations.

For our continuous outcome, fertilizer costs, we find an ICC of 0.16. At a baseline mean of 89.06 GHS in the control group (198.89 GHS in the full sample) and a pooled standard deviation of 545.14, we are powered to detect an absolute increase of 159.26 GHS. This corresponds to a standardized effect size of 0.29 standard deviations (or 178.29%).

Conditioning on baseline outcomes and covariates, i.e. estimating ANCOVA specifications, will further absorb noise from the data and hence increase power. In terms of power, this is especially helpful for those outcomes that are difficult to measure and typically show a relatively low autocorrelation over time, such as sales and profits (McKenzie, 2012).

15. Was IRB approval obtained?
    a. IRB Name: Ethics Committee for Humanities, University of Ghana
    b. IRB Approval Date: 11. June 2024
    c. IRB Approval Number: ECH 277 23-24