Productivity Impact of Integrating Soil-Fertility-Management interventions in Input-Subsidy Programs: Evidence from a Randomized Control Trial in Malawi

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Abstract

To enhance the effectiveness of input-subsidy programs (ISPs), we implemented a cluster randomized control trial (cRCT) in two districts in Malawi to evaluate the impact of adding organic fertiliser and agricultural lime to Malawi's Affordable Input Programme (Affordable Input Program). The findings are intended to guide reforms into large ISPs to make them more effective. We found insignificant treatment effects of organic fertiliser and agricultural lime to chemical fertiliser on maize yield but significant treatment effects of the treatments on maize yield per kilogram of fertiliser. We find the intention-to treat-effects of adding organic fertiliser to chemical fertilisers on maize yield per kilogram of fertiliser to be 54% and the local average treatment effects (LATE) to be 72%. The intervention significantly increased knowledge and adoption of integrated soil-fertility-management inputs and we found that the use of organic fertiliser is the most cost-effective intervention. Important policy recommendations include the need to consider incentivizing farmers on Affordable Input Program to use soil-fertility-management inputs, enhancing the presence of agricultural-extension services, and improving the performance of Affordable Input Program to make fertiliser available on time to enable participating farmers to apply appropriate quantities with the correct frequency.

Key words: Fertiliser response; integrated soil fertility management; maize productivity; cluster randomized control trial; Malawi.
JEL Classification: C93; Q16; Q18

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I. Introduction

Most of the agricultural growth observed in Africa has resulted from the expansion of cultivated areas (Djoumessi, 2022). Because of this, no more room exists for expansion. As a consequence, the need to raise agricultural productivity in Africa cannot be overstated. Agricultural productivity can be increased by intensifying the use of such inputs as fertiliser and improved seeds. Recognizing the role of input intensification in increasing agricultural productivity, many sub-Saharan African countries have been re-introducing input-subsidy programs (hereafter, ISPs). Sub-Saharan African countries' total expenditures on ISPs have grown to approximately one billion USD annually, accounting for roughly 14-26% of their combined annual public agricultural expenditures (Nhlengethwa et al., 2022). These huge investments in ISPs have been made with the expectation that African countries would produce adequate food to allow them to be self-sufficient and to trade among themselves (Nhlengethwa et al., 2022). However, African countries are still net food importers, especially from outside the region. At the farmer level, it has been observed that many farming households that have access to subsidized inputs also receive food aid, raising the need to reform the subsidy program.

Malawi is one of the countries that led the reintroduction of second-generation ISPs. The country re-introduced a large input-subsidy program in the 2005-2006 growing season. The program primarily targets smallholder farm households with 23:21:0 +4S basal fertiliser (NPK), urea for top dressing, improved maize seeds, and sometimes grain legume seeds (Chirwa & Dorward, 2013). In the 2020-2021 agricultural season, Malawi's input-subsidy program expanded access to subsidized inputs to smallholder farmers from 900,000 to 4.3 million. As expected, the input-subsidy program in Malawi increased fertiliser consumption from less than 10 kg kg/ha in 2005 to 55.8 kg kg/ha in 2016 (GoM, 2021). However, maize yield has marginally increased from one metric ton per hectare to around two metric tons/ha, against the potential of roughly seven metric tons metric tons/ha (Benson, 2021). Poor soil health, characterized by high acidity and low carbon, have caused maize yields to stagnate because of the minimal response of maize to fertilisers (Snapp et al., 2014; Jayne et al., 2018; Burke, Snapp & Jayne, 2020; Jayne & Sanchez, 2021). Farm-level fertiliser maize yield-response rates in Malawi have steadily declined from eighteen kgs maize/kg N between the mid-1980s and mid-1990s to around twelve kgs maize/kg N between 2000 and late 2000s (Burke, Snapp & Jayne, 2020). This is similar to regional averages that range from five to twenty-six kg maize/kg nitrogen (Jayne et al., 2018).

One key factor that contributes to poor soil health and low response to fertilisers in Malawi is poor soil management. Evidence suggests that poor farm-level soil management by smallholder farmers leads to nutrient depletion because of the extractive nature of their systems (Omuto & Vargas, 2018) and because of such factors as continuous cropping without fallowing, high erosion rates, burning of crop residues, limited crop rotation, and crop intensification when exclusive use of inorganic fertilisers is promoted (Snapp et al., 2014; Willy et al., 2019).

Poor soil health can be mitigated by supplementing inorganic fertiliser with alternative soil-fertility-management interventions. A number of studies have confirmed this finding in a general smallholder setting (Ayalew, 2011; Wanjiru, 2018; Ndengu et al., 2022), but not within the context of a large input-subsidy program. Conducting studies of input-subsidy programs would assist in showing the potential for redesigning the subsidy program to increase cost-effectiveness. Our study also assesses how our intervention increased the adoption of soil-fertility-management interventions. This is an important question because the productivity gains associated with soil-fertility-management interventions are expected to spur adoption, but levels of adoption of soil-fertility-management interventions are still low (Katengeza, Holden & Fisher, 2017; Mponela et al., 2016). Therefore, we measured the impact on productivity of integrating agricultural lime and organic fertiliser with inorganic fertilisers into the inputs provided to Affordable Input Program beneficiaries. We introduced organic fertiliser and agricultural lime to farmers by establishing demonstration plots and requesting that farmers establish their experimental plots. We also tested the treatment effects on farmers' adoption of organic fertiliser and agricultural lime that resulted from introducing these technologies in the demonstration and experimental plots.

We implemented a cluster randomized control trial among Affordable Input Program beneficiaries in two districts in Malawi. Our results show that adding organic fertiliser and agricultural lime did not have significant treatment effects on maize productivity. However, there was a significant positive treatment effect of adding organic fertiliser and agricultural lime on the fertiliser-response rate, which was measured as maize yield per kilogram of fertiliser applied. There were no treatment effects on maize productivity because the treatment arms did not apply adequate chemical fertilisers. Adding organic fertiliser and agricultural lime did not increase fertiliser-response rates compared to adding organic fertiliser only. This can be attributed to the fact that soils in the study regions are not highly acidic. The results of soil analyses showed average pH ranges that are not very different from those that agronomists normally consider suitable for crop production. Our findings showed that the intervention increased farmers' knowledge and use of organic fertiliser and agricultural lime.

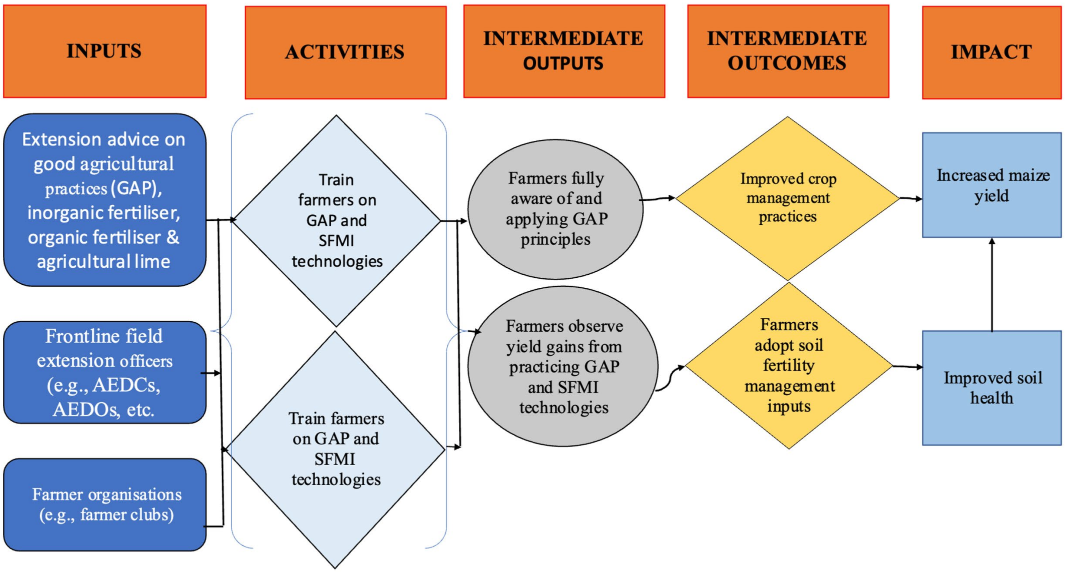
II. Conceptual Framework

We implemented this trial to demonstrate how the challenges of low maize productivity in Malawi can be addressed by redesigning the Affordable Input Program to address soil-health problems. Empirical evidence has shown that maize productivity significantly improves when grown in soils with high organic matter content and optimal soil acidity levels, which indicates good soil health (Snapp et al., 2014; Burke, Snapp & Jayne, 2020; Jayne & Sanchez, 2021). Good soil health enhances nutrient availability and uptake by crops, leading to higher productivity. Specifically, good soil health improves fertiliser use efficiency by creating an environment conducive to the dissolution and availability of nutrients from inorganic fertilisers, thereby effectively nourishing the plants.

This trial provided complementary inputs in the form of organic fertiliser and agricultural lime to improve soil health. Literature shows that soil acidity impairs crop productivity by up to 40% (Berihun et al., 2017). Soil amendments, such as agricultural lime, organic fertiliser, or a combination of both, mitigate the negative effects of soil acidity (Ayalew, 2011; Merlos, Silva & Hijmans, 2023. Frontline extension officers provide farmers with extension services on good agricultural practices to help them use inputs appropriately. The inputs provided to the farmers allowed them to test the knowledge gained at the demonstration plot on their experimental plot. Therefore, farmers were allowed to observe the maize yield gains from their experimental plots, which increased their knowledge and likelihood of adopting the technologies. When they adopt the technologies, soil health will improve, which will affect maize yield. Figure 1 below presents the theory of change matrix, which depicts the impact pathways of our trial from the inputs to the outcome level. The trial tested the observed yield gains and the impacts on adoption.

Figure 1: Theory of Change Matrix

Objective: To improve maize productivity and farm-level incomes



Source: Authors own estimation and depiction of impact pathways

III. The Intervention

We implemented the intervention in three agricultural districts of Mzimba North, Mzimba South, and Nkhotakota because the Department of Agricultural Research Services in the Ministry of Agriculture has recognized them as having the most acidic soils in the country, warranting the application of agricultural lime. In Malawi, agricultural districts are subdivided into Extension Planning Areas, which are further subdivided into agricultural sections. Each agricultural section is composed of five to fifteen and is managed by a frontline officer called an Agricultural Extension Development Officer. The interventions were implemented at the agricultural-section level.

We started implementing the intervention among Affordable Input Program beneficiaries in the last quarter of 2022 and continued until the first quarter of 2023. All farmers in the Affordable Input Program were expected to have access to subsidized inorganic fertiliser and improved maize seeds. We note, however, that the Affordable Input Program in 2022-2023 season faced many logistical challenges that affected access to fertiliser.

The intervention had three arms: the control arm, the organic-fertiliser arm, and the organic-fertiliser-plus-agricultural-lime arm. Farmers in the two treatment arms were given twelve kilograms of organic fertiliser or a combination of twelve kilograms of organic fertiliser plus eight kilograms of agricultural lime, depending on their treatment arm. Farmers in the control arm were not provided with the complementary inputs. All farmers were expected to use inorganic fertiliser and improved maize seed they received through the Affordable Input Program. Farmers in the treatment groups were required to apply five grams of inorganic fertiliser per plant while farmers in the control group were required to apply 2.5 grams of inorganic fertiliser per plant. The demonstration and experimental plots were supposed to be mounted on give ridges one meter in width, five meters in length, and, and spaced at 0.75 meters between them (or forty square meters). A summary of the interventions is presented in Table 1.

Table 1: Description of the interventions

Description	Control	Organic Fertiliser	Organic Fertiliser plus Lime
Recommended plot size	40 m^2	40 m^2	40 m^2
Inorganic fertiliser per plant	5g	2.5g	2.5g
Organic fertiliser application	No	95g/plant	95g/plant
Lime application	No	No	1200g/5m ridge
GAP training	Yes	Yes	Yes

Farmers in all arms were trained in general good agricultural practices associated with the inputs they were given. Good agricultural practices include timely planting, weeding, fertiliser application, and pest and disease management. We trained farmers in the control group to avoid overestimating the impacts of the inputs because the farmers in the treatment groups were also provided with extension services associated with the inputs they received. Each Agricultural Extension Development Officer mounted a demonstration plot within the section to demonstrate the farming practices designated for a particular treatment arm of the trial. Participating farmers and the extension officer collectively identified the site for the demonstration plot. Farmers mounted experimental plots within their fields to practice what they were learning from the demonstration plot.

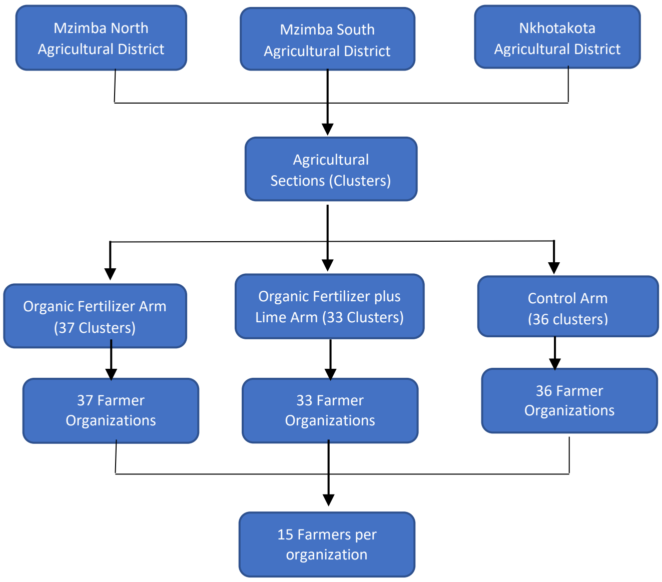
IV. Experimental design, data, and empirical strategy

4.1 Randomization

Our sample size determination assumed a 5% significance level, an intra-cluster correlation (ICC) of 0.1, and a minimum detectable effect of 0.24 to attain an 80% statistical power. to attain this, we required 106 clusters of thirteen farming households per cluster. The cluster size was adjusted by 15% to take non-response and attrition into account, which resulted in a cluster size of fifteen. This means that the initial total sample included 1,590 farmers.

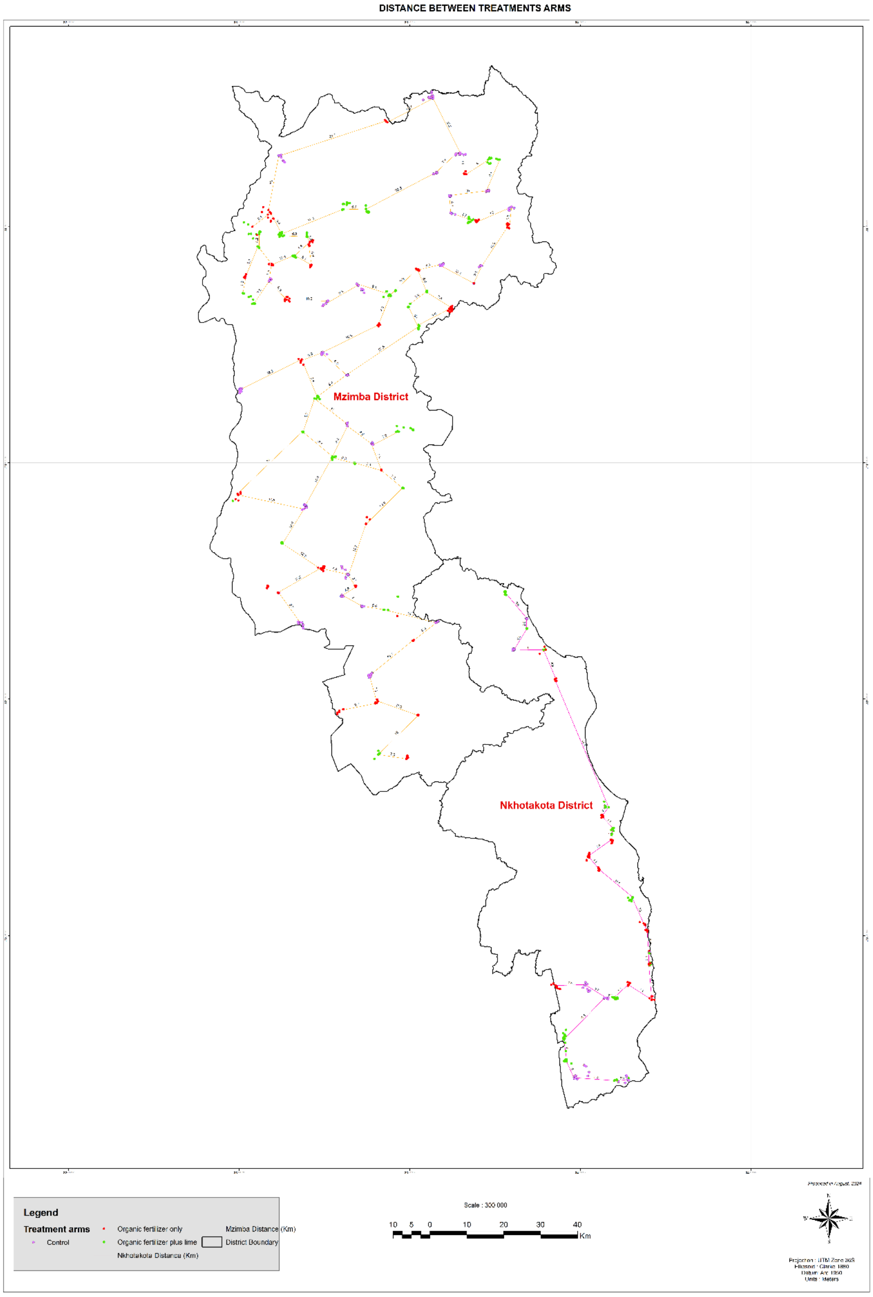
To randomize the farmers into treatment and control arms, we used the Affordable Input Program beneficiary list from three agricultural districts of Nkhotakota, Mzimba North, and Mzimba South. from each agricultural district, we randomly selected agricultural sections. The selected agricultural sections were then randomly assigned to the treatment and control arms. Figure 2 presents a summary of the randomization process and the distribution of the sample across treatment arms.

Figure 2: Description of the Randomization Procedure



To enrol participating farmers from the selected agricultural sections, we used farmer organisations (clubs, associations, or cooperatives) because Affordable Input Program inputs were administered through farmer organisations in the 2022-2023 growing season. We randomly chose one farmer organisation from each of the selected agricultural sections. The targeted fifteen farmers per cluster were then randomly selected per farmer organisation because most of the registered farmer organisations had more than fifteen farmers. The location of the selected farmers is presented in Figure 3.

Figure 3: Map of Selected Study Districts Showing the Location of Treatments



4.2 Data

4.2.1 Data Collection

We used three data sources: the soil survey, the midline survey, and the endline survey. In the soil survey, we collected and analysed data from a sub-sample of eighty-six farmers (thirty-five from the control arm, eighteen from the organic-fertiliser arm, and thirty-three from the organic-fertiliser-and-agricultural-lime arm). The farmers were selected randomly by the team of soil scientists while collecting data in the field. from each farmer, we collected soil samples at two depths (0-20 cm and 20-40 cm) for a total of 172 soil samples. The results of the analyses are presented in Table 2.

Table 2: Comparison of Soil Properties in the Three Treatment Arms

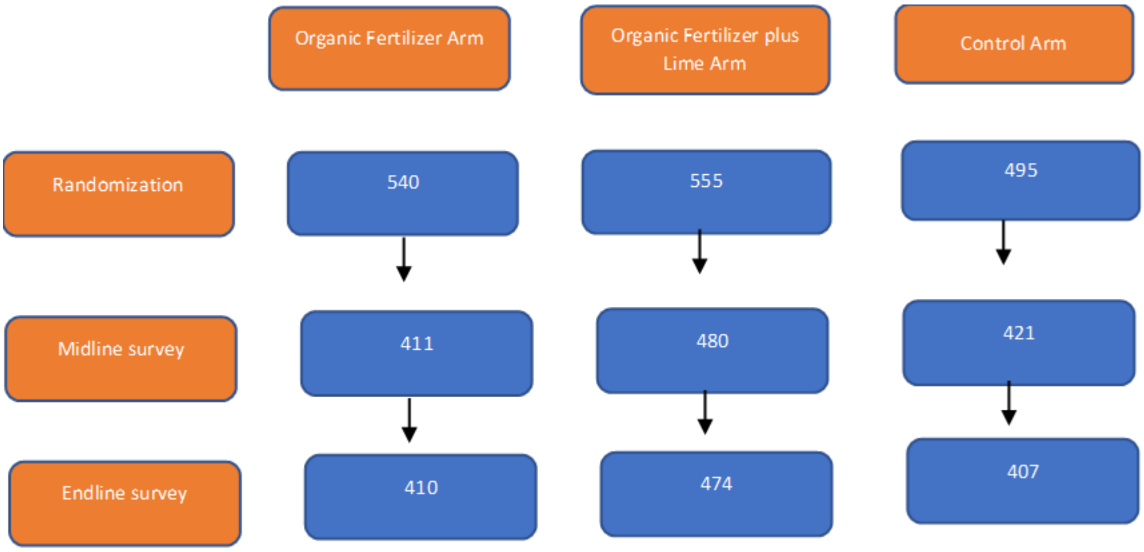
	Mean/(Var)			Mean Differences		
Soil Property	(1) Control	(2) Organic Fertilizer	(3) Organic Fertilizer and lime	(1)-(2)	(1)-(3)	(2)-(3)
Soil pH	5.850	5.954	5.918	-0.104	-0.068	0.035
	(0.642)	(0.455)	(0.711)			
Soil Carbon	0.583	0.875	0.764	-0.293	-0.181	0.111
	(1.363)	(1.683)	(1.827)			
Soil Organic Matter	1.004	1.509	1.317	-0.505	-0.313	0.192
	(4.050)	(5.001)	(5.429)			
Nitrogen	0.050	0.075	0.066	-0.025	-0.016	0.010
	(0.010)	(0.013)	(0.014)			
Silt	8.032	9.680	9.594	-1.648*	-1.562	0.086
	(93.674)	(143.655)	(221.371)			
Clay	12.549	11.251	12.888	1.297	-0.339	-1.637
	(277.358)	(345.839)	(406.952)			
Number of observations	70	36	66	106	136	102
Number of clusters	12	7	12	19	24	19

Note: ***, **, and * indicate significance at the 1, 5, and 10% critical level

The findings show that soils from the three treatment arms were similar in pH, organic matter, soil organic carbon, nitrogen, silt, and clay content. The soils in the study area are also slightly acidic, with an average pH range of between 5.84 and 5.9, which is higher than the recommended soil pH of less than 5.5 for lime application (Lolani & Kabambe, 2020). This is contrary to what was initially indicated in the official records but agrees with emerging evidence that states that most soils in southern Africa do not need liming (Merlos, Silva & Hijmans, 2023).

Data for estimating maize productivity were collected through a midline survey in June 2023, while data for measuring knowledge and adoption of organic fertiliser and agricultural lime were collected through an endline survey in February 2024. We used questionnaires to collect survey data through face-to-face interviews. Although we targeted 1,590 farmers, we interviewed 1,320 farmers at the midline survey, and 1,291 farmers during the endline survey. The distribution of the sample changes by treatment arms is presented in Figure 4.

Figure 4: Changes in Sample Sizes from Randomization to Endline Survey



A high level of attrition could potentially affect statistical power, external validity, and internal validity (Duflo, Glennerster & Kremer, 2006). We re-assessed our level of statistical power and found that we could attain 80% statistical power, with 5% statistical significance, if the effect size was at least 33% for the outcomes measured at midline (see the Appendix A). In an RCT, external validity is attained when the estimated impact can be generalized to the population of all eligible units, and this is possible if the evaluation sample is drawn randomly from the population of eligible units (Gertler et al., 2011; Duflo, Glennerster & Kremer, 2006). As such, sample attrition affects external validity if it is not random. External validity could have been guaranteed if the remaining sample had been comparable to the original sample. The external validity of the original sample was guaranteed by the randomization process. We were , however, unable to assess the impact of attrition external validity. We could not compare the characteristics of the sample at randomization and midline because we did not collect baseline data for the initial sample. Without concluding that the findings lack external validity, we are careful with the way we generalize our findings.

Attrition affects the internal validity of the evaluation if it is correlated to treatment assignment (Duflo, Glennerster & Kremer, 2006). The 1320 farmers at the midline survey were comprised of 767 farmers we could trace from the randomized sample and 557 farmers we could not trace from the randomized sample. Farmers could not be traced back at midline because of challenges with the identification variable we used to match farmers at baseline and midline.1 There were 824 farmers in the randomized sample who could not be traced in the midline sample because of the identification challenges. There was a great deal of duplication between the 824 farmers and the 557 farmers2. To assess the internal validity of the sample, we compared the randomized sample (those who could be traced back and those who could not be traced back during the midline survey) with the farmers that in the midline survey which could not be traced to the randomized sample in terms of the assigned treatments. We also compared the three the three sub-samples by using the multinomial logit model. The results presented in Appendix B show that the randomized sample is not different from the sub-sample from the midline survey that could not be traced to the randomized sample (p>0.10). The findings also show that the treatments were not correlated with the probability that the farmer will be in any of the three sub-samples (p>0.10). The distribution of the treatments in the sample that could be traced was similar to the distribution in the other two samples. With these findings, we have some level of confidence on the internal validity of the sample and thus the estimates will not be biased because of sample attrition.

We also conducted a balance test by using midline survey data to assess the randomness of the treatment assignments. The variables used in the balance test were

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[1] We used names to identify farmers and we noted that some individuals are known by different names, and that some individuals attended the interviews on behalf of their spouses.

[2] That is why the total number is greater than the original sample. However, these could not be match/traced because of the names.

selected via lasso. The results of the balance test are presented in Table 3.

Table 3: Midline Balance Test for the Maize Yield Variable

	Mean/(Var)			Mean Differences		
Variable	(1) Control	(2) Organic Fertilizer	(3) Organic Fertilizer and lime	(1)-(2)	(1)-(3)	(2)-(3)
Age of household head (Years)	46.998	46.943	45.888	0.054	1.110	1.056
	(2455.361)	(2622.243)	(2409.069)			
Primary education (1/0)	0.683	0.701	0.621	-0.018	0.062	0.080**
	(2.466)	(2.553)	(2.646)			
Household size (Number)	5.312	5.453	5.300	-0.140	0.012	0.153
	(47.001)	(48.453)	(58.938)			
Years in Community (years)	37.020	36.448	36.820	0.571	0.200	-0.371
	(3146.829)	(3692.500)	(3280.292)			
Access to extension before trial (1/0)	0.741	0.762	0.735	-0.021	0.006	0.027
	(2.183)	(2.208)	(2.187)			
Time to district headquarters (Min)	137.273	143.331	152.657	-6.057	-15.384	-9.326
	(62441.317)	(87165.413)	(1.11e+05)			
Time to daily market (Min)	38.512	36.893	43.274	1.620	-4.762	-6.381
	(15082.290)	(14773.372)	(15834.867)			
Time to nearest ADMARC (Min)	67.437	60.865	62.792	6.571	4.645	-1.926
	(24108.135)	(22203.471)	(21002.275)			
Number of observations	410	475	427	885	837	902
Number of clusters	37	40	39	72	71	73

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Standard errors in parentheses clustered at the agricultural section level.

The findings show that the samples from the treatments were largely balanced with the control sample and between themselves except for a the proportion of farmers with primary school education. This variable was used as control variable in the estimation of the treatment effects.

4.2.2 Outcome Variables

The primary outcome variable in this study was maize yield, defined as kilograms of maize harvested per hectare and the fertiliser-response rate, measured as kilograms of maize harvested per kilogram of inorganic fertiliser applied. In computing maize yield, we noted that some households recorded very high yields, and others recorded zero yields, largely because of measurement error and the impact of some shocks, respectively. We did not address the impact of shocks that was reflected in zero maize harvests but we addressed the impact of measurement errors by winsorizing the variable at 0% and 95% to ensure that the maximum yield did not exceed twelve tons per hectare, which is a reasonable potential. We calculated the fertiliser-response rate by dividing maize yield by the fertiliser applied per hectare at basal dressing. Partly as a result of logistical challenges, many farmers applied zero inorganic fertiliser, which made the computed rates fertiliser-response rates undefined. We replaced undefined fertiliser-response rates with the within-agricultural section medians.

We used knowledge and adoption of organic fertiliser and lime as secondary outcome variables, which we measured using dummy variables and composite indices. Dummy variables took values of one if farmers indicated they had ever heard about organic fertiliser and agricultural lime and zero otherwise. The composite knowledge indices were calculated based on farmers' responses to a set of statements that described the attributes of organic fertiliser and agricultural lime (Appendix C). Each correct response was assigned a score of 1, while incorrect answers received a score of 0. The composite indices were then calculated as simple averages of the responses. Summary statistics of the outcome variables are presented in Table 4. The distribution of the maize yield and fertiliser-response rates are presented in Appendix D.

Table 4: Comparison of Outcome Variables by Treatment Arm

	Control		Organic Fertiliser		Organic Fertiliser plus lime	
	Mean	SD	Mean	SD	Mean	SD
Maize yield (kg/ha	4332.284	3303.373	3932.691	2315.229	4046.141	2893.787
Fertiliser-response rate (kg of maize/kg of fertiliser)	10.658	10.35	13.616	21.204	12.407	16.428
Know about organic fertiliser	0.990	0.099	1.000	0.000	0.998	0.049
Know about agricultural lime	0.480	0.500	0.527	0.500	0.995	0.069
OF Knowledge Index	0.642	0.161	0.674	0.152	0.635	0.146
Agricultural Lime Knowledge index	0.092	0.170	0.104	0.192	0.267	0.206
Used organic fertiliser	0.726	0.446	0.768	0.423	0.812	0.392

Used agricultural lime	0.002	0.050	0.006	0.080	0.046	0.209

The findings show that farmers in the control arm had the highest maize yield at 4,330 kg/ha, compared to 4,011 kg/ha and 3,966 kg/ha for the organic-fertiliser-plus-lime and organic-fertiliser-treatment arms, respectively. For the fertiliser response, we found that the organic-fertiliser arm had the highest response rate of 13.6 kg of maize per kilogram of fertiliser, compared to 12.6 and 10.6 for the organic-fertiliser-plus-lime and control arms, respectively. The lower yields in the treatment arms were counter to our expectations and the literature on alternative soil-fertility-management inputs. In our trial, we have attributed this to a very high organic fertiliser substitution ratio between organic fertiliser and agricultural lime. The conditional mean for fertiliser-application rate in the control arm was 458 kg per ha compared to 333 kg per hectare for the two treatment arms. This shows that there was a 27% substitution ratio of inorganic fertiliser for organic fertiliser, but studies have recommended a substitution ratio of 8% (He et al., 2022). The higher substitution rate was based on the design of the intervention as presented in Table 1. The findings suggest that the intervention increased the effectiveness of inorganic fertiliser but that the amounts of inorganic fertiliser that were applied in the treatment arms were lower than the amounts applied in the control arm.

Although maize yields in the treatment arms were lower than those in the control arm, they were still higher than the national average, at around two tons per hectare. The level of yields in the control group suggests that, with good agricultural practices, including the right chemical fertiliser application, some soils in Malawi can still produce the yields targeted in the National Agricultural Policy of four tons per hectare.

Knowledge data showed that many farmers know about organic fertiliser, but the depth of their knowledge is low. The average knowledge index for the control group was 0.64, implying that farmers knew 9% (0.64/7) of the attributes that were asked. The findings also showed that 48% of the farmers in the control group knew about agricultural lime but only 2% (0.09/6) of the attributes of agricultural lime they were tested on. Similar patterns were observed regarding usage of the inputs with 72% of farmers in the control arm reporting to have used organic fertiliser and about zero% used agricultural lime.

4.2.3 Compliance with Treatment

Our trial was characterized by some degree of non-compliance with the assigned treatments. We considered farmers to have complied with the treatment if they used organic fertiliser or organic fertiliser plus agricultural lime, depending on the treatment arm to which they were assigned. We present the summary of compliance with the assigned treatment in Table 5.

Table 5: Comparison of Treatment Assignment and Uptake

Uptake	Assignment			Total
	Control	Organic Fertiliser	Organic Fertiliser plus Lime	
Control	319	10	15	344
Organic fertiliser	91	453	31	575
OF plus lime	0	12	381	393
Total	410	475	427	1312

The findings in Table 6 show that 320 farmers (78%) in the control group, 463 farmers (96%) in the organic fertiliser group, and 386 farmers (92%) in the organic fertiliser plus agricultural lime group (92%) complied with the treatments that were assigned to them. Thus, there was low compliance among farmers in the control group. About 22% of the farmers in the control group used organic fertiliser, which was not assigned to them. These were called the "always-takers" (Angrist & Pischke, 2009). The levels of non-compliance by farmers in the organic-fertiliser arm (1%) and the organic-fertiliser-plus-lime arm (8%) were low. If we used treatment assignment to measure impact, the always-takers would potentially bias the estimated treatment effects because they self-selected to adopt a treatment that was not assigned to them (Angrist & Pischke, 2009). The solution to this problem is to use the instrumental variables (IV) estimation technique in which treatment assignment is used as an instrument and treatment uptake is endogenous to obtain local average treatment effects (LATE) (Angrist & Pischke, 2009; Huang, 2018). to assess the potential impact of non-compliance on the treatment effects, we regressed the dummy variable for the always-takers and the compliers within the control group, and we found that the always-takers were different from the compliers. This meant that leaving the always-takers in the estimates of LATE would have biased the estimates. We, therefore, used all the farmers assigned to the control group in the estimation.

4.3 Empirical Strategy

4.3.1 Statistical model

We estimated the intention to treat the (ITT) effects of integrating organic fertiliser and agricultural lime on maize productivity and the adoption of integrated soil-fertility-management inputs by estimating the following regression.

$$Y_i=\alpha+\gamma T_1+\delta T_2+\varepsilon_i \qquad 1$$

where Y_i is the outcome variable of interest that could be the logarithm of maize yield, fertiliser response, and knowledge and adoption of the integrated soil-fertility-management inputs for farmer i; T_1 is a treatment dummy variable taking the value 1 if the farmer was assigned to the treatment arm 1 (organic fertiliser) and zero otherwise; T_2 is a treatment dummy variable taking the value 1 if the farmer was assigned to the treatment arm 2 (organic fertiliser plus agricultural lime) and zero otherwise; and ε_i is the error term. We applied log transformations fertiliser response to attain normal distribution in the dependent variables, but we used maize yield in its natural form because its distribution is almost normal. The parameter γ measures the treatment effect of adding organic fertiliser to Affordable Input Program beneficiaries, while parameter δ measures the treatment effects of adding organic fertiliser and agricultural lime to Affordable Input Program beneficiaries. We clustered the standard errors around agricultural sections.

Recognizing that the unbalanced variables could influence the outcome variable, we also estimated the model by including the unbalanced variables as control variables (Z_i) as in Equation 2. Insignificant control variables were dropped.

$$Y_i=\alpha+\gamma T_1+\delta T_2+\beta' Z_i+\varepsilon_{id} \qquad 2$$

As a consequence of farmers' imperfect compliance with the assigned treatment, we also estimated local average treatment effects because the ITT effects were potentially biased (Huang, 2018; Choi, 2023). In our case, non-compliance would have led to underestimating the treatment effect because the always-takers are in the control group. We, therefore, obtained unbiased treatment effects by estimating the local average treatment effect (LATE) using the instrumental variables technique. The LATE was estimated using the following model specification:

Y_i=α+γD_1+δD_2+ 〖β^′ Z_i+ ε〗_id 3

In model 3, D_1 is the uptake dummy variable taking the value 1 if the farmer the treatment arm 1 (organic fertiliser) used organic fertiliser and zero otherwise; D_2 is the uptake dummy variable taking the value 1 if the farmer in the treatment arm 2 (organic fertiliser plus agricultural lime) applied organic fertiliser and agricultural lime and zero otherwise; and 〖 ε〗_isd is the error term. The treatment assignment dummy variables, T_1 and T_2 were used as instrumental variables (Angrist & Pischke, 2009; Huang, 2018). to confirm the endogeneity of uptake dummy variables, we used the Durbin and Wu-Hausman tests and found insignificant statistics in regression models for maize yield, knowledge of organic fertiliser dummy and index, knowledge of lime index, usage of organic fertiliser, and usage of lime, implying that the uptake variables were exogenous in these regressions. We, therefore, used OLS to estimate the local average treatment effects by directly using the uptake variables. For the rest of the models, we used the instrumental-variable-estimation technique to derive the local average treatment effects.

to confirm the validity of the instruments, we regressed the uptake variables on the instruments and other exogenous variables (see Appendix E for these findings). The findings show a very high correlation between uptake and assignment variables, with an F-statistic greater than 10, implying that our instruments were not weak. We further tested for exogeneity of the instruments using the Sargan and Basmann tests and found that both statistics were insignificant, suggesting that the instruments were not correlated with the error terms and, hence, were valid.

4.3.2 Heterogeneous Effects

We expected the treatment effects to depend on farmers' sex and literacy levels and on pre-treatment access to agricultural-extension services. We expected farming men to experience greater treatment effects than farming women because of underlying differences in access to assets and services. Similarly, more educated farmers were expected to experience greater treatment effects than less educated farmers because they could more easily understand new information and practices. Farmers who had knowledge of and had used soil-fertility-management interventions before the treatment were also expected to have greater treatment effects. We tested the heterogeneous effects of these variables on the intention to treat the effects of the RCT by interacting the treatment assignment variable with these variables. We pooled the treatment arms when assessing the heterogeneous effects.

4.3.3 Mechanism of Impact

To understand the mechanism through which the treatments affected the outcomes, we estimated a simultaneous quantile regression model of the log of fertiliser response, with the same controls as in the original ITT equation and additional controls. The additional control variables were selected through lasso.

4.3.4 Cost-Effectiveness Analysis

In addition to the impact assessment, we assessed the proposed intervention's cost-effectiveness to provide policymakers with information efficiency. We used benefit-cost ratios (BCRs) and incremental cost-effectiveness ratios (ICERs) to assess the interventions' efficiency. The BCRs and ICERs were calculated as follows:

$$\text{BCR} = (\text{Benefits of the intervention})/(\text{Cost of the intervention}) \qquad 4$$

$$\text{ICER} = (\text{Change in benefits of intervention})/(\text{Change in costs of intervention}) \qquad 5$$

The calculation of the ICER compares the costs and benefits of the two treatment arms with the control group. This means that the changes implied in the calculations of the ICER imply subtracting the values from the control group from the values from the treatment arms. The benefits of this intervention refer to the amount of maize produced. In the BCR, we used official minimum maize prices to monetize the maize produced. In calculating the ICER, we used the actual amount of maize harvested in kilograms to measure the benefits. Cost of the interventions were calculated by aggregating all the costs of producing maize on these plots (see Appendix F). All calculations were computed per hectare.

V. Results

5.1 Impact of Soil-Fertility-Management Interventions on Maize Productivity

Table 6 presents the findings from the intention-to-treat (ITT) and local average treatment effects (LATE) of organic fertiliser and organic fertiliser plus lime on maize productivity.

Table 6: Impact of Adding Organic Fertiliser and Organic Fertiliser plus Agricultural Lime on Maize Productivity

Variable		Maize yield			Fertilizer Response	
	ITT no controls	ITT with controls	LATE	ITT no controls	ITT with controls	LATE
Organic fertiliser	-364.109	-360.235	-472.766	0.539***	0.538***	0.718***
	(434.101)	(434.541)	(572.916)	(0.172)	(0.172)	(0.228)
Organic fertiliser plus lime	-319.621	-338.456	-456.734	0.264	0.266	0.425*
	(448.903)	(447.759)	(569.146)	(0.192)	(0.192)	(0.244)
Head with primary education		-319.269*	-320.205*		0.035	0.037
		(178.861)	(178.373)		(0.072)	(0.072)
Constant	4330.259***	4548.543***	4652.777***	1.708***	1.685***	1.523***
	(372.048)	(388.133)	(498.907)	(0.155)	(0.160)	(0.208)
Adjusted R-squared	0.00	0.00	-0.00	0.03	0.03	0.02
N	1312	1312	1312	1312	1312	1312

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Standard errors in parentheses clustered at the agricultural section level.

The findings show that adding organic fertiliser and organic fertiliser plus agricultural lime had no significant treatment effects on maize yield, regardless of whether we used the ITT approach or the LATE approach to estimate treatment effects. Regarding fertiliser response, the findings show that farmers who were assigned to use organic fertilisers produced an average of 54% more maize per kg of chemical fertiliser than those in the control group. Meanwhile, the farmers who were assigned to use organic fertiliser plus agricultural lime did not have significant treatment effects. The LATE estimate for organic fertiliser was 72%, implying that organic fertiliser increased fertiliser-response rate by 72% for the farmers who actually used organic fertiliser. The LATE is greater than the ITT because of the presence of the always-takers whose use of organic fertiliser potentially increased the expected fertiliser response of the control group, thereby reducing treatment effects. The findings show that using organic fertiliser increased fertiliser-response rates but not the use organic fertiliser plus agricultural lime. Testing the equality of the parameters on the two treatments, the findings show that the treatment effects of using organic fertiliser were significantly greater than those of using organic fertiliser plus agricultural lime, based on both the ITT and the LATE.

The non-significant treatment effect on maize yield in the presence of treatment effects on fertiliser response can be explained by the low chemical-fertiliser-application rates. The low application of chemical fertilisers by farmers in the treatment arms was based on the recommendations that were provided in the trial (Table 1). However, the low recommendation in the trial was lower than what has been recommended by He et al. (2022), who recommended an 8% reduction in fertiliser-application rates. In contrast, our RCT recommended a 50% reduction but attained a 27% reduction. The application of lime made the soil very basic, which would likely reduce yields because lime application is recommended for soils with a pH of less than 5.5.

The findings show that adding agricultural lime and organic fertiliser had lower treatment effects on fertiliser response than did adding organic fertiliser alone, which can be explained by our finding that the soils in the study area were not highly acidic, as was earlier anticipated. Low soil organic carbon seems to be a more binding constraint for most Malawian soils than soil acidity. In our context, adding agricultural lime significantly increased the fertiliser-response rate relative to the control but not the organic-fertiliser arm. This suggests that farmers should only be introduced to agricultural lime when soils are highly acidic. The finding also calls for soil testing before the integration of agricultural lime can make economic sense. Empirical evidence suggests that the integration of agricultural lime is not economical for most of Southern Africa because, in most of these countries, soil acidity is not a binding nutrient constraint (Merlos, Silva & Hijmans, 2023).

5.2 Impact of Training in Soil-Fertility-Management Interventions on knowledge

The endline survey data were used to assess the intervention's impact on farmers' adoption and knowledge of soil-fertility-management interventions. Tables 7 and 8 present results on the impact that participation in the soil-fertility-management interventions trial had on farmers' knowledge of organic fertiliser and agricultural lime.

Table 7: Impact of Training Farmers on the Use of Organic Fertiliser and Agricultural Lime on Simple Knowledge of These Technologies

Variable	Organic Fertilizer		Agricultural Lime	
	ITT	LATE	ITT	LATE
Organic fertiliser	0.010^{**} (0.005)	0.012^{**} (0.006)	0.057 (0.055)	0.065 (0.073)
Organic fertiliser plus lime	0.007 (0.005)	0.009 (0.006)	0.506^{***} (0.037)	0.563^{***} (0.051)
Constant	0.990^{***} (0.005)	0.988^{***} (0.006)	0.481^{***} (0.036)	0.467^{***} (0.047)
Adjusted R-squared	0.00	0.00	0.22	0.19
N	1286	1286	1286	1286

Notes: * p < 0.10, ** p < 0.05, *** p < 0.01. Standard errors in parentheses clustered at the agricultural section level.

Table 8: Impact of Training Farmers on the Use of Organic Fertiliser and Agricultural Lime on Comprehensive Knowledge of These Technologies

Variable	Organic Fertilizer		Agricultural Lime	
	ITT	LATE	ITT	LATE
Organic fertiliser	0.037^{*} (0.022)	0.053^{**} (0.022)	0.016 (0.020)	0.020 (0.017)
Organic fertiliser plus lime	-0.011 (0.019)	0.005 (0.020)	0.173^{***} (0.023)	0.184^{***} (0.022)
Constant	0.642^{***} (0.016)	0.627^{***} (0.019)	0.092^{***} (0.013)	0.089^{***} (0.012)
Adjusted R-squared	0.02	0.02	0.14	0.15
N	1278	1278	1286	1286

Notes: * p < 0.10, ** p < 0.05, *** p < 0.01. Standard errors in parentheses clustered at the agricultural section level.

The findings show that participation in the training increased simple knowledge of organic fertilisers by only one percentage point among the farmers who were assigned to this treatment condition. No significant treatment effects were found, however, among farmers who were assigned to use organic fertiliser plus agricultural lime (Table 7). The training increased farmers' comprehensive knowledge of organic fertiliser of farmers assigned to the organic fertilizer arm by 0.04 points (Table 8). The impact was higher (0.05) for farmers assigned to the organic fertilizer arm and had uptake the assigned treatment. There were no significant treatment effects among farmers who were assigned to use organic fertiliser plus agricultural lime.

We also found that the treatment effect of the training on simple knowledge about agricultural lime was significant among farmers assigned to use organic fertiliser plus agricultural lime, but insignificant treatment effects were noted among farmers assigned to use organic fertiliser. The training increased simple knowledge among those assigned to the organic-fertiliser-and-agricultural-lime arm by fifty-one percentage points, and among those who used organic fertiliser and agricultural lime by fifty-six percentage points. The training increased the comprehensive knowledge of agricultural lime of farmers assigned to use organic fertiliser and agricultural lime by 0.17 points. The impact was higher at 0.18 points among farmers who had uptake the assigned treatment. The negligible treatment effects on knowledge are explained by very high baseline levels of knowledge because almost all farmers knew about organic fertilisers before the trial. As expected, there was no significant treatment effect on the knowledge of agricultural lime among farmers who were only exposed to organic fertiliser.

5.3 Impact of Training on Soil-Fertility-Management Interventions on their Adoption

After farmers were exposed to the inputs through the demonstration project and their experimental plots during the first season, we assessed the impact of the trial on the adoption of organic fertiliser and agricultural lime in the follow-up season. In Table 9, we present the results of the training on the adoption of integrated soil-fertility-management interventions.

Table 9: Impact of Training Farmers on the Use of Organic Fertiliser and Agricultural Lime on the on the Adoption of Organic Fertiliser and Agricultural Lime

Variables	Organic Fertilizer ITT	Agricultural Lime LATE	Organic Fertilizer ITT	Agricultural Lime LATE
Organic fertiliser	0.055	0.081*	0.002	0.007**
	(0.045)	(0.044)	(0.004)	(0.003)
Organic fertiliser plus lime	0.088**	0.096**	0.046***	0.050***
	(0.043)	(0.045)	(0.011)	(0.011)
Constant	0.721***	0.704***	0.002	-0.000
	(0.034)	(0.036)	(0.002)	(0.000)
Adjusted R-squared	0.01	0.01	0.02	0.02
N	1281	1281	1286	1286

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Standard errors in parentheses clustered at the agricultural section level.

Our findings show that the intervention affected the adoption of organic fertiliser and agricultural lime. Significant treatment effects for both treatments and on the use of both organic fertiliser and agricultural lime were only observed when we measured the impact through the LATE. The adoption rate for organic fertiliser increased by eight percentage points for farmers who used organic fertiliser and ten percentage points for farmers who used organic fertiliser and agricultural lime. On agricultural lime, we found that the intervention increased the adoption of agricultural lime by one percentage point among farmers in the organic-fertiliser-treatment arm and one percentage point among the farmers in the organic fertiliser and agricultural lime treatment arm. This may be attributed not to the ineffectiveness of organic fertiliser but rather to agricultural lime supply-chain challenges. For organic fertiliser, the increase in the use of organic fertiliser should be considered sizeable, considering that many farmers were already using organic fertiliser before the trial.

Table 10: Heterogeneous Effects of Household Head's Sex, Literacy Level and Baseline Access to Agricultural Extension

	Maize yield	Fertiliser Response	OF Knowledge index	Fertiliser Knowledge index	Used OF	Used Agricultural Lime
Panel A: Sex of Household Head						
Treatment dummy	-548.994	0.510**	0.024	0.101***	0.093	0.015*
	(511.597)	(0.243)	(0.024)	(0.032)	(0.067)	(0.008)
Sex (1=male)	-278.034	-0.006	0.033*	0.005	0.056	0.003
	(369.756)	(0.228)	(0.018)	(0.018)	(0.055)	(0.003)
Treatment#sex	266.644	-0.130	-0.012	-0.015	-0.029	0.010
	(410.004)	(0.247)	(0.022)	(0.029)	(0.064)	(0.011)
Constant	4544.704***	1.713***	0.616***	0.088***	0.677***	-0.000

	(467.772)	(0.225)	(0.020)	(0.019)	(0.056)	(0.000)
Adjusted R-squared	0.00	0.02	0.00	0.04	0.01	0.01
Panel B: Literacy of Household Head						
Treatment dummy	-474.310	0.518**	0.059	0.055	0.050	0.000***
	(657.866)	(0.252)	(0.044)	(0.042)	(0.096)	(0.000)
Head literacy	-361.436	0.204	0.086**	-0.001	0.069	0.003
	(547.328)	(0.184)	(0.036)	(0.031)	(0.082)	(0.003)
Treatment#Literacy	131.551	-0.115	-0.046	0.040	0.029	0.027***
	(648.563)	(0.216)	(0.041)	(0.038)	(0.096)	(0.008)
Constant	4653.880***	1.526***	0.564***	0.093***	0.659***	-0.000
	(555.376)	(0.222)	(0.039)	(0.035)	(0.083)	(.)
Adjusted R-squared	0.00	0.02	0.02	0.04	0.01	0.01
Panel C: Baseline Access to Agricultural Extension						
Treatment dummy	-842.178*	0.309	-0.001	0.069**	0.088	0.004
	(426.009)	(0.205)	(0.025)	(0.028)	(0.065)	(0.012)
Access to extension	-71.305	0.109	-0.008	0.006	0.108**	-0.010
	(392.317)	(0.166)	(0.017)	(0.022)	(0.052)	(0.010)
Treatment#Extension	667.205	0.134	0.021	0.026	-0.024	0.025*
	(448.850)	(0.194)	(0.024)	(0.030)	(0.065)	(0.014)
Constant	4383.347***	1.627***	0.648***	0.087***	0.641***	0.010
	(363.682)	(0.175)	(0.019)	(0.021)	(0.053)	(0.010)
Adjusted R-squared	0.01	0.02	0.00	0.04	0.01	0.01
N	1312	1312	1278	1286	1281	1286

Notes: *** p<.01, ** p<.05, * p<.1. Standard errors are in parentheses. Standard errors are clustered at the agricultural section. The effects were computed after controlling for factors that were tested by using lasso.

5.4 Heterogenous Effects

Table 10 shows the results of our testing for the heterogeneous effects of the sex of the household head, the literacy level of household head, and the households' pre-treatment access to agricultural-extension services on our study outcomes: maize yield, fertiliser response, organic fertiliser knowledge index, fertiliser knowledge index, the use of organic fertiliser, and the use of agricultural lime. The results show that the treatment's impact on agricultural outcomes was influenced by the household head's characteristics, but these effects were generally modest. The treatment improves fertiliser response and knowledge about fertiliser, particularly for male-headed and literate households. However, it appears to reduce maize yield when baseline access to extension services is considered. A detailed discussion of is presented in the following subsections.

Panel A (sex of household head) shows that the treatment did not have a significant effect on maize yield, with a negative, albeit non-significant coefficient. However, the treatment significantly improved fertiliser response by 0.510 units ($p < 0.05$) and increased the fertiliser-knowledge index by 0.101 units ($p < 0.01$). The effects on the organic fertiliser knowledge index, use of organic fertiliser, and use of agricultural lime were positive but not statistically significant, except for a small significant effect on agricultural lime use (0.015, $p < 0.1$). The interaction between treatment and sex of the household head was not statistically significant across all outcomes, indicating that the effect of the treatment did not differ significantly in households headed by men compared to those headed by women. Panel B (literacy of household head) shows that the treatment significantly increases fertiliser response (0.518, $p < 0.05$) and use of agricultural lime (0.000, $p<0.001$). Other outcomes such as the organic fertiliser knowledge index, fertiliser knowledge index, and use of organic fertiliser did not show significant changes that could be attributed to the treatment. The interaction between treatment and literacy showed no significant effects on maize yield, fertiliser response, and knowledge indices, indicating that the treatment's effectiveness did not vary significantly based on the literacy level of the household head. There was, however, a significant positive effect on the use of agricultural lime (0.027, $p < 0.01$), suggesting that literate household heads were more likely to adopt lime use when treated. Lastly, the literacy of the household head had a significant positive effect on the OF knowledge index (0.086, $p < 0.05$) but did not significantly affect other outcomes.

Panel C (baseline access to agricultural extension) shows that the treatment significantly reduces maize yield (coefficient of -842.178, $p < 0.1$), which is contrary to expectations. It also has a positive and significant effect on the fertiliser knowledge index (0.069, $p < 0.05$), but other effects are not significant. There is no significant interaction effect on most outcomes, except for a marginally significant positive effect on the use of agricultural lime (0.025, $p < 0.1$). This suggests that households with prior access to extension services were more likely to adopt lime use under treatment. Lastly, households' baseline access to agricultural-extension services did not significantly affect most outcomes, except for a positive effect on the use of organic fertiliser (0.108, $p < 0.05$).

5.5 Mechanism of Impact

We estimated a quantile regression model of the log of fertiliser response to compare the effects across different points of the distribution (i.e., at the 20th to the 80th quantile) as one way of understanding the mechanism of impact. The results are presented in Tables

11, 12, and figures 5 to 7.

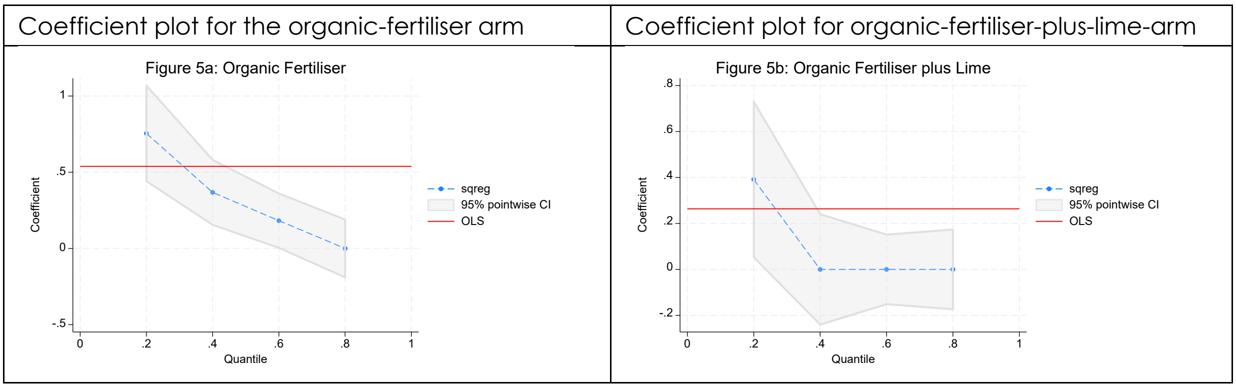
Table 11: Mechanism of Impact on Log of Fertiliser Response at 20th, 40th, 60th and 80th Quantile

Variable	20th quintile	40th quintile	60th Quintile	80th Quintile
Organic fertiliser	0.755**	0.368**	0.182	0.000
	(0.331)	(0.170)	(0.144)	(0.121)
Organic fertiliser plus lime	0.392	0.000	0.000	0.000
	(0.374)	(0.192)	(0.152)	(0.125)
Constant	0.855***	1.792***	2.303***	2.890***
	(0.322)	(0.139)	(0.118)	(0.093)
N	1312	1312	1312	1312

Notes: *** p<.01, ** p<.05, * p<.1. Standard errors are in parentheses. Standard errors are clustered at the agricultural section. The effects were computed after controlling for factors that were tested by using lasso.

These findings are consistent with earlier results but provide an additional nuance that the impact is more significant and higher among farmers with low fertilizer response rates. The size and significance of the impact declines as we move from low quintiles to high quintiles. On the other hand, the return rates for integrating agricultural lime remained below the reference threshold across all quantiles with no clear pattern. These findings suggest that farmers with low productivity due to limited access to traditional inputs such as inorganic fertiliser and complementary inputs would such as organic fertilisers benefit more from using these inputs compared to farmers with better access.

Figure 5: Coefficient Plots for Organic Fertiliser and Organic Fertiliser Plus Lime


Coefficient plot for the organic-fertiliser arm

Coefficient plot for organic-fertiliser-plus-lime-arm

When we add control variables in our intentional-to-treat (ITT) model, we found a similar but more pronounced pattern in organic fertiliser, but no significant impact in the organic fertiliser and agricultural lime treatments (Table 12).

Table 12: Mechanism of Impact on Log of Fertiliser Response at 20th, 40th, 60th and 80th Quantile with Additional Controls

Variable	20th quintile	40th quintile	60th Quintile	80th Quintile
Organic fertiliser	0.850***	0.264	0.127	0.009
	(0.308)	(0.167)	(0.134)	(0.120)
Organic fertiliser plus lime	0.470	-0.081	0.029	0.049
	(0.329)	(0.209)	(0.138)	(0.129)
Household head age	0.004	0.007***	0.004**	0.003
	(0.003)	(0.003)	(0.002)	(0.003)
Relationship with traditional leader	-0.190**	-0.082	-0.045	-0.036
	(0.075)	(0.068)	(0.056)	(0.063)
Access to extension before trial	0.111	0.215**	0.162**	0.237***
	(0.090)	(0.091)	(0.073)	(0.071)
Constant	0.624*	1.385***	2.012***	2.552***
	(0.338)	(0.161)	(0.138)	(0.163)
N	1312	1312	1312	1312

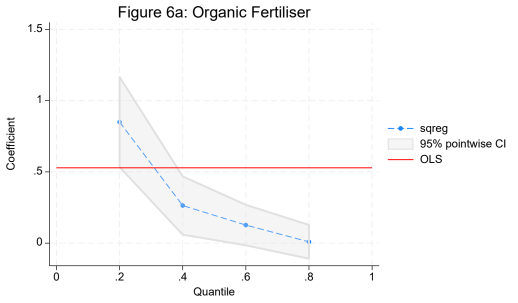
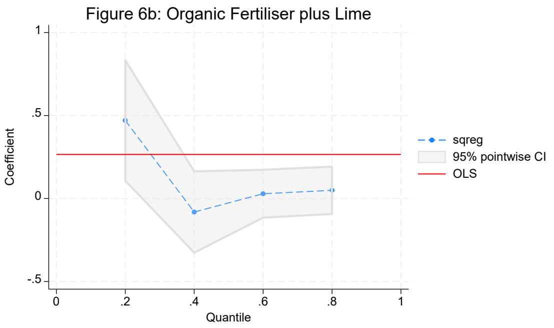
Notes: *** p<.01, ** p<.05, * p<.1. Standard errors are in parentheses. Standard errors are clustered at the agricultural section. The effects were computed after controlling for factors that were tested by using lasso.

The quantile regression results (shown by the blue dashed line in Figure 6) show a similar pattern as above. The treatment effect of organic fertiliser is positive and substantial at the lower quantiles but diminishes toward higher quantiles. This suggests that the treatment effect was more pronounced for farmers at the lower end of the outcome distribution, with a progressively weaker effect as distribution increased. The OLS estimate, represented by the red line in Figure 6, lies within the 95% confidence interval of the quantile regression estimates across all quantiles. However, it masks the nuanced relationship observed in the quantile analysis. Because it only estimates average treatment effects, the OLS estimate fails to capture the variability in the treatment effect across different segments of the distribution. The varying impact of organic fertiliser across quantiles suggests that policy recommendations based solely on average effects could overlook significant nuanced effects experienced by different subpopulations of farmers within the distribution.

As for the organic-fertiliser-plus-lime treatment arm, the results show that the effect remains relatively consistent across the distribution (Figure 5). The estimates fluctuate slightly around the mean but remain within a narrow range, suggesting that the organic-fertiliser-plus-lime treatment exerted a fairly uniform effect across different quantiles of the fertiliser response distribution. Similarly, the OLS coefficient, represented by the red line in

Figure 5, lies within the 95% confidence intervals (shaded area) of the quantile regression estimates across all quantiles, implying that the average effect captured by OLS was representative of the treatment effect throughout the distribution. There was no significant variability that an OLS approach would miss. The narrow confidence bands observed across most quantiles further support the robustness of these findings.

Figure 6: Coefficient Plots of Heterogenous Effects of Organic Fertiliser and Organic Fertiliser Plus Lime after Controlling for Variables That Failed Balance Tests

Coefficient plot for the organic-fertiliser arm	Coefficient plot for organic fertiliser plus lime
	

Regarding the effect of the control variables, we find that fertilizer response for farmers in the lowest distribution of fertilizer response (20th quintile) is negatively affected by the relationship with the traditional leader. Farmers that are related to a traditional leader and operate in the lowest fertilizer response quintile have lower response rates than farmers with no relationship. There are positive and significant relationships between fertiliser response rates, and age of the household head and access to agricultural extension for farmers from the 40th to the 80th quintile. The size of the impacts reduces as we go higher on the fertilizer response rates distribution. Older farmers have higher fertiliser response rates which may be due to higher access to inputs and more knowledge of crop production. Access to agricultural extension increases fertilizer response rates due to improved agronomic practices that are imparted on the farmers through extension services.

5.6 Cost-Effectiveness of the Interventions

Considering the differences in the amount of fertiliser applied, we calculated actual and expected cost-effectiveness indicators. The actual cost-effectiveness indicators were based on average yields from the intervention arms, while the expected yield was calculated based on the required amount of fertiliser and the fertiliser-response rates. We present the findings for the cost-effectiveness analysis in Table 13 below.

Table 13: Cost-Effectiveness of Adding Organic Fertilizer and Organic Fertilizer Plus Agricultural Lime

	Actual			Expected		
	Control	Organic Fertiliser	Organic Fertiliser plus Lime	Control	Organic Fertiliser	Organic Fertiliser plus Lime
Maize yield (kg)	4,330	3,966	4,010	4,850	6,229	5,711
Maize price (MK/kg)	660	660	660	660	660	660
Revenue (MK)	2,857,800	2,617,560	2,646,600	3,201,145	4,111,008	3,769,432
Cost of production (MK)	2,069,020	2,589,020	3,568,831	2,069,020	2,589,020	3,568,831
Gross margin (MK)	788,780	28,540	(922,231)	1,132,125	1,521,988	200,600
BCR	1.38	1.01	0.74	1.55	1.59	1.06
ICER (MK/kg)		(1,428.57)	(4,686.91)		377.20	1,741.86

The interventions were not cost-effective when considering actual maize yield, as shown by very low BCRs and negative ICERs. BCRs of less than unity imply that for every Malawian kwacha invested, the intervention generates less than 1 kwacha in benefits. At the same time, the negative ICERs suggest that the interventions were less effective and more costly. However, the expected BCRs and ICERs based on the fertiliser-response rates and expected fertiliser-application rates show that the interventions were effective. The organic-fertiliser intervention was the most efficient, with a BCR of 1.59 (i.e., higher than the control group, which had a BCR of 1.55). Organic fertiliser plus agricultural lime was the least efficient, with a BCR of 1.06, because of the lower acidity of the soil. This result is corroborated by the ICERs, which were MK377.20/kg and MK1,741.86/kg for the organic fertiliser and the organic-fertiliser-plus-agricultural-lime interventions, respectively. These findings imply that the additional kilogram of maize in the organic-fertiliser arm cost MK377.20 to produce, which was lower than the minimum official selling price, thereby making the intervention profitable. A kilogram of maize under the organic-fertiliser-plus-agricultural-lime arm cost MK1,741.86 to produce, more than double the official minimum selling price. The result shows that for soils whose acidity is not too high, integrating organic fertiliser is an efficient soil-fertility-management intervention and not liming.

VI. Conclusions and Policy Implications

We investigated whether integrating organic fertiliser and organic fertiliser plus agricultural lime into agricultural inputs subsidy programs (ISPs) would improve maize productivity within the specific context of Malawi's Affordable Inputs Program. study also assessed the impact on adoption rates of introducing organic fertiliser and organic fertiliser plus agricultural lime through demonstration plots and farmer-managed experimental plots as well as the cost-effectiveness of the intervention.

Evaluating the impact of these interventions on maize productivity is critical for countries such as Malawi that are experiencing falling or stagnant yields in their staple food crops because of deteriorating soil health and resulting low yields. For Malawi, historical estimates for maize, a staple food crop, have shown yield-response rates falling from roughly 18 kgs maize/kg N between the mid-1980s to mid-1990s, to around 2.6 kg maize/kg N on average against the regional averages of between 35-37 kgs maize/kg N on experimental plots (Burke, Snapp & Jayne, 2020). Complementary inputs, such as organic fertiliser and agricultural lime are believed to ameliorate the negative effects of poor soil health and improve productivity (Merlos, Silva & Hijmans, 2023).

We conducted a cluster Randomized Control Trial (cRCT) in the Mzimba and Nkhotakota districts targeting Affordable Input Program beneficiaries. We estimated the intention-to treat-effects and the local average treatment effects (LATE) to account for non-compliance encountered during implementation. Cost-effectiveness was measured by using the benefit-cost ratios and incremental cost-effectiveness ratios.

Our results show that integrating organic fertiliser and organic fertiliser plus agricultural lime into the Affordable Input Program significantly increased the fertiliser-response rate (i.e., the quantity of maize produced per kg of fertiliser). However, the marginal effect of liming over organic fertiliser is slightly muted by the fact that the soils in the two districts are not highly acidic and, thus, do not require liming. In such contexts, then, liming cannot be expected to enhance yield significantly. Concerning impact mechanisms, the results show strong but waning impacts of integrating organic and agricultural lime at all quantiles. The effect of integrating agricultural lime, though significant, is more muted throughout the quantiles. Further, we did not find any treatment effects on maize yield because the farmers assigned to use organic fertiliser and agricultural lime were asked to use less inorganic fertiliser.

The analysis of the heterogeneous effects of the treatment shows that the household head's characteristics influenced the impact of the treatments on various agricultural outcomes, but these effects were generally modest. The treatment improved fertiliser response and knowledge about fertiliser, particularly for literate households and those headed by men. However, it appears to have reduced maize yield when baseline access to extension services were considered. The interaction effects show that treatment's effectiveness varied slightly with literacy and prior extension access, particularly in promoting agricultural lime use.

Regarding the mechanism of impact, the results show that providing complementary inputs accompanied by extension support was more beneficial for poor farmers who were previously not meaningfully exposed to these inputs. Also, those who had lived a long time in a community and had stronger connections were more likely to experience stronger impacts of integrating complementary inputs.

The results also clearly show that organic fertiliser should be used alongside chemical fertilisers to increase their effectiveness. To obtain optimal results on maize yield, farmers should apply sufficient chemical fertiliser in combination with organic fertiliser. The insignificant findings on integrating organic fertiliser and agricultural lime with chemical fertiliser point to the need to conduct soil tests before soils are limed. In our intervention, soil test results were not conducted in all fields, and we used a blanket recommendation made by the government for the whole district. This implies that integrating organic fertilisers and agricultural lime with chemical fertiliser can work well with the availability of soil testing services.

We also show that the intervention increased the use of organic fertiliser and agricultural lime among the treated farmers. It is interesting to note that the increase in the use of organic fertiliser and other complementary inputs was attributed to the trial. Despite a number of projects promoting the use of organic fertiliser, adoption had been low. We suspect that the introduction of the trial increased the likelihood of farmers adopting the technologies.

Based on these findings, we recommend that organic fertilisers be integrated into the Affordable Input Program. This integration should be accompanied by the delivery of extension services as a package.

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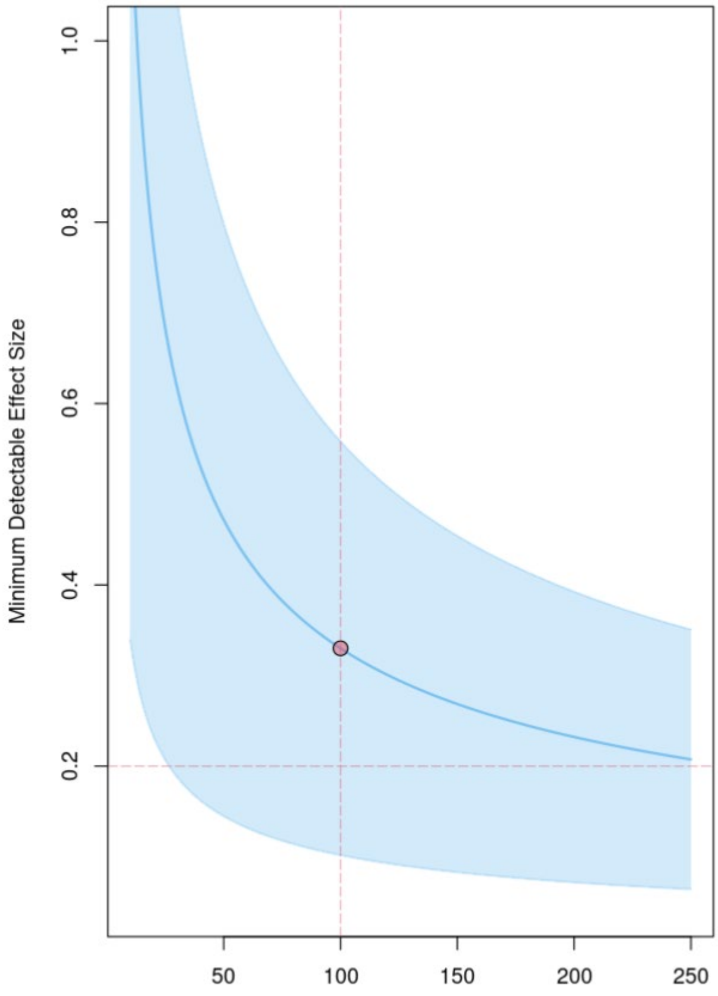
Appendices

Appendix A: Power Calculations



Appendix B: Correlation Between Attrition Variable and Treatment Variable

Appendix B1: Correlation between the randomized sample and the new sample at midline

	Coefficients
Organic Fertilizer	-0.000
	(0.045)
Organic Fertilizer plus Agricultural Lime	-0.065
	(0.045)
Constant	0.765***
	(0.032)
chi2	
N	2141

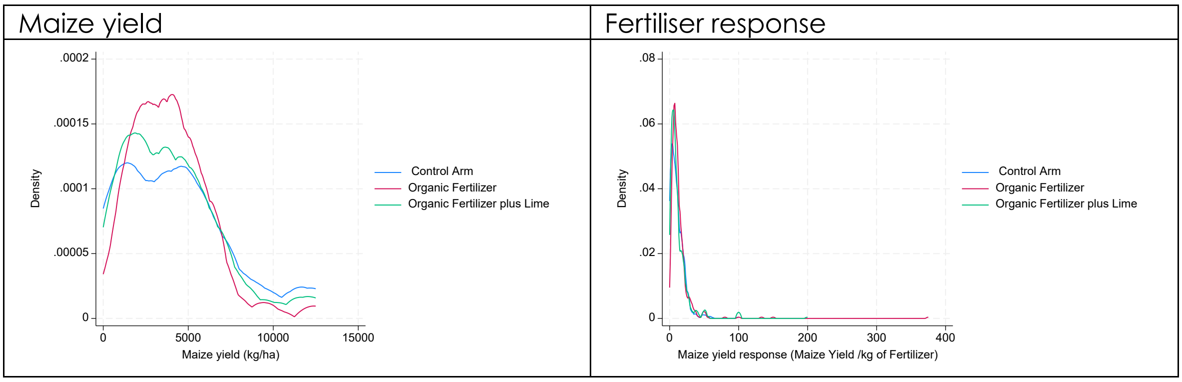
Notes: Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Appendix B2: Comparison Between maintained sample, the new sample at midline, and the untraced randomized sample

	New midline sample	Untraced randomized sample
Organic fertilizer only	-0.185	-0.377
	(0.378)	(0.334)
Organic fertilizer plus lime	0.393	0.105
	(0.385)	(0.340)
Constant	-0.397	0.171
	(0.266)	(0.228)
chi2	4.37	
N	2141	

Notes: Standard errors in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01

Appendix C: Distribution of Maize Yield (kg/ha) and Maize Response Rates to Fertiliser (Kgs Maize/Kg of Fertiliser) by Treatment Arm



Maize yield

Fertiliser response

Appendix D: Correlations of Treatment Uptake Variables and Treatment Assignment Variables

	Uptake the Organic Fertiliser	Uptake Organic Fertiliser Plus Lime
Organic fertiliser	0.746***	0.012*
	(0.034)	(0.006)
Organic fertiliser and lime	-0.171***	0.919***
	(0.035)	(0.020)
Sex of farmer (male=1)	-0.019	0.005
	(0.023)	(0.013)
Literacy of household head	0.028	-0.020
	(0.045)	(0.016)
House with a mud floor	-0.010	0.015
	(0.015)	(0.012)
Household head with primary education	0.003	-0.006
	(0.039)	(0.011)
Household head with secondary education	0.010	-0.011
	(0.039)	(0.014)
Time to reach government school	-0.000	-0.000
	(0.000)	(0.000)
Constant	0.219***	0.016
	(0.045)	(0.017)
Adjusted R-squared	0.67	0.86
N	1312	1312

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Standard errors are in parentheses.

Appendix E: Statements Used to Generate Knowledge Indices

No	Statements	Yes	No
Knowledge Index of Organic Fertiliser			
1	Benefits of: Improve soil nutrient content	1	0
2	Benefits of: Improve ability of soil to retain water	1	0
3	Benefits of: Improve ability of the soil to release nutrients to plants	1	0
4	Knowledge of: OF should be used instead of IF	0	1
5	Knowledge of: IF are better than OF	0	1
6	Knowledge of: IF should be used together with OF	1	0
7	OF cannot replace IF	1	0
Knowledge Index of Agricultural Lime			
1	Which type of soils require the application of agricultural lime? Acidic soils	1	0
2	Which type of soils require the application of agricultural lime? Less fertile soils	0	1
3	Which type of soils require the application of agricultural lime? Sandy soils	1	0
4	Which type of soils require the application of agricultural lime? Clay soils	0	1
5	How do you know whether your soils need lime or not? When the soil is less fertile	0	1
6	How do you know whether your soils need lime or not? The soil should be tested	1	0

Appendix F: Costs of Producing Maize Under The Three Intervention Arms

	Price (MK)	Control		Organic Fertiliser		Organic Fertilize plus Agricultural Lime	
		Quantity	Amount (MK)	Quantity	Amount (MK)	Quantity	Amount (MK)
Seed	1100	25	27,500	25	27,500	25	27,500
Lime	467.12	0	-	-	-	1,937	904,811
Land preparation	150000	1	150,000	1	150,000	1	150,000
NPK	87000	458	796,920	333	579,420	333	579,420
UREA	85000	458	778,600	333	566,100	333	566,100
Funani Organic fertiliser	291.67	0	-	3,000	875,000	3,000	875,000
Transport costs (Fertiliser)	16000	1	16,000	1	16,000	1	16,000
Labour costs (planting)	75000	1	75,000	1	75,000	1	75,000
Labour costs (weeding)	150000	1	150,000	1	150,000	1	150,000
Labour cost OF application	75000	0	-	1	75,000	1	75,000
Labour costs (fertiliser application)	75000	1	75,000	1	75,000	1	75,000
Labour costs (lime application)	75000	0	-	-	-	1	75,000
Total			2,069,020		2,589,020		3,568,831