The impact of agricultural extension and input subsidies on knowledge, input use and food security in Eastern DRC

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Abstract

Small holder farming in sub-Saharan Africa is plagued with low productivity and technology levels. We use a field experiment in Eastern DRC to examine the impact of an agricultural extension program and input subsidy scheme on knowledge, input use and food security. We find little evidence for synergistic benefits in our study sample. While we find a positive impact of extension on knowledge, yields and food security, adding input subsidies does not generate additional gains. In addition, we find that proximity to treatment villages increases the transfer of knowledge of inputs use, but not that this does not translate in additional yields, food security or resource use. Furthermore, we find that project impacts vary by household characteristics such as proximity to markets, soil quality of plots owned and willingness to learn about new technologies. These findings have implications for policy makers attempting to seek to stimulate agricultural led growth strategies.

1. Introduction

Smallholder farmers in sub-Saharan Africa face acute constraints to productivity due, amongst others, to poor output price incentives, high input prices, lack of liquidity, poor access to functioning credit markets, and lack of knowledge. Two primary tools for raising smallholder incomes and improving food security are agricultural extension and input subsidies. Extension primarily targets information gaps through the transfer of knowledge on, and experimentation with, higher-yielding inputs and farming techniques. Input subsidization programs, directly aim to address constraints of high input prices, poor liquidity, and barriers to credit by lowering input prices; thus opening input markets to farmers previously excluded. This paper assesses the effectiveness of these two different agricultural policy tools. In particular, we focus on the existence of potential synergistic benefits of using both tools simultaneously for multi-constraint targeting. Furthermore, we explore heterogeneity of program impact across space and within subgroups.

Theoretically, the two policy tools of agriculture extension and input subsidy programs could have synergistic benefits if provided in conjunction. If farmers are poorly informed with no or limited access to credit markets and face high transportation costs to input and output markets, then provision of one or the other intervention may not be sufficient for increasing technology adoption and food security. However, little systematic evidence on the impact of complementary provision of the two interventions exists.[1] This also holds more generally: there is a clear lack of understanding on how interventions that try to relax a single adoption constraint fare relative to interventions that try to overcome multiple barriers simultaneously (Jack, 2013). Additionally, despite the popularity of both types of programs, evidence on their independent effectiveness remains limited and estimated results are confounded by issues of endogeneity, selection bias, and measurement error (Birkhaeuser, Evenson, and Feder, 1991; Anderson and Feder, 2007; Morris et al., 2007).

This paper aims to increase the evidence base on joint provision of extension services with input subsidies and assesses impacts on smallholder knowledge, input uptake, productivity and food security. Our study design features three treatment arms: one group receiving an extension project, one receiving the same extension project plus the possibility to purchase subsidized inputs, and a control group. This design facilitates a causal analysis on the effectiveness and complementarity of two key agricultural development policy tools as well as well as an exploration of potential channels through which the interventions may operate. We hypothesize that improved welfare and food security comes about through a causal chain starting with an increase in (i) knowledge that translates into (ii) higher adoption of new inputs and crop management techniques, which results in (iii) better yields that produce (iv) higher incomes and (v) increased food security.

[1] One reason for not having an abundance of joint programs around may be due to potential conflicts of interest if information providers are also responsible for managing offers and distribution of subsidized inputs (Anderson and Feder, 2007).

We further extend the literature on extension and subsidy schemes to the Democratic Republic of the Congo (DRC); a region ranked among poorest and least food security in the world with high malnutrition rates and is severely challenged by infrastructural, institutional, and market constraints than countries previously studied.

We find little evidence for synergistic benefits in our study sample. While we find a positive impact of extension on knowledge, yields and food security, we find that the addition of input subsidies does not generate additional gains. We examine our findings in more detail by doing an analysis of spillover effects and heterogeneous treatment effects. We find that proximity to treatment villages increases the transfer of knowledge of inputs use. However, there are no spillover effects in terms of increased yields or food security there. This suggests that extension sessions convey other – more hands-on – knowledge, which does not readily transfer between villages. Furthermore, we find that project impacts vary by household characteristics such as proximity to markets, soil quality of plots owned and willingness to learn about new technologies. These findings suggest that NGOs seeking to implement an extension scheme should focus on geographic breadth, rather than depth. As complex information responsible for intervention benefits does not transmit easily between villages and since household response to the intervention varies by attributes, practitioners seeking to implement an extension scheme should prioritize geographic breadth and targeted household participation.

The outline of our paper is as follows. Section 2 explores existing literature on the effectiveness of agricultural extension and input subsidy programs as well as the literature on the determinants of agricultural technology adoption. In section 3 we describe the agricultural context of eastern DRC and the intervention design. In section 4 we discuss the data. In section 5 we discuss our empirical strategy to identify the ITT effects of the treatments on knowledge, adoption, yields and food security. Section 6 presents the results, including treatment spill-overs and heterogeneous impacts. Section 7 concludes.

2. Literature Review

Our study speaks to three existing literatures. First, we contribute to empirical research that measures the impact of agricultural extension programs and, second, to the debate on the effectiveness of input subsidy programs. Third, our study contributes to the existing discussion on the determinants of technology adoption, particularly within the agricultural sector. We discuss each of these literatures in turn.

Extension services can take many forms including farmer field schools, training and visit systems (T&V), innovation platforms and fee-for-services (Aker, 2011; Kondylis et al., 2014). Earlier attempts to evaluate the effectiveness of these initiatives have largely been non-experimental (see e.g. Birkhaeuser, Evenson and Feder, 1991; Davis, 2008; Dercon et al., 2009; Rivera, Quamar and Crowder, 2001). Yet, a recent strand of literature has employed novel experimental or quasi-experimental designs to address non-random assignment and participation. The picture emerging from these studies is that extension services have only limited impact on technology adoption.

Duflo, Keniston and Suri (2014) assess the impact of a coffee training program in Rwanda on the adoption of 'best practices' for growing coffee. By randomly assigning farmers to a training program and varying the proportion of applicants within treatment communities, they study adoption rates and speed of diffusion for the different types of recommended practices. They find increased levels of awareness across practices, but behavioral change was observed only for those practices that require minimal adoption effort. Agyei-Holmes et al. (2011) evaluate the effectiveness of the Millennium Challenge Account-Ghana program using a randomized phased-in design. The intervention entails training farmer-based organizations in improving their business capacity through technical skills and helping them connect to value chains. They find no effect on crop yields or income. Pamuk et al. (2014, 2015) use an experimental design to investigate whether innovation platforms[2] are able to boost adoption of improved agricultural practices. They find suggestive evidence of innovations platforms outperforming traditional extension approaches in terms of poverty alleviation, yet adoption only increases for one out of four types of technology domains, with considerable heterogeneity across sites.

[2] These are centralized initiatives at the village level where the various stakeholders, ranging from research experts to government representatives, producers, customers, and financial organisations come together to identify and propose solutions for local bottlenecks to agricultural development.

Kondylis, Mueller and Zhu (2014) evaluate the impact of a randomized T&V system to increase adoption of sustainable land management (SLM) practices in central Mozambique, where they compare the standard T&V model to a modified version. In the standard T&V system, extension agents are trained by technical staff from the Ministry of Agriculture (MINAG), and subsequently train 'contact' farmers in their communities on new SLM techniques, under the expectation that contact farmers will transmit this information to those within their communities. In the modified version contact farmers receive the same training directly from the MINAG's technical workers. They find that a direct training of contact farmers leads to higher levels of demonstration, private adoption, and learning-by-doing among these contact farmers, yet has limited impact on adoption levels of SLM techniques among other farmers in the community.

Regarding input subsidy programs, the past ten years have witnessed a revival of programs with greater emphasis on better targeting those considered most in need, improved linkages with other markets, and better facilitation of commercial fertilizer sales (e.g. World Bank, 2007; Morris, 2007). Yet again, there is little consensus or rigorous assessment of these programs (see Jayne and Rashildl 2013; Druilhe and Barreiro-Hurlé 2012; Morris 2007 for recent syntheses on the evidence). Exceptions include a randomized control trial by Duflo et al. (2011), which estimated a positive impact of fertilizer vouchers on fertilizer use, and a recent experimental study by Carter et al. (2014), which reported positive impacts of vouchers for fertilizer and improved seeds that were consistent with a social learning model of adoption. They found an increased use of fertilizer for households with a higher proportion of social network members receiving the voucher. These studies suggest that liquidity constraints form an important barrier to adoption of modern farming technologies.

Finally, we contribute to the literature on the determinants of technology adoption. Theoretically, the level and speed of adoption and diffusion often observed within Sub-Saharan Africa are considered sub-optimal (see e.g. Foster and Rosenzweig, 2010; Conley and Udry, 2010; Giné and Yang, 2009; Bandiera and Rasul 2006). This study is among the first that estimates the causal incremental impact of a subsidized inputs offer in conjunction with agricultural extension, thereby testing whether addressing information, input supply-and financial constraints simultaneously leads to greater improvement in outcomes compared to addressing information gaps alone.

We extend the research beyond the immediate causal effect of the two agricultural policy tools to explore the underlying mechanisms potentially amplifying observed outcomes. Furthermore, we analyze heterogeneity of impacts across five types of farmer characteristics: gender of the household head, security of property rights, distance to markets, use of media for agricultural learning, and the soil quality of farm plots. These dimensions were selected as they can offer insights into the channels through which our interventions affect knowledge, production, and food security outcomes of interest. In particular, they shed light on the relative importance of different types of binding constraints to technology adoption.

Gender of the household head

Female-headed households have been found to have higher constraints in access to knowledge and resources and are frequently targeted by development programs (see Quisumbing and Pandolfelli, 2010). Under such conditions, we would expect to observe larger treatment effects on female-headed households as greater informational, liquidity, and market access barriers are overcome. However, our treatment was not targeted to female-headed households, so it is possible that information flows did not reach females to the same extent as it reached male farmers. For example, female-headed households may have benefited less from the extension trainings if they were socially more distant from the trained community farmers (Magnan et al., 2015). This would result in weaker treatment effects on the knowledge of and use of inputs. Furthermore, as control villages have a significantly higher fraction of female-headed households (Table 2), this gender-based heterogeneous treatment effect analysis serves as a robustness check on whether the gender imbalance between groups is biasing the intention-to-treat effects observed earlier.

Security of property rights

It has been theoretically well established that more secure property rights reduce investment risk and increase access to credit, thus positively affecting agricultural production investments (Besley, 1995). However, evidence suggests that in areas governed by informal property right institutions, the relationship between land tenure security and investment may actually be reversed. Braselle et al. (2002) argue that investment instead drive land tenure security. They explain this one-directional effect as investments acting as a visible indication of land-use, a major pillar of informal property right systems. At the same time, tenure provides little benefit for access to credit, as formal credit markets are generally poorly functioning in those regions governed by informal property right systems. Similarly, Goldstein and Udry (2008) suggest that investments in soil fertility may strengthen land claims by shortening fallow periods and therefore increasing visible land use. In a meta-study, Fenske (2011) finds a stronger relationship between property rights and investment for longer run investments, e.g. tree-planting, compared to shorter run investments, e.g. fertilizer use.

Our study area is a region characterized by informal land tenure systems, weak formal credit markets, and high levels of migration due to protracted conflict. Therefore, the relationship between property rights and intervention effects is of interest. Farmers within our sample fall into one of two categories, either above 80% ownership of farmed land, or below 20% of ownership. This strong dichotomy in property rights within our sample provides an interesting variation to explore. Under traditional theories of property rights and production investment, the farmers in the >80% group will have stronger intervention effects on input adoption. Yet if investments instead drive improvements in tenure security, we expect to observe the <20% group responding more strongly to the intervention.

Distance to markets

Distance to input markets is likely to affect farmers' expectations of the ongoing benefits to be gained from training and input subsidy programs. Households living closer to input markets have stronger incentives to acquire knowledge and experiment with new inputs as they have a greater probability of continued access to inputs even after conclusion of the program (Jacoby, 2000). As input markets are typically in close proximity to output markets, households living closer are better able to capitalize on gains in quality or quantity of crop production through direct market sales (Ali, 2011). However, these stronger incentives to participate may be offset by less demand for the extension and subsidy interventions as households closer to markets are less likely to be constrained by information gaps and access to inputs (Abebaw and Haile, 2013). With this rational, we would expect the impact of the program to be most pronounced for households close enough to markets to expect long term benefits from new knowledge about improved inputs, but far enough for information gaps and access to markets to pose real constraints. We therefore split the sample by terciles of market distances in the analysis to assess the relationship between distance to market and marginal returns of our study's interventions on the outcome of interest set.

Use of Media for Learning

A large part of the training component in each intervention is based on the transfer of information regarding new crop management processes and technologies. Farmer-led extension services consist of training a small number of farmers in each village and then rely on interactions between farmers (or "social learning") for the dissemination of knowledge (see Carter et al., 2014). Besides having differential social distance to trained-farmers, households vary in terms of effort exerted in seeking out information. Even in the absence of extension programs, some households more actively educate themselves on agricultural developments through media outlets such as newspapers, leaflets and the radio. We term these households 'active-learners'.[3] To the extent that the intervention offers information that is new within the region, we expect program impacts to be stronger for active-learners. The local availability of information covered in the extension trainings varies with some topics being covered by local media sources and others being newly introduced to the region by the intervention. For 'active-learners', we expect to see more significant impacts

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[3] We do not delineate between active-leaners motivated by higher intrinsic demand for knowledge, lower cost to access knowledge, or stronger interest in the intervention technologies, but merely distinguish between those individuals who report using media outlets to gain knowledge versus those who do not.

on outcomes reflecting knowledge of new topics in comparison to knowledge on topics discussed by local media.

Soil Quality

Plots with more fertile soil produce larger crop yields, but the impact of soil fertility management strategies on yield gains may not be a directly linear relationship (Sauer and Tchale, 2009; Matsumoto and Yamano, 2009). The use of chemical fertilizer independently has varied results when analyzed by initial soil quality levels, ranging from no differentiation in yield gains (Matsumoto and Yamano, 2009) to lower effects on fields with more fertile soil quality pre-intervention (Sileshi et al., 2010). Marenya and Barrett (2009) instead found that farmers with higher soil quality had stronger fertilizer demands, driven by higher marginal returns to fertilizer use. The arising discontinuity in fertilizer demand would suggest that improving access to fertilizer may not be sufficient for increasing adoption of fertilizer amongst smallholder farmers.

However, more integrated soil fertility management approaches that combine the application of chemical fertilizer, improved seeds, and legume production were found to outperform chemical fertilizer alone in generating yield gains (Sileshi et al., 2010). Legume production was found to be more beneficial to sensitive and less resilient soils while fertilizer was more effective on plots with higher soil quality (Sileshi et al., 2010). This integrated soil fertility management approach thus targets a wider range of soil qualities and may be more effective in increasing yield gains for a diverse set of farmers. Our study relies on self-reported soil fertility at baseline, where farmers were asked to indicate the fertility of their plots on a five point Likert scale. We would expect to see larger intervention effects on outcomes measuring knowledge for farmers with lower soil fertility as these households have greater incentive to explore fertility improving technologies. However, based on existing literature we do not anticipate these effects to be sustained further down the causal chain in the form of increased use of improved inputs or larger gains in crop yields.

3. Project area and intervention design

Our study is set in eastern DR Congo, a region facing severe infrastructural and market under-development. Farmers face numerous challenges in crop production including protracted violent conflict, extreme poverty and unfavorable climatic conditions (Ansoms and Marivoet, 2010; Vlassenroot and Raeymaekers, 2004). With more than 70 percent of its population holding their primary employment in the agricultural sector, the majority being rural smallholder producers, agriculture is an impactful sector to target for economic growth efforts. The area demonstrates high potential for sustainable agricultural growth, but as a result of recurring violence and high population displacement, agricultural development initiatives have been obstructed (Vlassenroot and Raeymaekers, 2004). Currently, the region ranks amongst the highest in the world for food insecurity and malnutrition rates and is classified as a low-income food-deficit country (LIFDC) (Lambrecht et al. 2016; WFP 2014; UNDP, 2015). Recognizing the need to strengthen agricultural sector performance, the Congolese government has identified increased agricultural productivity and connecting farmers to markets as key priorities in their Poverty Reduction Strategy Paper (PRSP) and National Agricultural Investment Plan 2013-2020.

In this context, DRC, together with seven other Sub-Sahara African countries, was selected for the first phase of the so-called N2Africa program that kicked off in 2009. The primary objectives of the N2Africa program are to improve agricultural yields, food security, and incomes while increasing soil health through the delivery and dissemination of technologies that advance biological nitrogen fixation (BNF) through grain legumes production.[4] N2Africa specifically targets smallholder farmers in sub-Saharan Africa, as nitrogen depleted soils are ubiquitous across sub-Saharan Africa and are a key contributor to low agricultural yields among rural subsistence producers. N2Africa's focus is the use of Rhizobia, bacteria which attaches themselves to the plant root and naturally converts nitrogen from an atmospheric gas-state (NH_2) into ammonia (NH_3), making it available for direct absorption for the host plant (Wagner, 2012). The result is a symbiotic relationship in which the Rhizobia obtain energy from the plant while the plant benefits from higher nitrogen levels in the

[4] Legumes are interesting crops to produce for African smallholders, many of whom are seeking opportunities to diversify income sources and improve their diets that often contain insufficient protein (Woomer et al., 2014).

surrounding soil (Mulongoy, 1992). BNF is considered to have great potential in increasing agricultural intensification by sustainably improving soil fertility thus increasing yields (Peoples et al., 1995).

While the whole of the N2Africa program spans three agro-ecological zones East, Central, and West Africa, our study area focuses exclusively on the eastern Congo in the province of South-Kivu (see Figure 1). The research area stretches along three axes within the South-Kivu province. The Northern Axis stretches north from the provincial capital of Bukavu following the shore of Lake Kivu, at an altitude of some 1500m. The Western Axis is located in the highlands to the west of Bukavu. The Southern axis comprises the Ruzizi plain to the south of Bukavu, at an altitude of 600m. Soil type, rainfall, temperatures, sunlight, and land use vary substantially across the three axes, necessitating careful tailoring of agricultural interventions to fit local agro-climatic needs.[5]

The N2Africa program in Eastern DRC is managed by the International Center for Tropical Agriculture (CIAT), the International Institute for Tropical Agriculture (IITA), the Consortium for Improving Agriculture-based Livelihoods in Central Africa (CIALCA), and the Catholic University of Bukavu (UCB). As the delivery and dissemination of inputs and BNF technologies lie at the heart of the N2Africa programs, N2Africa teams up with "outreach partners" that make use of local organizations to conduct the relevant N2Africa activities in communities of the target region (Woomer et al., 2014). In South-Kivu, N2Africa formed partnerships with 6 locally operating NGOs, each of which had prior experience with agricultural development initiatives undertaken within the designated project zone.

N2Africa training intervention

The N2Africa intervention begins by establishing experimental trials during which the production of legumes using traditional techniques is compared to production using new techniques and improved inputs. For the eastern DRC program, the trials were conducted at

[5] Our intervention worked closely with communities to fit these variabilities. In our analysis we include community fixed effects to control for wide heterogeneity across axes as well as variations in implementing partner protocol executions and potential unobservables between communities.

the research station in Kalambo (close to Bukavu) and managed by researchers from CIAT, these trials primarily consisted of the intercropping of soybean with either cassava or maize. Local farmers can attend the demonstration plots and associated demonstration meetings to learn about the improved production processes and inputs. Farmer groups and extension workers visiting these trials are able to select the improved inputs and processes they expect to be most successful given local constraints and conditions.

Extension workers travel to interested villages, consult with the local authorities and begin “sensitizing” interested households and farmers’ groups (some 15-30 farmers) on the use of new techniques and inputs. During these visits extension workers engage famers in a ‘situation analysis’ to identify local needs and constraints. Participating communities, in conjunction with extension workers, select ‘master’ farmers from eligible individuals who are able to read and write, are landowners, have extensive experience in farming, and have access to external sources for agricultural advice and improved inputs. Master farmers receive legume technology packages that include inputs for a legume of choice (seed, fertilizer, inoculant, adhesive etc.) in addition to training in new management practices from extension. Using these techniques and inputs, master farmers set up local demonstration plots, where other farmers can observe the application of different management techniques always compared against a control of traditional methods. Interested farmers from within the community can ask to receive small input packages with which to experiment on their own fields. Extension workers regularly visit the communities during the growing season to assess results, listen to farmers’ experiences and provide tailored advice. After the harvest, the extension workers organize field days for those community members not yet participating in the project and exchange visits between communities where households can visit demonstration trials or other households’ fields in agro-ecological zones different from their own. Within the eastern DRC, field days were not systematically organized but occurred on an ad hoc basis in those more ‘active’ communities that took initiative in their arrangement.

Input subsidy program

Of the treatment villages in our study, half were randomly selected to receive a second overlaying intervention. In these villages, households were offered the opportunity to buy a package of subsidized inputs after the N2Africa training intervention had been completed in August 2013. Local development committees (CLD) informed community members of the possibility to buy new inputs at a reduced price (75% of the market price) and provided a delayed payback scheme, in which a deposit of 500 FC ($0.54 USD) was required upfront and the remainder was owed after the next harvest. Participants were also offered the option the pay back in kind (seeds) instead of money if preferred. Each implementing partner NGO customized six variations of input packages (each worth about 26 USD) that all contained a combination of improved seeds, fertilizer and (or) inoculant to best suit the preferences and needs of the local farmers.[6] CLDs were made responsible for registering community farmers and ordering the necessary packages. Agro-dealers were expected to deliver the ordered inputs to the communities before the start of the new planting season (September 2013). Inputs were delivered to the CLDs, who were then responsible for coordinating the distribution of the inputs to the respective buyers and collecting the remaining payment owed after the harvest.

4. Data

Our research project is set in 92 villages, all located within the three project axes: Northern, Western, and Southern (see Figure 1). The sampling frame was developed in collaboration with the partners listed above and required villages selected satisfy (i) that at least one of the implementing partners had established contacts within the community, (ii) that the village was accessible by motorized transport; and (iii) that the village had not participated in any N2Africa intervention previously.

Based on these three criteria, implementing partners identified the treatment villages, which were then randomly assigned to one of the two study interventions. Subsequently, an additional 28 villages were selected in consultation with the implementing partners as

[6] Inoculant refers to a commercially available product. Grain legumes are coated (inoculated) with bacteria that fix nitrogen gas from the air into a form usable by plants. The nitrogen fixation thereby contributes to the production of high-protein legumes, increases yields and improves soil fertility (N2Africa, 2014).

our comparison group in the analysis. This non-random selection of the control group is accounted for within the analysis with a difference-in-difference empirical strategy.

During January 2013 a census of all 92 communities was conducted in order to ensure randomized selection within each community of ten households that were to be surveyed in each data collection phase. Thus our sampling strategy was a two-stage cluster sampling procedure stratified by axis, with villages as the primary and households as the secondary sampling unit.

To ensure that the NGOs' relationships of mutual trust with communities were effectively leveraged, implementing partners were assigned to the villages in which they implemented the N2Africa program based on previous project experience within the village. Building on existing relationships with villagers was considered a priority in order to increase probabilities of program success, precluding random assignment of NGOs to villages. While NGOs may vary slightly in their action plans for extension implementation, the N2Africa intervention had a detailed protocol outlining specificities of workshops and training sessions for the participating NGOs in order to ensure as standardized an N2A intervention as possible.

The household baseline survey was conducted in June and July 2013 with at-home visits for each selected household[7]. The endline survey was conducted in the same manner in October 2014. Both questionnaires included modules on demographics, housing, agriculture (including sources of agricultural knowledge), food security, and social and formal financial support systems.[8] In addition to the household interviews, community meetings were organized and covered community conflict history, disease outbreaks, rainfall levels, shocks experienced and proximity to public services (e.g. markets, schools, hospitals). All community members and authorities were invited to join these sessions. Surveys were

[7] Interviews were conducted primarily in Swahili and data was recorded using ODK software on program-owned tablets.
[8] See Bulte et al 2015, *Farm Households in Eastern Congo. Baseline Survey Report* for a report on the baseline data.

conducted by 37 enumerators, recruited with the assistance of the Catholic University of Bukavu (UCB).

The treatment group consists of 33 villages receiving only the N2Africa extension services (referred to as the 'N2Africa' group) and 31 villages receiving both N2Africa extension services *and* the input subsidy (referred to as 'input subsidy' group). The control group consists of 28 villages that received no intervention. Due to the control villages not being randomly selected, it is important to compare characteristics across treatment and control groups at baseline.

Table 1 provides variable definitions and Table 2 presents baseline descriptive statistics and balance test results across the three groups. In Table 2 the columns (1), (2), and (3) present the mean and standard deviations for the Control, N2 Africa, Input Subsidy and Control groups respectively, while column (4) presents summary statistics for the entire sample. Columns (5) presents the *p*-value from an F-test of the jointly equality of means across groups. The results show that there are five significant differences between the three groups both in terms of key outcomes of interest and for control variables, we control for these in our analysis below.

While knowledge of fertilizer is quite high (93%), only 6% of the households knew about inoculant during the baseline. It should be noted that knowledge was tested by asking specific questions about the use of fertilizer and inoculant. Use of improved inputs is very low throughout the sample of villages. Only 3% of households report using chemical fertilizer while less than 3% report having used inoculant in the previous season. These numbers indicate that the use of improved inputs by farmers within our sample is very low and inoculant is a new technology being introduced to 98% of households within the study.

Yields for beans amount to about 40 kg per ha and are comparable across all the sample groups. Food security is measured using the Household Food Insecurity Access Scale (HFIAS) (Coates et al. 2007). This scale measures food insecurity over three domains that capture different aspects of food insecurity: Anxiety, Quality and Intake. Higher scores on these domains signify greater food insecurity. Insecurity is reported to be very high throughout the whole sample, but with the input subsidy treatment group being slightly worse off than the control and N2Africa groups.

Household size is 6.5 on average and varies from 1 to 19 persons. The overwhelming majority of households are male-headed with only 15% of households being female-headed in the full sample. Households in the control group are 8 percentage points more likely to have a female head than households in the N2Africa group. Average age of the household head is statistically different between the control group (48 years) and the N2Africa group (45 years). These differences in gender and household ages may reflect a bias in NGOs targeting.

Perceived soil quality, primary crop of production, market access, and channel of produce sale do not vary significantly across groups, regardless of whether treatment villages are pooled or differentiated. Given some imbalance between the groups we will use both base- and end-line data, village fixed effects and include relevant household level variables that showed up significant in the balance test within the empirical analysis.

For all villages surveyed, more than 90 percent of the households report being involved in agriculture, and nearly 80 percent of households claim agriculture as the household head's primary occupation. Approximately 50% of surveyed households receive information about agricultural practices through the media, while less than 20 receive agricultural information through farmer cooperatives.

Attrition

During endline data collection, measures were taken to minimize household and village attrition. Enumerators announced the arrival of the research team one day in advance to ensure that all targeted households were present during the scheduled enumerator visits. For those instances where households were not present on the scheduled visit, a second date was scheduled to interview any missing households. Despite these measures, 17% of the households that were part of the baseline sample could not be reached during the endline. To some extent, this is to be expected given the post-conflict setting where migration is high. In Table A 1in the appendix, we analyze both whether attrition is random and whether any correlation to treatment is observed. We find no correlation of attrition to treatment, but younger household heads and smaller households are more likely to have dropped from the sample after baseline. We include these variables as controls in all of our regressions.

In Table A2 we assess the difference between attrited and non-attrited household in terms of the outcome variables (as measured during baseline). The table suggests that there is difference between the groups with respect to both yield indicators, confirming that attrition was not random. Since the differences do not correlate with treatment assignment, we do not consider this a large problem for our estimates of treatment effects. However, it might affect the external validity of our results.

5. Empirical strategy

Intention-To-Treat Effect

We measure the impact of the N2Africa on knowledge, use of new inputs, and food security indices relative to a control condition. In addition, we separately estimate the impact of N2Africa with and without a complementary program where households were given the opportunity to receive subsidized inputs. Because we randomized treatment assignment, comparing the subsidy with the training treatments at endline yields unbiased estimates. However, the control group was not selected randomly. Furthermore, as can be seen in Table 2, the treatment groups are not perfectly balanced on all indicators. We account for any time invariant unobserved heterogeneity between villages by specifying a difference-in-difference model. Specifically, we estimate:

$$Y_{ijt} = \alpha_j + \beta Post_t + \delta\ Treatment_j \times Post_t + \gamma X_{ijt} + \varepsilon_{ijt} \quad (1)$$

where Y_{ijt} is the outcome measure for individual *i*, in village *j*, at time *t*, α_j is a village level fixed effect, $Post_t$ is a dummy indicating the endline survey round, $Treatment_j$ is a dummy that takes value 1 if village *j* is any of the treatment groups, X_{ijt} is a set of time-varying household characteristics, and ε_{ijt} is an error term. In all estimations, we cluster standard errors at the village level.

Next, to measure the impact of N2Africa with and without subsidies, we estimate:

$$Y_{ijt} = \alpha_j + \beta Post_t + \delta^T Training_j \times Post_t + \delta^S Subsidy_j \times Post_t + \gamma X_{ijt} + \varepsilon_{ijt} \quad (2)$$

where $Training_j$ is a dummy that takes value 1 if village j received the training-only treatment, and $Subsidy_j$ is a dummy that takes value 1 if village j received training and access to subsidized inputs. Hence δ^T is the estimated intention to treat (ITT) effect of training-only on outcome Y_{ijt} while δ^S estimates the ITT effect of training combined with subsidized inputs. Comparing the two estimates allows us to assess whether the subsidy scheme has incremental impacts, beyond the effect of the extension training, on our set of outcomes.

Spillover Effect

Spillovers or externalities are important issues in understanding the diffusion of new technologies. Others can often freely observe first adopters and learn how to use a new technology, generating positive spillovers (Besley and Case, 1993; Conley and Udry, 2001; Oster and Thornton, 2010). One of the key assumptions underlying N2Africa extension training interventions is that knowledge and inputs indeed spreads within and across villages.

Unfortunately, we lack data on specific social network structures in our sample. To assess spillovers we use variation in the geographic distance between treatment and control villages. This approach provides two-advantages. First, it allows us to determine whether our intention-to-treat effect estimate is underestimated due to control villages benefiting from nearby villages receiving treatment. Second, it allows us to explore the extent to which knowledge is being transferred and therefore whether inter-village diffusion of knowledge can be relied upon for raising productivity and increasing food security in surrounding communities. If inter-village knowledge spread is sufficient for increasing agricultural productivity, policies can be designed cost-effectively through geographical targeting. We estimate the size of these spillover effects by modifying equation 1 to include an interaction term between $Post_t$ and an indicator, $Proximity_j$, for control villages being in the proximity of treatment villages. We define proximity to a treatment village as being within 1km distance.

$$Y_{ijt} = \alpha_j + \beta Post_t + \tau Post_t \times Proximity_j + \delta Treatment_j \times Post_t + \gamma X_{ijt} + \varepsilon_{ijt} \qquad (3)$$

We run equation 3 over the same set of outcome indicators analyzed in the ITT analysis to assess where along the causal chain intervention spillovers have the greatest relevance. Like the ITT models, equation 3 is estimated with a fixed effects model and has standard errors clustered at the village level.

Heterogeneous Treatment Effects

In addition to overall effects, we explore how the impacts of agricultural extension and subsidization of inputs vary across several key dimensions. We explore five heterogeneous treatment effects based on household characteristics and look at gender composition, access to media, security of property rights, perceived soil quality, and distance to markets. Such analysis is exploratory rather than causal by construction, but nonetheless very informative and elucidate where the treatments where more or less successful in changing outcomes. We conduct this analysis by splitting the sample within each heterogeneous characteristic and running equation (2) on each sub-sample independently. We present the subgroup outcomes graphically, reporting the point estimate and 95% confidence intervals.

6. Results

Intention-to-treat Effect

Below in Table 3 and Table 4, we report effects for outcomes along the full causal chain (outlined in section 1), going from knowledge about fertilizer and inoculant, to input use, to production (yields) of beans, and food security.

In Table 3 we compare the pooled treatments against control, lumping both training input subsidy treatments together. We find a large and positive impacts on knowledge of inoculant, bean yields and a strong reduction in food anxiety. Bean yields improve by 89%, effectively doubling farm level outputs. Food anxiety decreases by xx, again a substantial change indicating that respondents in the treatment group worried less about nutrition status. This provides hopeful evidence for organizations involved in extension and input provision. The results suggest that improvements in yields are driven by increased knowledge of farming techniques. We find no effect suggesting impact via increased input use. Both inoculant and fertilizer use are not influenced by the treatments.

Table 4 presents the intention-to-treat effects for each of the interventions independently. Again, inoculant knowledge and bean yields improve in both. We however find limited additive impacts of the subsidy scheme when offered in addition to training. Even though coefficients are slightly larger for the subsidy group, they are statistically equivalent. We do find some incremental impact of access to subsidized inputs on the likelihood of using fertilizer, which increases by 5.6% in villages receiving the subsidy program, compared to control and training-only villages. Since the end-line data collection wave is lagged one season behind the intervention, this result suggests some persistence in fertilizer use resulting from the subsidy scheme.

The training intervention has an estimated impact of increasing bean yields by approximately 86%. This translates to a USD$40 market-value increase in the value of bean output per hectare. This dollar value is calculated using a full-sample average bean price and the baseline mean bean yields of households in the control villages. As few farmers in the study sample produce beans on plot sizes as large as a hectare, adjusting this market value to the average bean plot size of .35 Ha results in an estimated market value increase in bean output of USD$15 for farmers in training intervention villages compared to the control group.

Spillover effects

Results from the spillover analysis are reported in

Table 5. We find that people living in control villages that are in the proximity of treatment villages are 8 percentage points more likely to correctly answer questions about inoculant than those further away (column 1). This effect is significant at the 1% level. Despite these strong knowledge spillovers occurring, there is no determinable effect on other outcome indicators such as input use, yields and food security.

These findings may suggest that lack of knowledge or information is not a sufficient constraint to address in overcoming poor adoption rates of new inputs. Additionally, results in

Table 5 show improvement in bean yields and food security for the training-only treatment group, even in the absence of increased input use, but we do not find these same causal chain effects in the geographically nearby control villages. This may suggest that knowledge that is relatively easily processed (e.g. the purpose of inoculant and on which crops to use it) can be transmitted in a straightforward manner, but more complex information and experiences gained from experimentation may not transmit as readily. It is likely the more complex knowledge gained from the training intervention that is driving improvements in yields and food security observed within the training treatment group outcomes.

Heterogeneous Treatment Effects

In this section, we assess whether the program had differential impacts among varying sub-groups of participants in order to reveal potential underlying mechanisms driving the ITT effects. We identify five dimensions over which the participants differ: gender of the household head, distance from markets, use of media, soil quality, and property rights. We graphically examine how the set of four intention-to-treat effects observed in the main results section differ heterogeneously across these 5 variables. Results are presented in in

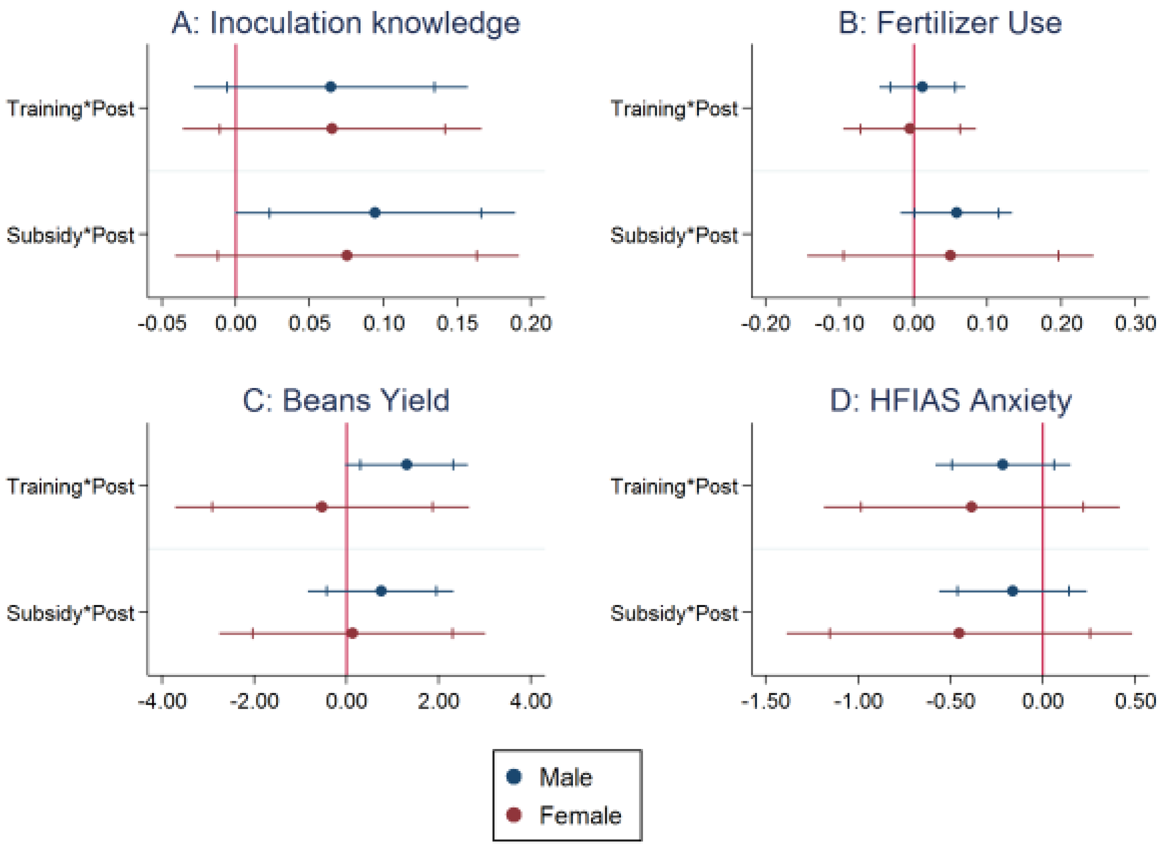


Figure 2 through

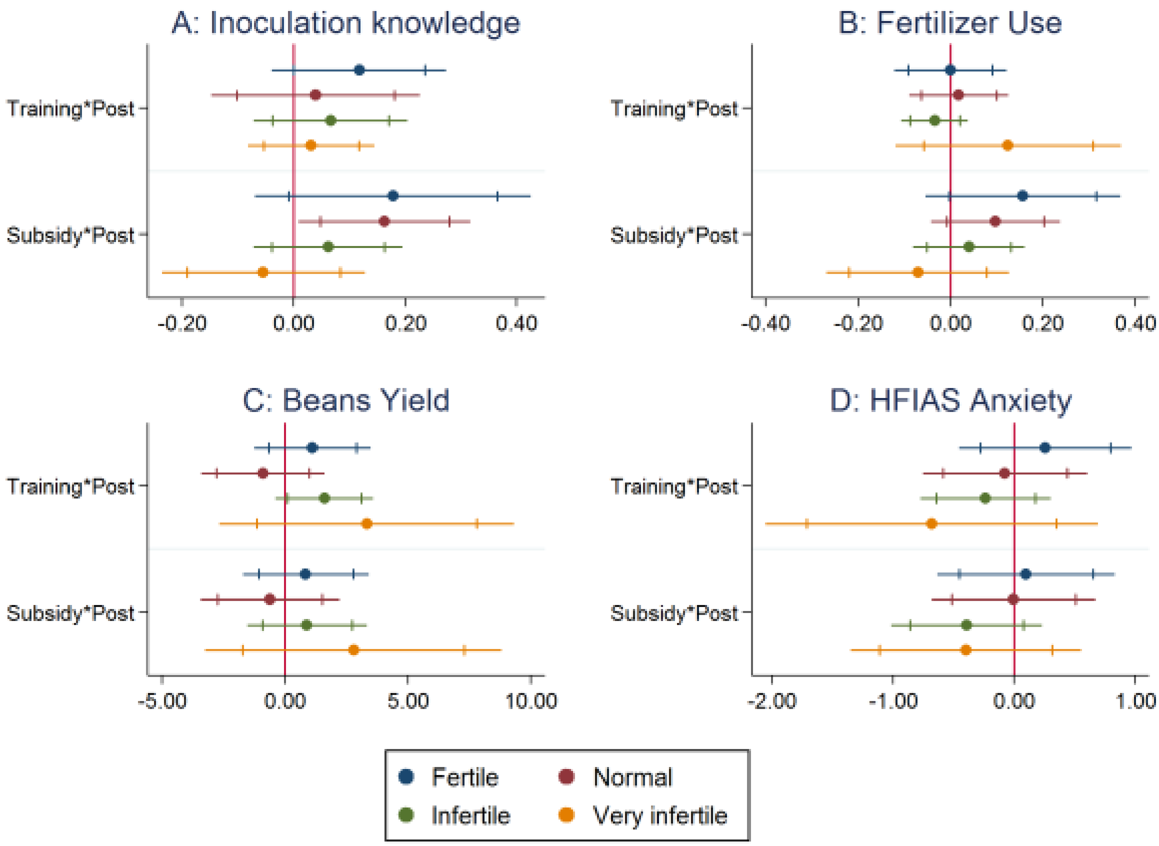


Figure 6.

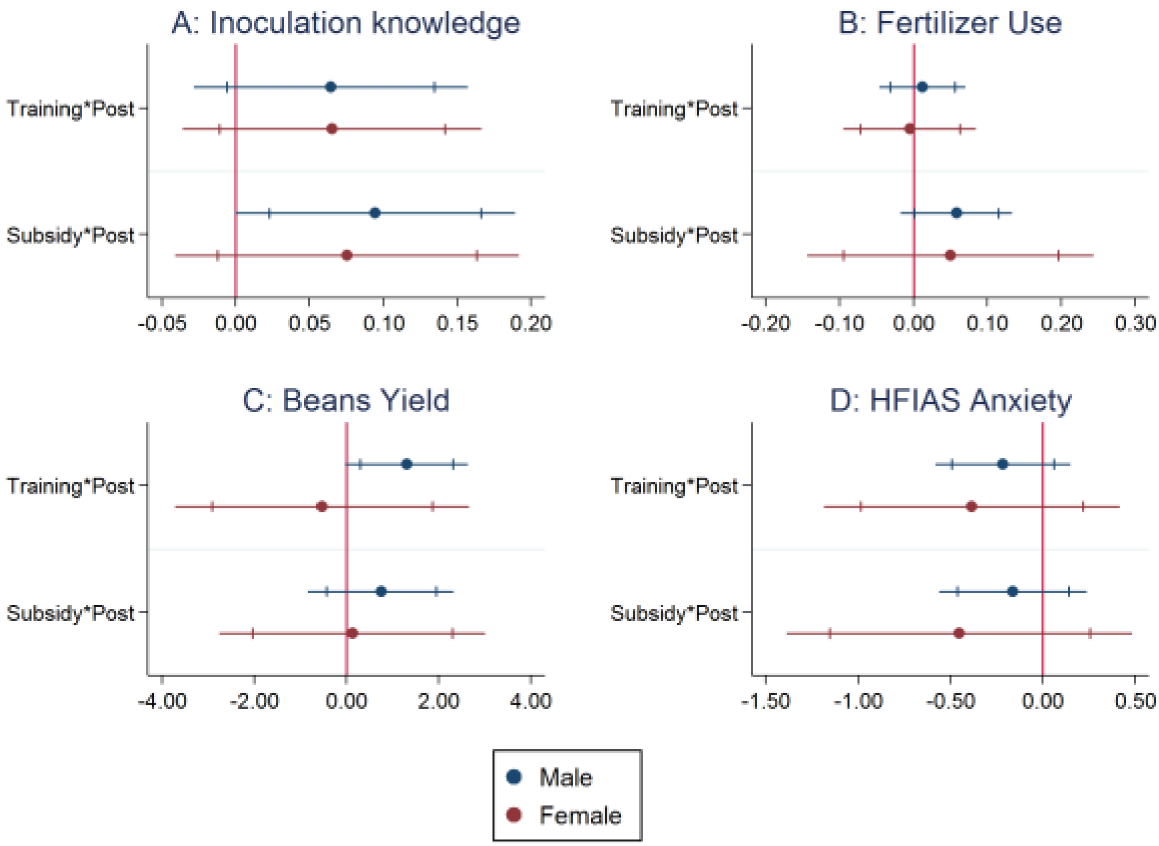


Figure 2 presents the main results discussed in the section above, with the sample split by gender of the household head, while the results in

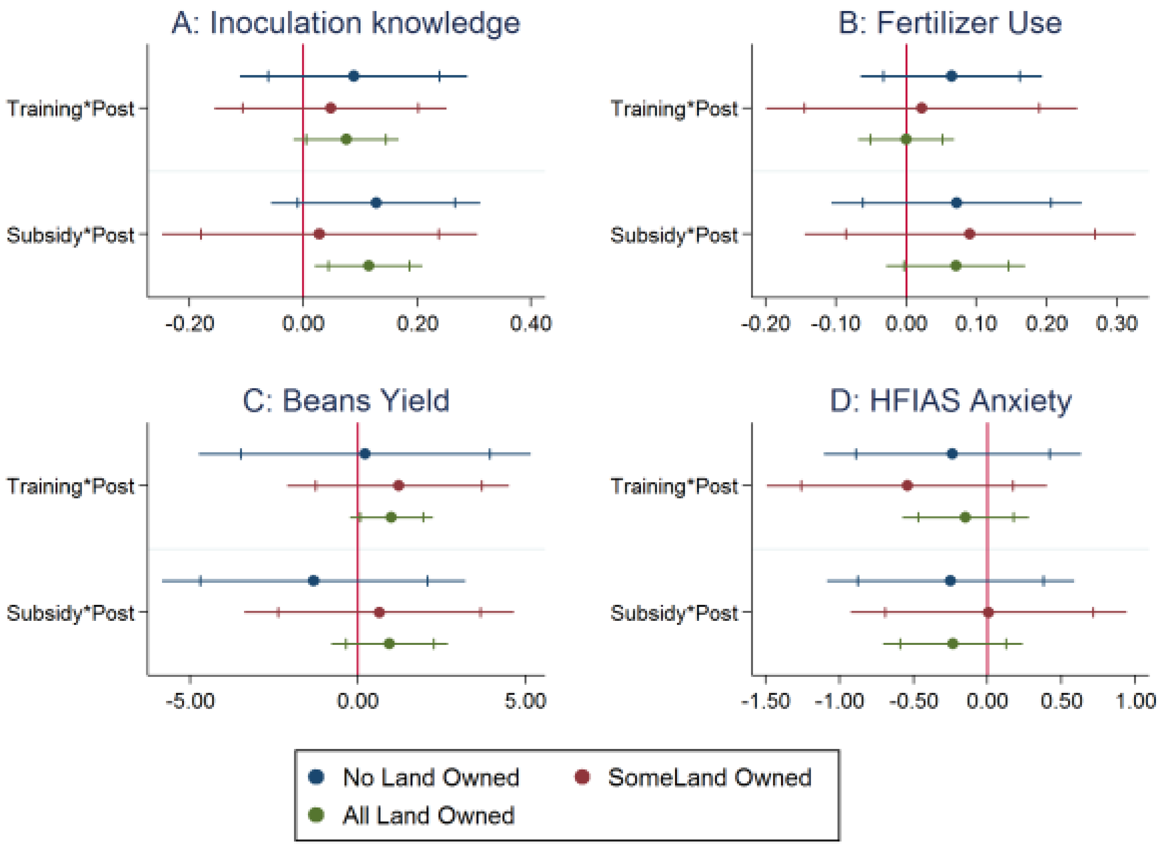


Figure 3 are split by tenure security. In neither figure striking differences are present between the treatment effects. Thus we find no evidence of informal property rights driving investment in production or of disproportional capture of intervention benefits by male-headed households. Nor do we anticipate our overall intention-to-treat effect to be biased by gender-imbalance within the sample, as no differential impacts were found for female-headed households.

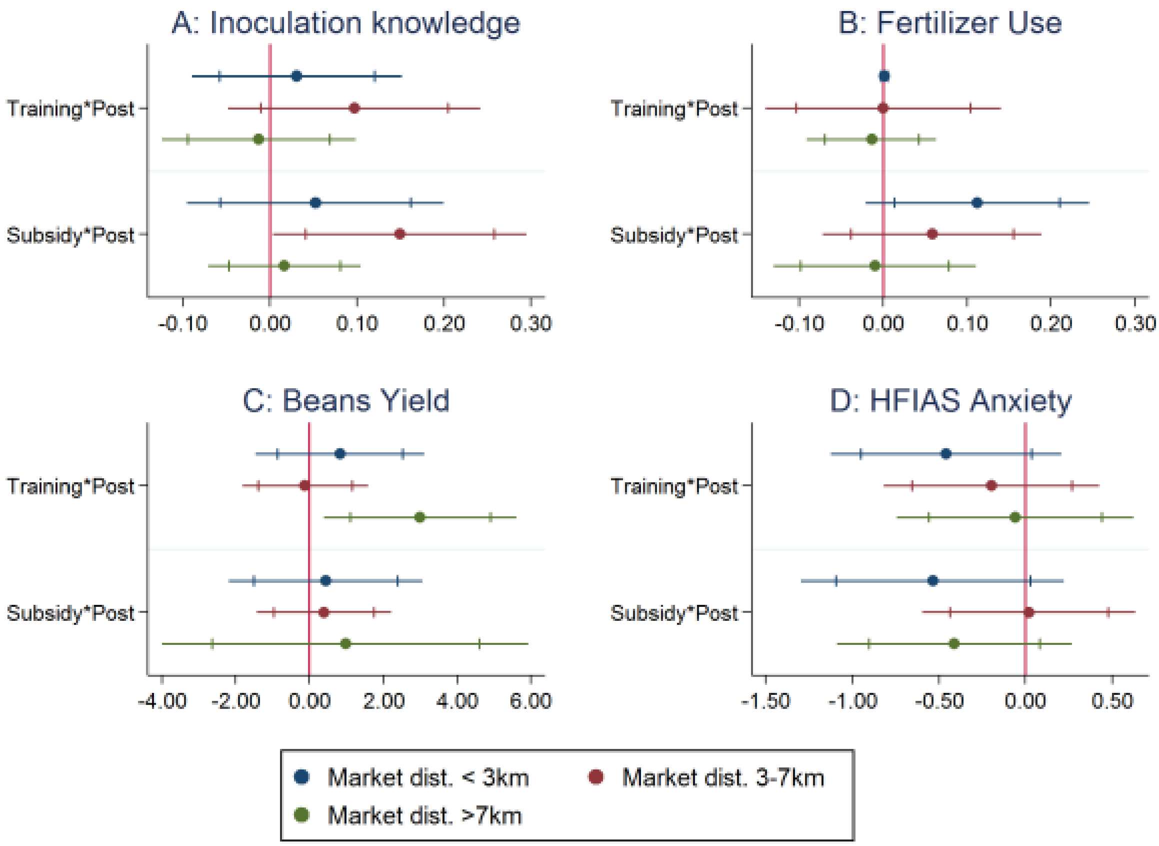


Figure 4 presents the main results discussed in the section above, with the sample split by market distance terciles. Panel A presents the finding that inoculant knowledge increased in both treatment arms, but significance of results is lost due to the restricted sample size created by the market-distance split. We find that the intent-to-treat effect on inoculant knowledge is driven by villages 3-7km from markets. This supports the idea that this knowledge is most beneficial for farmers who are not too close but also not too far from markets, while options to obtain this knowledge do not come by frequently. In contrast, the effect of the subsidy program on fertilizer use clearly declines with distance to a market; the effect is highest in communities that are closer than 3km to a market (Panel B). As our end-line survey was conducted one season after the intervention was implemented, our measure of fertilizer use captures persistence of fertilizer purchases post-intervention. As households closer to the market face lower transportation costs, and thus overall lower purchasing costs of inputs, it is logical that these villages are more likely to continue to buy fertilizer after conclusion of the program.

As discussed above, improvement in later-stage causal chain outcomes (yields and food insecurity) appear to have materialized through better crop-and farm management techniques, rather than through an increased adoption of inputs. Arguably farmers in remote areas still have much more to gain from these techniques to increase their yields, whereas closer villages may have lower marginal returns from improving farm management processes and are producing close to optimum given infrastructural, market, and institutional constraints that can only be shifted in the long run. Higher marginal returns to information on management processes for more market-constrained villages would explain larger gains in bean yields (

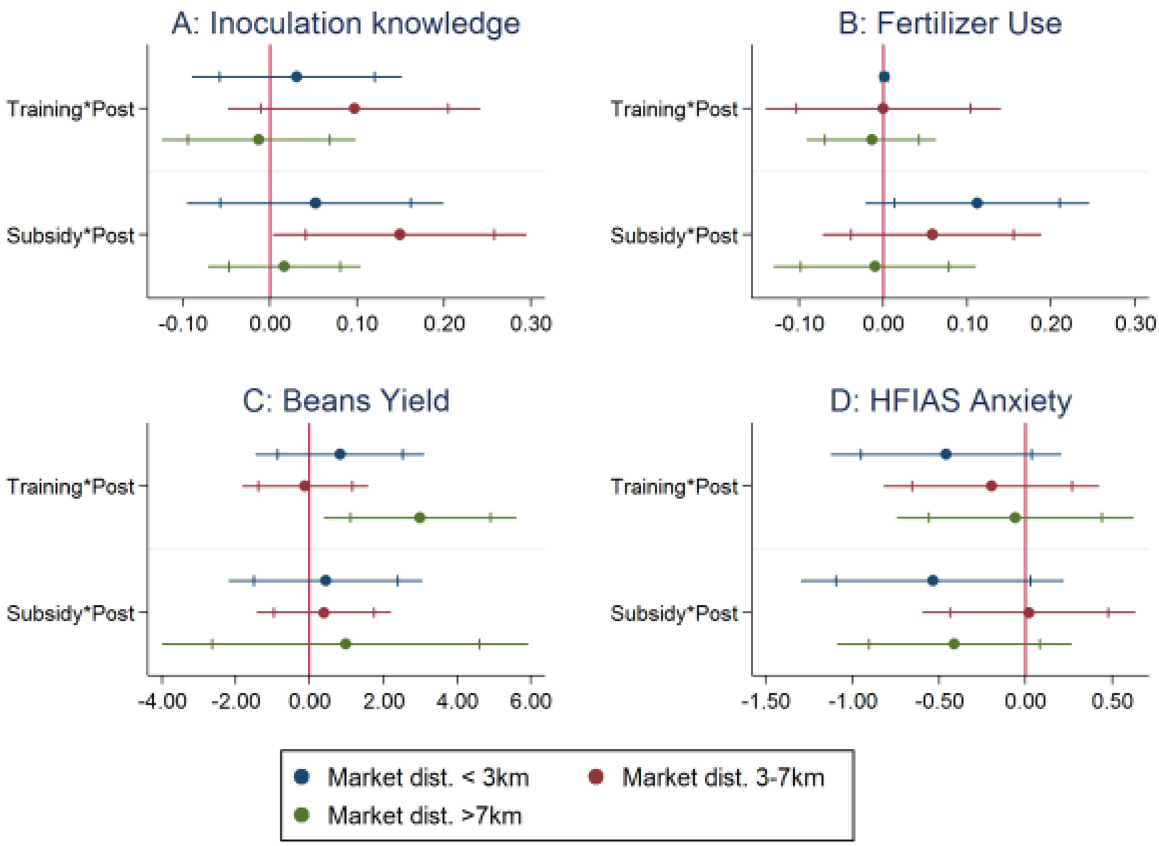


Figure 4, Panel C) for more distant villages. However these increases in yields do not translate into lessened food insecurity for these distant villages (

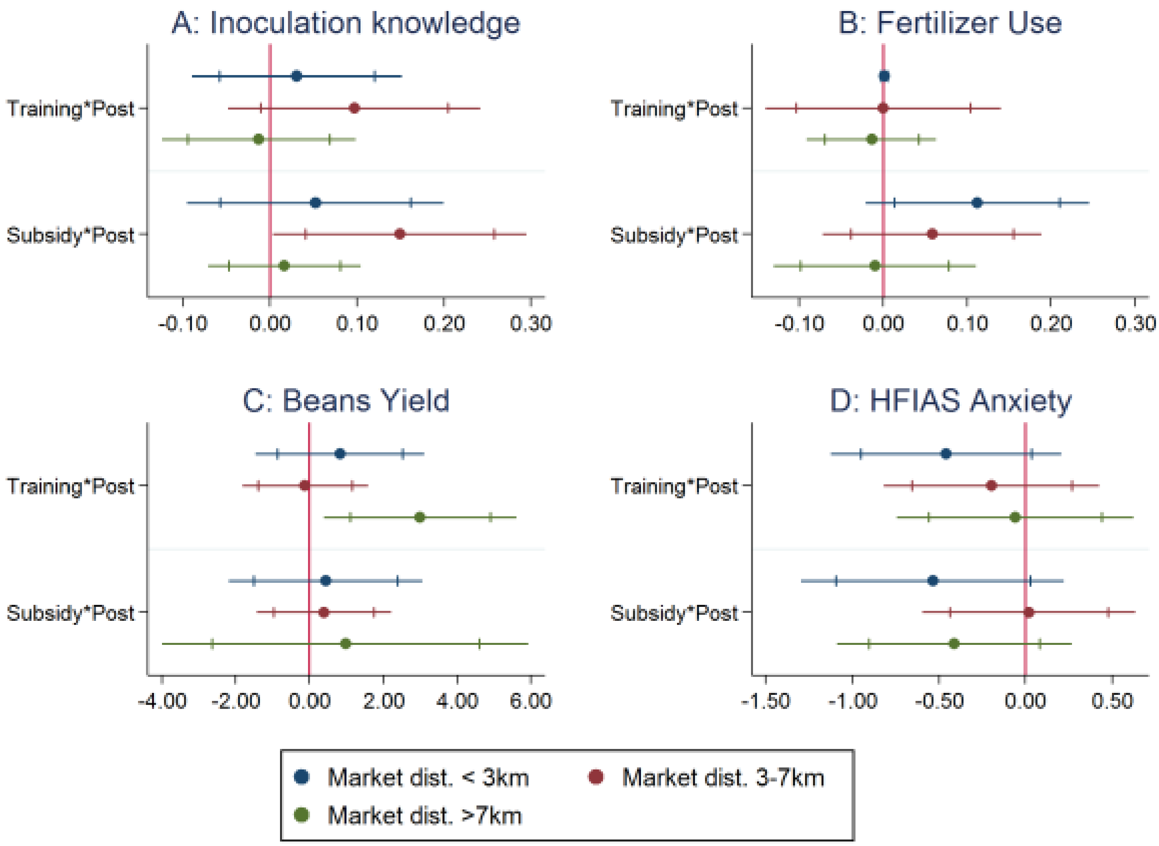


Figure 4, Panel D). While bean production is a primary focus for the N2Africa program, beans are only a single crop within a farmer's production portfolio. The increases in yields for beans is easily offset by variance in output of primary food crops (e.g. maize or cassava), resulting in observed yield gains not effecting food security levels. Overall it would seem that villages located closer to markets benefit more in terms of input-adoption while more distant villages benefit more from information, identifying that information-gaps may be a stronger and more binding constraint for more remote villages.

When we split our sample into active-learners and passive-learners based on the use of media for gaining agricultural knowledge (

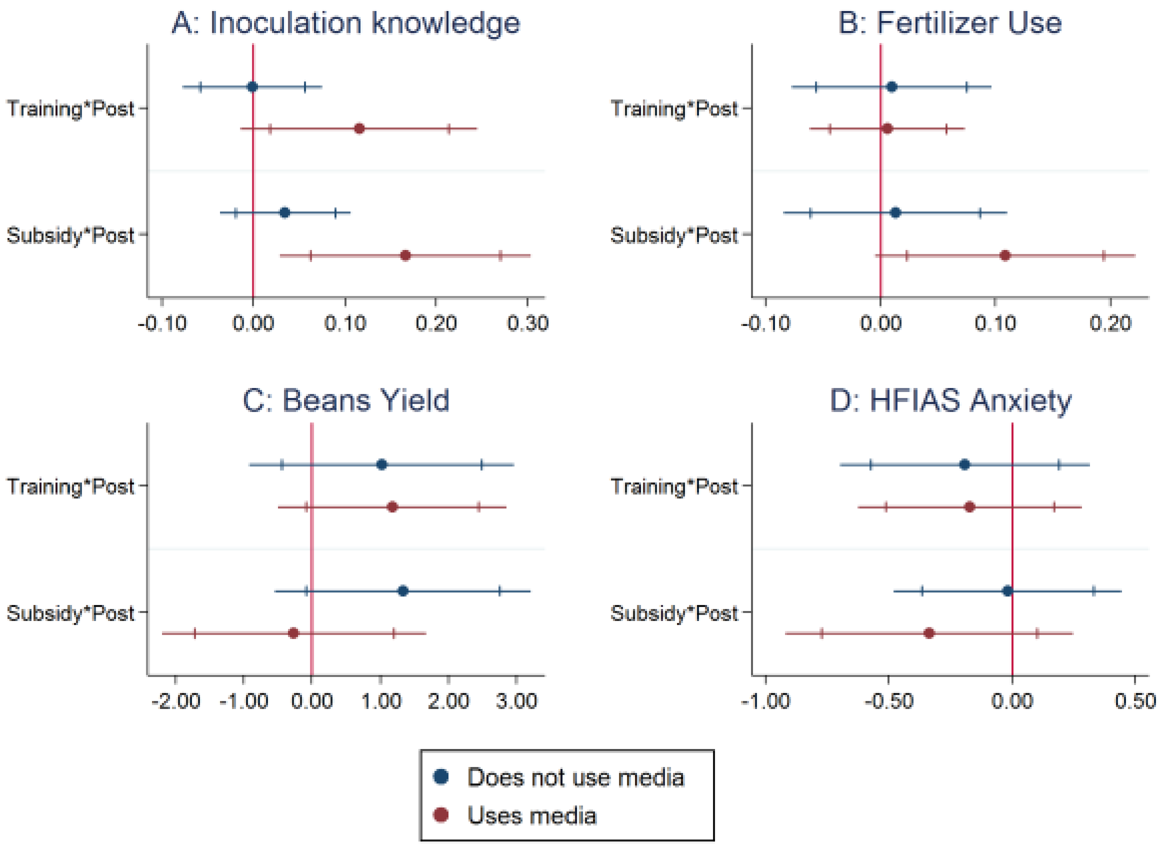


Figure 5), active-learners demonstrate greater increases in knowledge about inoculant in comparison to passive-learners for both interventions. As inoculant is a novel technology in the region, these results suggest that farmers' who are more active in seeking information indeed are more likely to learn about new agricultural production technologies. This appears to translate into fertilizer use as well, as media-users in the subsidy-program intervention have higher adoption rates compared to non-media users. Previous evidence has shown that farmer's position in village social networks matters for knowledge spillovers (e.g. Carter et al., 2014). Since we do not have detailed data on village social networks, we cannot rule out that use of media and social network position are correlated. Yet our results suggest that the use of media could be used as an indicator of farmers' willingness and/or ability to learn and experiment with new farming technologies.

In

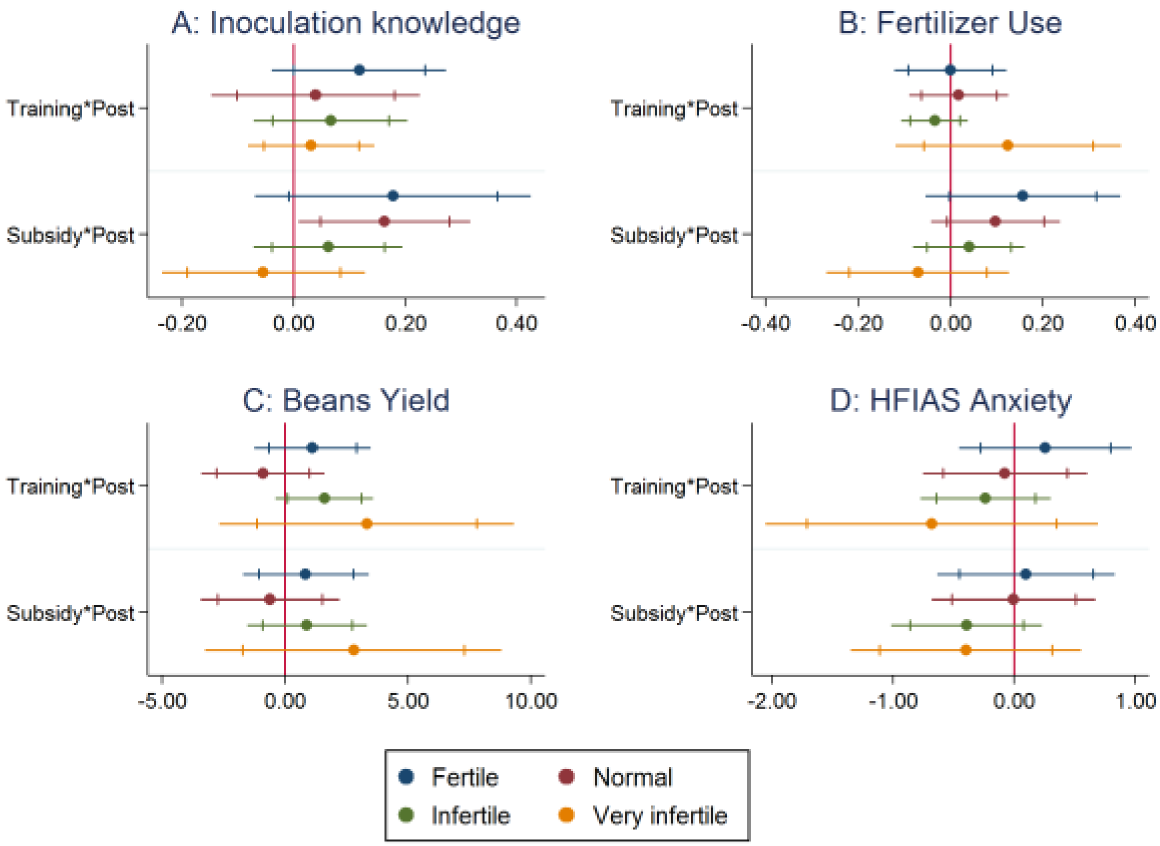
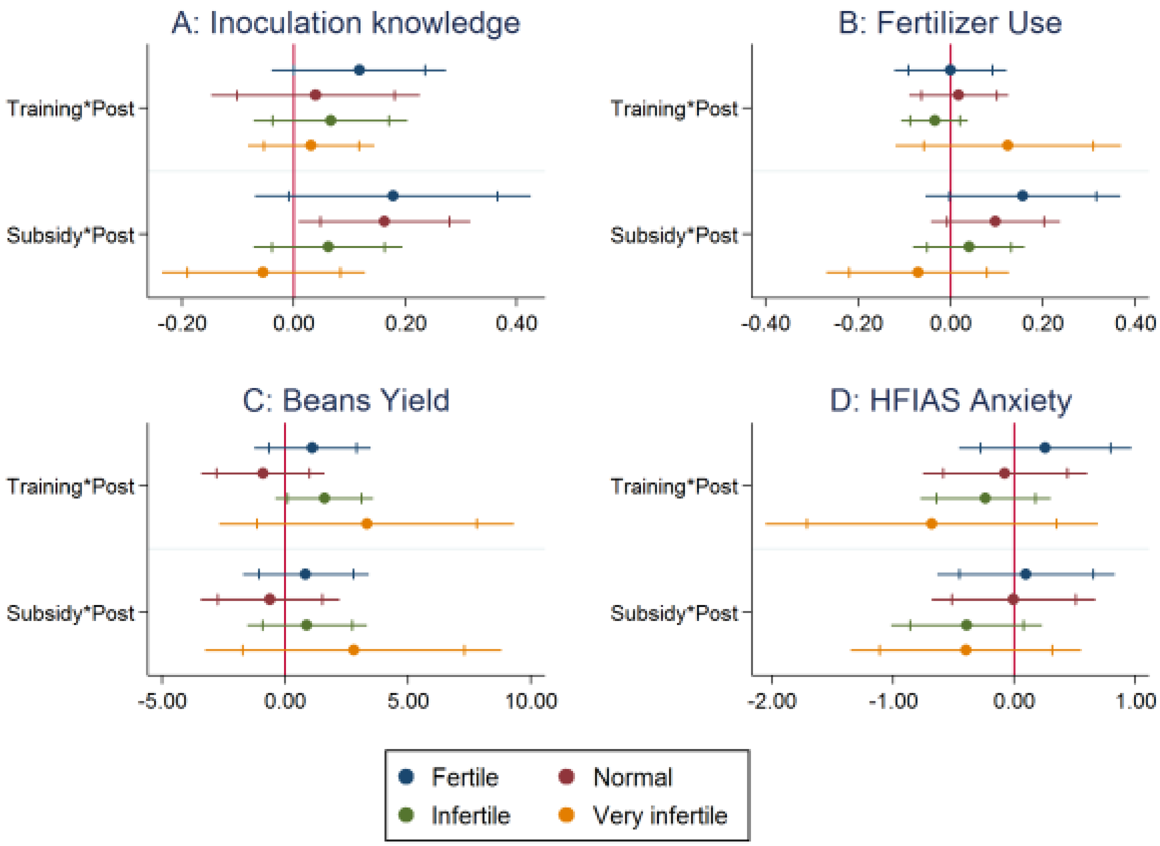


Figure 6, we split our sample by self-reported soil fertility. Counter to expectation, knowledge of inoculant increases more for farmers with fertile soil compared to farmers with less fertile soil. While this pattern is stronger in the subsidy-intervention, it is present in both treatment groups. This same pattern translates over to adoption of fertilizer for the subsidy group. As each subsidized package offered in the subsidy intervention contained chemical fertilizer, the subsidy group is more likely to have experimented with fertilizer during the study period. The finding that farmers with more fertile soil persisted in the use of fertilizer after the intervention conclusion, while farmers with less fertile soils did not, suggests that marginal returns to fertilizer were lower for farmers with poorer initial soil qualities. Our findings thus lend non-causal evidence in support of existing theories that demand for fertilizer is discontinuous along farm soil quality. For both treatment groups, the intervention appeared most beneficial to farmers with lower soil fertility levels in both bean yield (



A: Inoculation knowledge
B: Fertilizer Use
C: Beans Yield
D: HFIAS Anxiety
Training*Post
Subsidy*Post
-0.20
0.00
0.20
0.40
-0.40
-5.00
5.00
10.00
-2.00
-1.00
1.00
Fertile
Normal
Infertile
Very infertile

Figure 6, Panel C) and food insecurity (

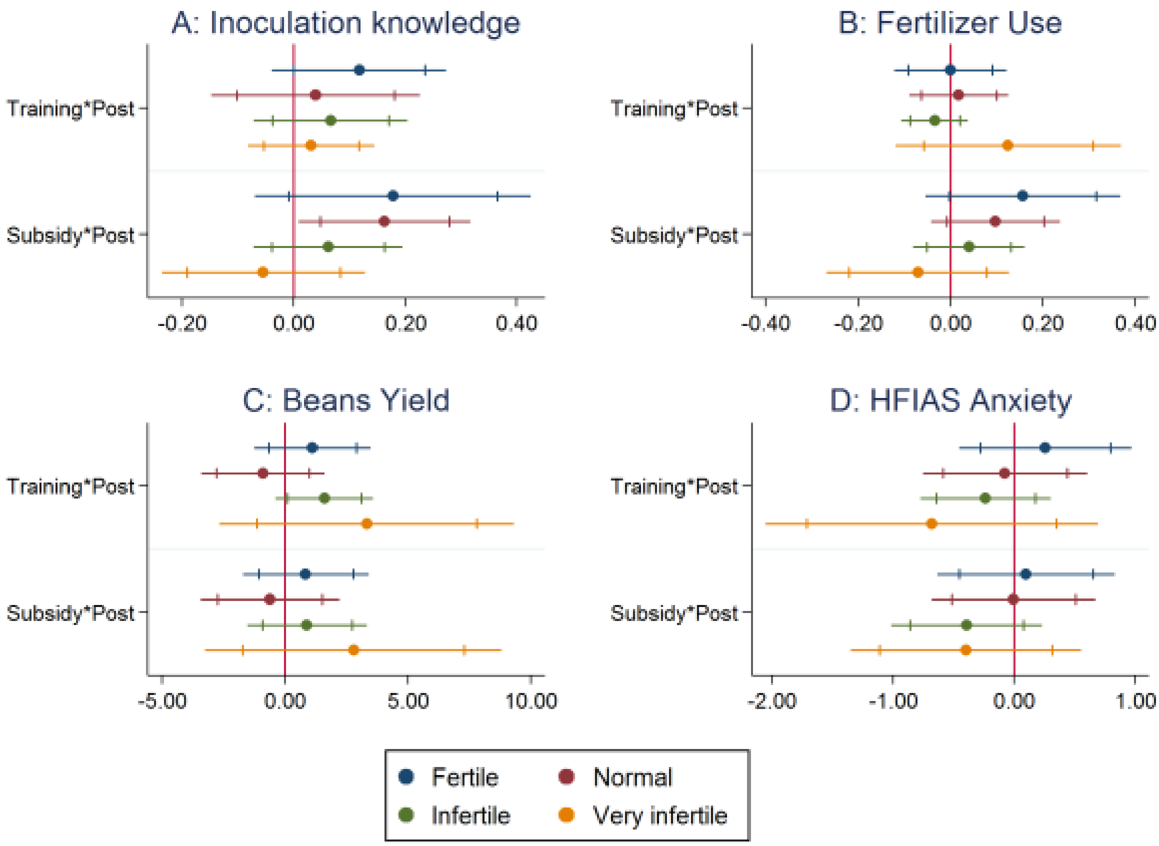


Figure 6, Panel D) outcomes. That these same farmers showed lower intervention effects on inoculation knowledge and fertilizer use suggests that the secondary lessons on crop and farm management covered in the trainings are driving these effects on later-stage causal chain outcomes as, unlike inputs of fertilizer and inoculant, they require little financial investment yet still generate benefits to farmers in addressing existing challenges and constraints to production.

Taken together, these results suggest that impact early on in the result chain (increased inoculant knowledge and fertilizer use) is easier to achieve with farmers that are close to markets or in intermediate distance from markets, who use media for agricultural learning, and have more fertile soil quality on their plots. However, the greatest potential for improvement further down the result chain (yields and food security) lies with households farming on plots with poorer soil quality. Furthermore, it suggests that more remote farmers and farmers with poorer soil quality may have larger informational gaps that can be improved with information on improved farm management.

7. Discussion and conclusions

Small holder farming in sub-Saharan Africa is plagued with low productivity and technology levels. We causally estimate the potential gains from a two-pronged intervention approach that targets (i) information gaps through a farmer-led extension training program and (ii) short run financial barriers through a subsidized input package offer. The financial sustainability and cost-effectiveness of agricultural input subsidization is questioned within existing literate, however potential complementary benefits of addressing two agricultural productivity constraints simultaneously may be substantial enough to offset high program costs. We analyses complementary gains of a combined extension and subsidy offer treatment over an extension-only treatment and a no-intervention comparison group using a quasi-experimental research design. We estimate an intention-to-treat effect for outcomes capturing a larger theory of change of increased knowledge catalyzing adoption of inputs which raises farmer productivity and thus reduces food insecurity. By incorporating the entire causal change, we aim to identify the role knowledge gaps and financial barriers play in constraining household agricultural development and determine cost-effective approaches for overcoming local barriers to agricultural growth. Additionally, we explore how programs can be better tailored to increase cost-effectiveness by leveraging geographical spillovers and targeting responsive households.

Our intention-to-treat estimates suggest that the intervention was successful in raising knowledge of a novel improved input, inoculant, but less successful in improving knowledge of an improved input already present within the region, chemical fertilizer. However, these knowledge benefits did not translate directly into adoption rates, as the intervention did slightly increased the probability of continued use of chemical fertilizer post-intervention, but had no discernible effect on the continued use of inoculant post-intervention. When the treatment arms were analyzed independently, only the combined treatment arm of extension-plus-subsidy offer significantly increased persistent fertilizer adoption levels, however neither treatment effected the adoption of inoculant.

Inoculant use sits at the core of the N2Africa program objectives, but it is a novel technology that is difficult to source in local markets. This difference in results for adoption of chemical fertilizer versus inoculant highlights the variation in response to an existing versus novel technology. While closing the knowledge gap and lowering short run costs of chemical fertilizer was sufficient for a small rise in adoption rates, the same is not true for inoculant. Instead, larger interventions that target market structure may be required in order to develop local supply chains thus lowering the longer term costs of purchasing improved inputs locally could have more dramatic effects on adoption rates for both inoculant and chemical fertilizer.

While our two treatments directly targeted knowledge gaps and adoption of inputs, later stage outcomes in the causal chain of yields and food security are secondary indirect effects operating through the knowledge gains and adoption levels. Both bean yields and food security indicators do improve as a result of the intervention, although higher and significant gains are observed for the extension-only treatment arm. These empirical findings suggest farmers “skip” the hypothesized step from increased knowledge about new inputs to increased use of these inputs, with the largest gains attributed to the extension trainings closing informational gaps. While improved input use was the primary focus of extension training sessions, secondary topics of crop management and direct experience observing and experimenting with improved methods were also incorporated. Our results suggest that these secondary topics are significantly contributing to the observed effects of higher productivity and lower food insecurity. However, our focus on ‘adoption’ is limited to inoculant and fertilizer use, necessitating further research using a broader set of measures of adoption that enables the research to identify which management process element(s) of the program are most successful.

Our intention-to-treat results support the theory that informational gaps are acting as a more binding constraint to smallholder agricultural productivity within the eastern DRC region. Increasing farmer awareness and experience with improved inputs may not be sufficient for increasing adoption. This insufficiency may be attributed to persistent and systemic obstacles within output markets, transportation infrastructure, and access to credit, all slower-moving factors that can only be adjusted in the longer run. Thus, the marginal returns to information-based interventions pose a cost-effective means of raising agricultural productivity. However, the severe underdevelopment of market institutions and local infrastructure warrant a prioritization of knowledge transfer over input subsidization as no significant additional returns are observed for a dual-intervention approach.

Our results are extendable only to those regions in which comparable market and infrastructural constraints present equally formidable challenges to accessing and profiting from the use of improved inputs. Our intervention faced pragmatic challenges mirroring those battled by many development initiatives: multiple implementing partners and wholesale distributors, limited telecommunication infrastructure, and poor transportation infrastructure. While all possible steps were taken to ensure a standardized action plan, setbacks of delayed, incomplete, or missing subsidy input packages were reported. While these reports may bias estimated impacts of the combined extension-and-subsidy intervention, and potentially weaken internal validity of our results, they do accurately reflect the hurdles and missteps experienced by development agencies carrying out policy agendas.

In analyzing how best to target agricultural development initiatives, we explore between-village spillovers. We find that between-village spillover effects on knowledge of inoculant are nearly equivalent to that of the direct treatment effect however no subsequent effects are observed on adoption of inputs, yields, or food security. Thus, simple knowledge is transmitted more easily then complex or experiential knowledge, however it is through complex knowledge that gains to productivity are realized. Practitioners should be aware of these information diffusion limitations by concentrating funding and project design on larger numbers of villages without relying on geographical spillover generating higher agricultural productivity.

For differential treatment effects within-villages, we explore responsiveness to the intervention across five observable household characteristics (i) gender of the household head (ii) property rights (iii) distance to markets (iv) use of media in agricultural learning and (v) soil quality of farmed land. We find that those dimensions related to knowledge and market access are more relevant for differential treatment impacts. While no differential effects were found for gender or property rights, farmers further from markets benefited most in knowledge gains while farmers closest to markets were most likely to adopt chemical fertilizer. These results suggest that the share that knowledge gaps and financial constraints each contribute to lower agricultural productivity fluctuates depending on a household's access to market. Policies that target market constraints may be better suited for households closer to markets while policies that target information deficiencies are more effective for more remote villages. Furthermore, farmer use of media in agricultural learning is positively related to larger effects on inoculant knowledge, but only for the subsidy-treatment group do these knowledge gains translate into higher fertilizer adoption and lower food insecurity. More research is requires on who 'active-learners' are within community social networks to determine whether 'active-learners' could be suitable injection points for efficient information diffusion.

Finally soil quality, which is not directly linked to knowledge or fertilizer but may indirectly proxy household wealth or farming experience and skill, is found to have mixed effects. Knowledge appears more pertinent to households with lower soil quality while fertilizer is in higher demand by households with more fertile soils. Farmers with low soil quality levels experienced the greatest returns to the intervention in the forms of raising bean yields and lowering food insecurity, reinforcing our earlier hypothesis that knowledge gaps within the region are currently more binding a constraint for agricultural production.

Practitioners operating in comparable local contexts should prioritize information-intensive interventions in addressing agricultural productivity constraints. Interventions should target communities uniformly and not rely on between-village knowledge diffusion for generating higher smallholder productivity. Furthermore, differential treatment effects require that programs carefully consider their target population and tailor their intervention design specifically for intended recipients in order to maximize cost-effectiveness.

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Tables

Table 1: Variable Definitions

Outcome Indicators	
Knowledge	
Household Head knows inoculant	1= if the household knows something about input inoculant, 0=otherwise
Household Head knows fertilizer	1= if the household knows something about input fertilizer, 0=otherwise
Input Use	
Household Head uses inoculant	1= if the household uses fertilizer, 0=otherwise
Household Head uses fertilizer	1= if the household uses inoculant, 0=otherwise
Yield	
Yield bean (in Kg/ha)(log-transformed)	Yield of bean given by the quantity harvested (in kg) divided by the surface (ha) log transformed
Yield cassava (in Kg/ha)(log-transformed)	Yield of cassava given by the quantity harvested (in kg) divided by the surface (ha) log transformed
Food Insecurity	
HFIAS Anxiety	1= if the household has been worried on not having enough food during the past 04 weeks, 0=otherwise
HFIAS Quality	Score food insecurity indicator from 0 (less food insecure in terms of quality) to 9 (more food insecure in terms of quality)
HFIAS Intake	Score food insecurity indicator from 0 (less food insecure in terms of calorie) to 12 (more food insecure in terms of calorie)
Controls	
Household Size	Total number of people living in the household
Household Head is female	1=if the household head is a female, 0=otherwise
Household Head age	Age of the head of the household in years
Household Head level of education	0= No level of education , 1= Some primary, 2= Primary Complete, 3= Some secondary**,** 4= Secondary complete, 5= Higher education, 6**=** Professional education
Household Head was born in the village	1=if the household head was born in the village, 0=otherwise
Household does agriculture	1=if the household does agriculture , 0=otherwise
Household Head is literate	1=if the household is literate , 0=otherwise
Household Head primary occupation is farmer	1= if the household head primary occupation is a farmer, 0=otherwise
House roof material is thin	1= if the household roof construction material is thin , 0=otherwise

Household Head uses media	1= if the household uses media (radio, internet, leaflets, newspaper) to get agricultural information , 0=otherwise
Household Head is a member of an agricultural cooperative	1= if Household Head is a member of an agricultural cooperative , 0=otherwise

Table 2: Baseline descriptive statistics and balance

	(1) Control	(2) Training only	(3) Training+ subsidy	(4) Overall	Joint orthogonality (p-value)
Inoculation knowledge	0.070	0.049	0.055	0.057	0.711
	(0.019)	(0.017)	(0.013)	(0.009)	
Fertilizer knowledge	0.930	0.947	0.926	0.935	0.713
	(0.021)	(0.019)	(0.020)	(0.011)	
Inoculant Use	0.013	0.026	0.039	0.027	0.183
	(0.007)	(0.012)	(0.013)	(0.006)	
Fertilizer Use	0.039	0.026	0.031	0.032	0.725
	(0.012)	(0.010)	(0.009)	(0.006)	
Beans Yield	4.111	3.570	3.496	3.714	0.293
	(0.251)	(0.383)	(0.388)	(0.205)	
Cassava Yield	7.897	7.775	7.646	7.771	0.519
	(0.146)	(0.132)	(0.165)	(0.084)	
HFIAS Anxiety	1.826	1.891	2.086	1.937	0.025
	(0.066)	(0.077)	(0.071)	(0.042)	
HFIAS Quality	5.948	6.091	6.547	6.202	0.090
	(0.195)	(0.188)	(0.205)	(0.115)	
HFIAS Intake	5.183	4.740	5.625	5.177	0.066
	(0.362)	(0.248)	(0.285)	(0.173)	
Household size	6.574	6.785	6.590	6.654	0.604
	(0.204)	(0.146)	(0.196)	(0.104)	
Female household head	0.200	0.121	0.141	0.152	0.078
	(0.029)	(0.020)	(0.031)	(0.016)	
Age household head	48.200	44.898	46.862	46.567	0.108
	(1.056)	(1.152)	(1.034)	(0.638)	

Education level head (category)	1.465	1.591	1.306	1.455	0.224
	(0.109)	(0.104)	(0.129)	(0.067)	
Household head born in village	0.643	0.645	0.590	0.626	0.660
	(0.054)	(0.050)	(0.048)	(0.029)	
Household does agriculture	0.939	0.921	0.902	0.920	0.578
	(0.018)	(0.017)	(0.034)	(0.014)	
Household head is literate	0.604	0.675	0.613	0.632	0.257
	(0.026)	(0.036)	(0.035)	(0.019)	
Household head is farmer	0.783	0.792	0.785	0.787	0.968
	(0.033)	(0.026)	(0.031)	(0.017)	
Household has a tin roof	0.539	0.517	0.531	0.529	0.940
	(0.045)	(0.046)	(0.046)	(0.026)	
Knowledge through media	0.591	0.574	0.504	0.555	0.236
	(0.047)	(0.036)	(0.036)	(0.023)	
Member of agr. coop.	0.174	0.196	0.148	0.173	0.491
	(0.026)	(0.028)	(0.029)	(0.016)	
Crops sold at Roadside	0.111	0.122	0.058	0.097	0.353
	(0.036)	(0.046)	(0.028)	(0.022)	
Crops sold at Market	0.741	0.800	0.802	0.782	0.752
	(0.069)	(0.054)	(0.065)	(0.036)	
Crops sold at Trader	0.136	0.089	0.128	0.117	0.652
	(0.048)	(0.035)	(0.039)	(0.023)	
Main crop: Cassava (1=yes)	0.688	0.723	0.643	0.685	0.332
	(0.042)	(0.034)	(0.041)	(0.023)	
Main crop: Beans (1=yes)	0.005	0.000	0.004	0.003	0.359
	(0.005)	(0.000)	(0.004)	(0.002)	
Distance input market (Km)	11.575	4.918	7.506	7.709	0.043
	(2.782)	(0.772)	(1.916)	(1.089)	

Distance output market (Km)	8.559	4.450	6.549	6.355	0.111
	(2.121)	(0.690)	(1.562)	(0.865)	
Distance credit institution (Km)	11.348	8.934	9.930	9.842	0.810
	(3.706)	(1.647)	(2.562)	(1.408)	
N	230	265	256	751	

Notes: standard deviations in parentheses. P-value computed with robust standard errors, clustered at the village level; * significant at 10%; ** significant at 5%; *** significant at 1%

Table 3: Knowledge, input use, yield and food security outcomes (pooled treatments)

	(1) Inoculation knowledge	(2) Fertilizer knowledge	(3) Inoculant Use	(4) Fertilizer Use	(5) Bean Yield	(6) Cassava Yield	(7) HFIAS Anxiety	(8) HFIAS Quality	(9) HFIAS Intake
t	-0.0468**	-0.000674	-0.00172	-0.000148	0.368	-0.0499	0.235**	0.403	-0.406
	(0.0203)	(0.0227)	(0.00933)	(0.0156)	(0.304)	(0.195)	(0.0919)	(0.270)	(0.415)
Pooled*Post	0.0764***	-0.000172	-0.00860	0.0320	0.891**	0.0496	-0.231*	-0.316	-0.250
	(0.0247)	(0.0297)	(0.0130)	(0.0203)	(0.406)	(0.257)	(0.117)	(0.335)	(0.495)
Constant	-0.000768	0.886***	-0.0320	0.0326	3.337***	7.621***	2.192***	6.892***	6.573***
	(0.0252)	(0.0241)	(0.0204)	(0.0210)	(0.421)	(0.208)	(0.115)	(0.276)	(0.360)
Village FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Baseline Mean	0.06	0.93	0.03	0.03	3.71	7.77	1.94	6.20	5.18
Baseline SD	0.23	0.25	0.16	0.18	2.88	1.79	0.96	2.37	3.45
N	1475	1475	1475	1475	752	1054	1475	1475	1475
# Clusters	92	92	92	92	89	92	92	92	92
Overall R2	0.02	0.00	0.02	0.00	0.05	0.00	0.03	0.03	0.05

Notes: Robust standard errors in parentheses, clustered at the village level, * significant at 10%; ** significant at 5%; ***significant at 1%. Regressions include controls for the level of education, the gender and the age of the head of the household and village level fixed effects.

Table 4: Knowledge, input use, yield and food security outcomes (by treatments)

	(1) Inoculation knowledge	(2) Fertilizer knowledge	(3) Inoculant Use	(4) Fertilizer Use	(5) Beans Yield	(6) Cassava Yield	(7) HFIAS Anxiety	(8) HFIAS Quality	(9) HFIAS Intake
t	-0.0468**	-0.000652	-0.00171	-0.000116	0.368	-0.0500	0.235**	0.403	-0.406
	(0.0203)	(0.0227)	(0.00933)	(0.0156)	(0.304)	(0.195)	(0.0919)	(0.270)	(0.415)
Subsidy*Post	0.0898***	0.0170	0.00112	0.0570**	0.917*	0.0180	-0.211	-0.358	-0.376
	(0.0289)	(0.0333)	(0.0175)	(0.0271)	(0.531)	(0.315)	(0.142)	(0.401)	(0.585)
Training*Post	0.0636**	-0.0166	-0.0179	0.00804	0.864*	0.0755	-0.251*	-0.275	-0.129
	(0.0281)	(0.0368)	(0.0142)	(0.0204)	(0.437)	(0.300)	(0.132)	(0.379)	(0.545)
Constant	-0.000709	0.886***	-0.0320	0.0327	3.337***	7.621***	2.192***	6.892***	6.572***
	(0.0250)	(0.0241)	(0.0203)	(0.0210)	(0.422)	(0.208)	(0.115)	(0.277)	(0.360)
Village FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Baseline Mean	0.06	0.93	0.03	0.03	3.71	7.77	1.94	6.20	5.18
Baseline SD	0.23	0.25	0.16	0.18	2.88	1.79	0.96	2.37	3.45
Train = Subs (p)	0.36	0.38	0.30	0.06	0.92	0.86	0.78	0.83	0.65
N	1475	1475	1475	1475	752	1054	1475	1475	1475
No. clusters	92	92	92	92	89	92	92	92	92
Overall R2	0.02	0.00	0.02	0.01	0.05	0.00	0.03	0.03	0.05

Notes: Robust standard errors in parentheses, clustered at the village level, * significant at 10%; ** significant at 5%; *** significant at 1%. Regressions include controls for the level of education, the gender and the age of the head of the household and village level fixed effects.

Table 5: Treatment spillovers

	(1) Inoculation knowledge	(2) Fertilizer knowledge	(3) Inoculant Use	(4) Fertilizer Use	(5) Beans Yield	(6) Cassava Yield	(7) HFIAS Anxiety	(8) HFIAS Quality	(9) HFIAS Intake
t	-0.0730***	0.0116	-0.00850	-0.00677	0.281	-0.0458	0.255**	0.551	-0.529
	(0.0267)	(0.0273)	(0.0116)	(0.0214)	(0.372)	(0.228)	(0.118)	(0.377)	(0.516)
Pooled*Post	0.103***	-0.0125	-0.00181	0.0386	0.978**	0.0454	-0.251*	-0.463	-0.127
	(0.0303)	(0.0334)	(0.0146)	(0.0251)	(0.459)	(0.282)	(0.139)	(0.426)	(0.583)
Distance to Control	0.0853***	-0.0400	0.0221	0.0216	0.305	-0.0157	-0.0648	-0.481	0.401
	(0.0303)	(0.0482)	(0.0185)	(0.0254)	(0.623)	(0.425)	(0.180)	(0.417)	(0.849)
Constant	-0.000844	0.886***	-0.0320	0.0326	3.334***	7.620***	2.192***	6.893***	6.573***
	(0.0253)	(0.0241)	(0.0204)	(0.0211)	(0.422)	(0.208)	(0.115)	(0.277)	(0.360)
Village FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Baseline Mean	0.06	0.93	0.03	0.03	3.71	7.77	1.94	6.20	5.18
Baseline SD	0.23	0.25	0.16	0.18	2.88	1.79	0.96	2.37	3.45
N	1475	1475	1475	1475	752	1054	1475	1475	1475
No. clusters	92	92	92	92	89	92	92	92	92
Overall R2	0.01	0.00	0.01	0.00	0.04	0.00	0.03	0.03	0.05

Notes: Robust standard errors in parentheses, clustered at the village level, * significant at 10%; ** significant at 5%; *** significant at 1%. Regressions include controls for the level of education, the gender and the age of the head of the household and village level fixed effects; Wald (p) indicates p-value of F-test for equality of Treatment*Post and Proximity * Post.

Figures

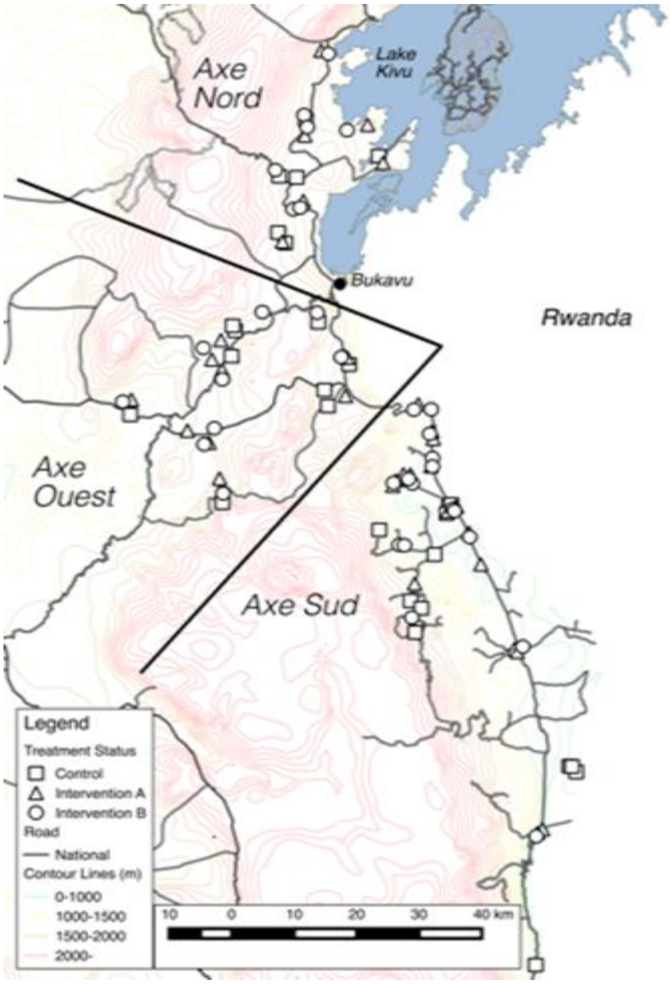

Figure 1: Eastern DRC Research area with treatment and comparison sites.

Note: XY coordinates were purposefully distorted and locations are approximate

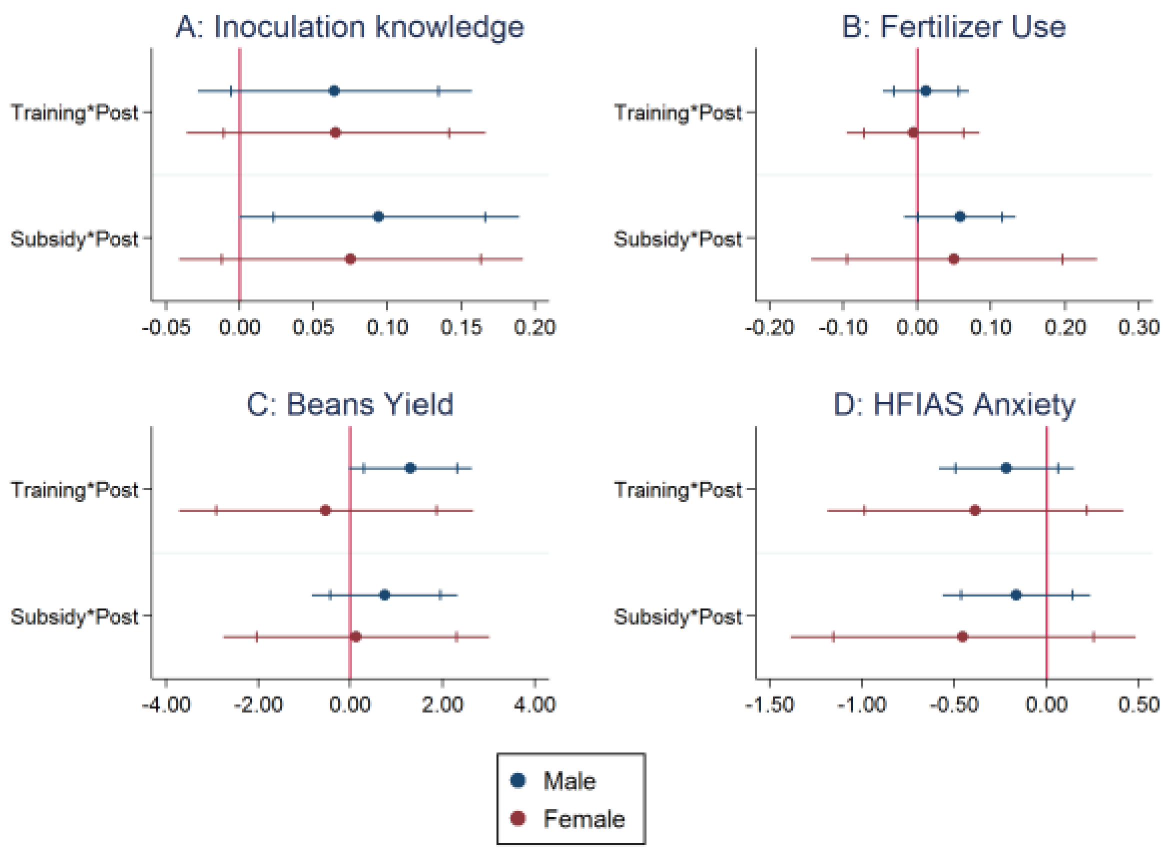

Figure 2: Results by Gender of Household Head

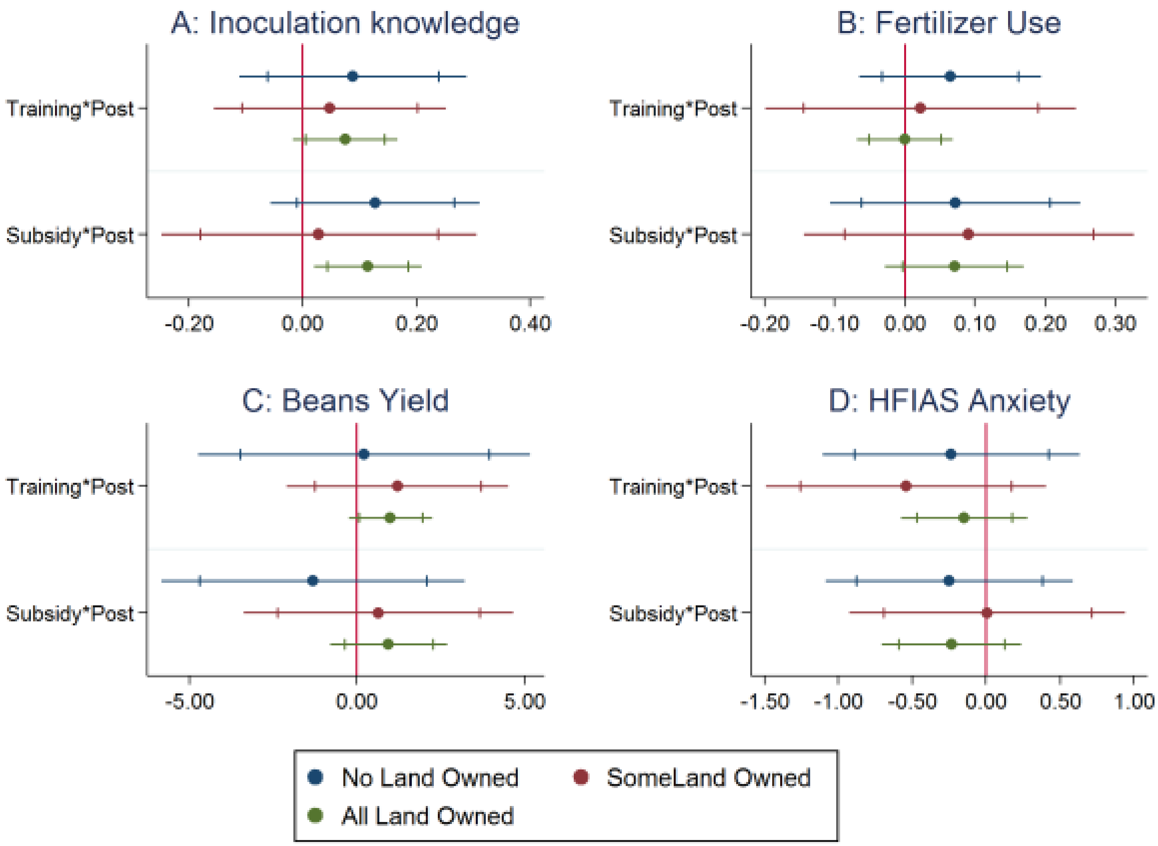

Figure 3: Results by tenure security

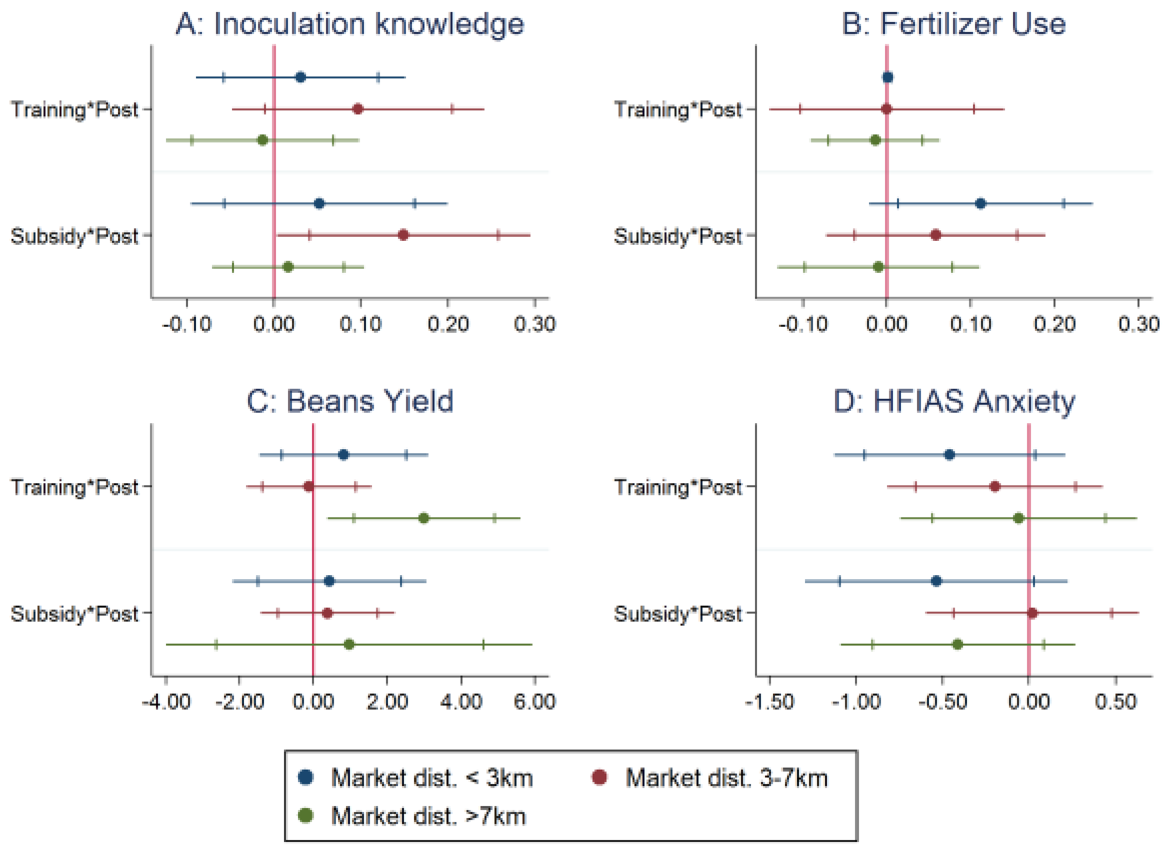

Figure 4: Results by Market Access

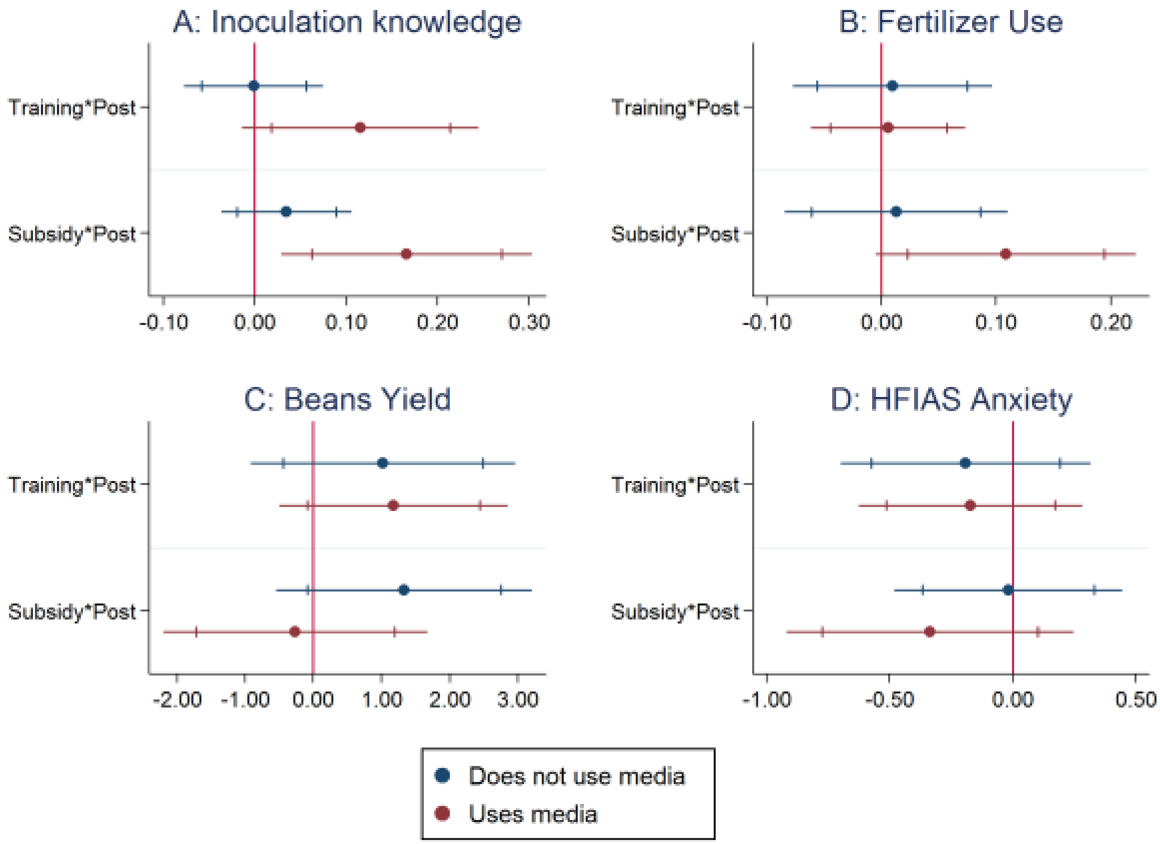

Figure 5: Results by Media Use

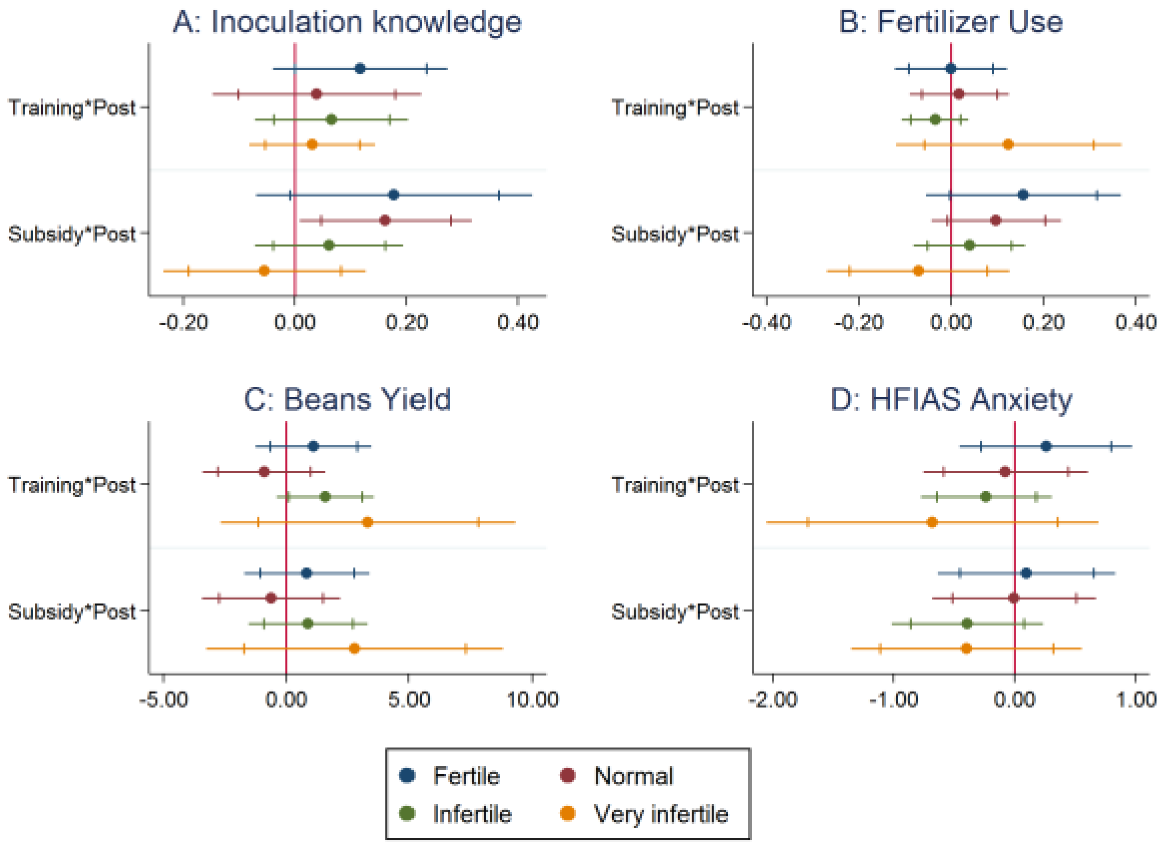

Figure 6: Results by Soil Quality

Appendix

Table A 1: Correlates of Attrition

	(1)
	attr
Training	0.0643
	(1.36)
Subsidy	0.0409
	(1.02)
Partner 2	0.00394
	(0.03)
Partner 3	-0.104*
	(-1.90)
Partner 4	-0.0513
	(-0.43)
Partner 5	0.122
	(1.07)
Partner 6	0.0192
	(0.35)
Household size	-0.0128***
	(-2.87)
Age household head	-0.00220***
	(-2.85)
Female household head	0.00368
	(0.10)
Education level hh head	0.00701
	(0.73)
Hh head born in village	-0.0353
	(-1.24)
Household took loan or credit in last 12 months	0.0173
	(0.70)
West Axis	-0.218***
	(-4.00)
South Axis	-0.130
	(-1.09)
Constant	0.469***
	(3.43)

N	898
No. clusters	93
Pseudo R2	
HH. Controls	
Vill. Controls	

Table A 2: Outcome indicators by attrition status

	(1) Non-attrited	(2) Attrited	Difference (2) - (1)
Inoculation knowledge	0.057	0.068	-0.011
	(0.009)	(0.022)	(0.023)
Fertilizer knowledge	0.935	0.938	-0.003
	(0.011)	(0.021)	(0.021)
Inoculant Use	0.027	0.012	0.014
	(0.006)	(0.009)	(0.011)
Fertilizer Use	0.032	0.043	-0.012
	(0.006)	(0.018)	(0.019)
Bean Yield	3.714	4.423	-0.709*
	(0.205)	(0.395)	(0.411)
Cassava Yields	7.771	7.303	0.468*
	(0.084)	(0.212)	(0.236)
HFIAS Anxiety	1.937	1.876	0.062
	(0.042)	(0.080)	(0.086)
HFIAS Quality	6.202	6.050	0.153
	(0.115)	(0.201)	(0.215)
HFIAS Intake	5.177	5.155	0.022
	(0.173)	(0.315)	(0.333)
N	751	161	912
Proportion	0.823	0.177	