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HARVESTING THE RAIN: THE ADOPTION OF ENVIRONMENTAL TECHNOLOGIES IN THE SAHEL

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ABSTRACT

Many agricultural and environmental technologies require large upfront investments in exchange for longer-term benefits. This time profile of costs and benefits makes adoption particularly sensitive to liquidity and credit constraints, which are prevalent in low-income settings. We test the importance of these barriers to the adoption of an agricultural technique that helps reduce land degradation and restore soil fertility in Niger. We find little evidence that liquidity or credit constraints deter adoption: instead, providing farmers with training increases the share of adopters by over 90 percentage points, whereas adding conditional or unconditional cash transfers has no additional effect. Adoption increases agricultural output, reduces land turnover and leads to adoption spillovers up to three years after treatment. These results imply that training can be a cost-effective and scalable means of promoting the adoption of profitable technologies.

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1. Introduction

Since the 1960s, agricultural yields have more than doubled around the world. The sole exception to this trend is sub-Saharan Africa, where yield growth has stagnated. To meet the consumption needs of a growing population, the agricultural sector has increased total output by bringing more land into production. This strategy is unsustainable: the demand for land has pushed production onto increasingly marginal soils and shortened fallow periods, and increasingly frequent climate shocks have exacerbated these challenges (Jayne 2014, Warren et al. 2001).

Interrupting this cycle of land degradation and poor yields requires intensive agricultural practices that both increase water storage within the soil and replenish soil nutrients. Rainwater harvesting (RWH) techniques, which capture rainfall and reduce runoff, present a compelling option in settings where irrigation is technically unfeasible and chemical input use is limited. Our study takes place in Niger, where the adoption of RWH follows a familiar story line: agronomists or engineers predict high returns to adoption (Vohland and Boubacar 2009), yet adoption levels remain low (Liniger et al. 2011, authors' calculations).[1] A number of adoption barriers may contribute to this gap. Like many environmental technologies, RWH techniques require a considerable investment upfront (in labor) and generate benefits over multiple agricultural seasons. As a result, adoption could be low because of cash-on-hand liquidity constraints at the time of adoption (e.g., Karlan et al. 2014) or high interest or discount rates that make the present value of benefits too small to justify the costs (e.g., Berkouwer and Dean 2019). At the same time, relaxing financial constraints will only be effective if farmers have adequate information about the technology, and informational barriers may independently deter adoption (e.g., Emerick and Dar 2020).

We provide experimental evidence that information is the binding constraint to technology adoption in a setting where savings levels are low and credit access is limited. We carried out our experiment in the eastern region of Zinder in Niger. Small-scale farmers in 180 villages were assigned to one of four treatment arms or a control group, with treatments designed to relax specific barriers to adoption. The *training* treatment received only training, which included a session on the technical requirements for constructing demi-lunes. The remaining treatment arms received some type of cash transfer in addition to the training.

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[1] We focus on one RWH technique (the *demi-lune*) that is particularly well-suited for recuperating degraded soils that are no longer productive. Demi-lunes are half-moon shaped berms, constructed on the field to collect rainfall and runoff. Farmers plant crops in and around the demi-lunes. Unlike a number of other RWH techniques, they do not require the application of complementary inputs (e.g., fertilizer or manure) and require little maintenance after the first year. Decades of agronomic trials suggest that *demi-lunes* can reduce soil degradation, lower the risk of crop failure, and boost average profits (Concern Worldwide 2011, Warren et al. 2001, Vohland and Boubacar 2009).

The “early” unconditional cash transfer arm (*UCT-early*) was assigned to a lump sum payment of USD 20 after the training, to relax cash-on-hand liquidity constraints at the time of adoption.[2] The conditional cash transfer arm (*CCT*) received a payment of USD 0.40 per demi-lune constructed, paid immediately before the planting period, about 3 months after the *UCT-early* arm, to increase the short run returns to demi-lune construction. To address the difference in timing between the *UCT-early* and *CCT* arms, a final treatment arm (*UCT-late*) provided an unconditional transfer of USD 20.50 at the same time as the *CCT* payout. The treatments were administered during the first year, and data collection followed the sample for three subsequent years.[3]

We have four main findings. First, all four treatments significantly increased adoption in the short- and medium-term. The training intervention alone increased the likelihood that a farmer adopted any demi-lunes by over 90 percentage points relative to the control. Relative to training only, the cash transfer arms had no additional effect on the probability of adoption. In the first year, farmers in the training arm constructed 35 more demi-lunes than did farmers in the control. Farmers in the *UCT-early* and *CCT* arms adopted 26 and 42% more demi-lunes than did farmers who received training only in the first year. Yet, by the third year, adoption levels were indistinguishable across treatments. We thus conclude that training alone was sufficient to explain all of the medium-term impacts on adoption across all treatment arms.

Second, adoption occurred through a combination of hiring labor and reallocating household labor. In the first year, treated households hired more labor, sent fewer household members to engage in seasonal migration and did less wage work in order to construct demi-lunes. Households also hired labor for other agricultural tasks, such as sowing and weeding. None of these effects were statistically significant different across treatment arms. Despite the impacts on labor allocation, we find no evidence of general equilibrium effects on wage rates, in part because the timing of demi-lune construction coincides with the slack agricultural season in Niger.

Third, the interventions had significant impacts on downstream outcomes, namely, agricultural production and land use. Across all treatments, total agricultural production increased by 0.12 to 0.15 standard deviations relative to the control, with stronger effects in the medium- than short-run. While we observe no impact on land use in the first year,

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[2] All transfer arms were announced in a separate visit after the training. To minimize experimenter demand effects, and emphasize that the UCT treatments were unconditional, households were told that they could use the cash for anything they wanted.

[3] The value of the UCT-early treatment was equivalent to 1/4 of the estimated cost of constructing demi-lunes on one hectare of land, based upon pilot research. The amount of the CCT was based upon prior pilot work, as well as the UCT amount. The UCT-late treatment received an additional USD 0.50 as compensation for the delay in payment, based upon local interest rates.

households in treated villages were cultivating an additional 0.3 hectares of previously uncultivated land by the third year. We combine the effects on labor allocation and hiring with the effects on revenue in a basic private cost benefit calculation: in the first year alone, when most of the investment costs were incurred, the treatment effect on agricultural revenue was USD 40 per year while the costs were approximately USD 30. These benefits persisted after the first year, while private costs fell to near zero.

Finally, we observe significant adoption spillovers within villages. We find that farmers in treated villages were 50 percentage points more likely to have a neighbor adopting demi-lunes relative to farmers in control villages. We also find that, in a spillover sample, farmers were 20 percentage points more likely to adopt demi-lunes in treatment villages than in control villages.

What makes a one-day training so effective at increasing adoption? The impacts of the training that we study – like most training programs – may operate through a number of distinct channels. First, the training may have made farmers aware of the existence of the technology, thereby increasing their adoption. Second, by providing relevant technical advice, the training may have increased farmers' knowledge of how to better construct demi-lunes. Third, by organizing farmers into groups and practicing construction, the training may have facilitated social learning during and after the training. And finally, the training may have influenced other channels, such as motivation or social norms.

While our experiment does not allow us to distinguish between these explanations, we provide suggestive evidence that multiple channels contributed to the large impacts of training. While a majority of farmers were familiar with demi-lunes prior to the training, approximately 1/3 farmers were not. As a result, the awareness provided by the training could have been pivotal. Despite these high levels of initial awareness, technical knowledge improved significantly with the training, especially along those dimensions that were necessary for effective adoption. In addition, both adoption spillovers and self-reports of shared labor and learning are consistent with social learning. Together, this implies that multiple aspects of the training may have triggered adoption among different segments of the population.

Our study contributes to a large literature on the barriers to technology adoption. In low-income settings, liquidity and credit constraints are often blamed for low adoption of agricultural or environmental technologies that incur upfront costs with delayed benefits (see Magruder (2018) on agriculture and Fowlie and Meeks (2021) on energy efficiency).[4] However, evidence that credit or liquidity is a binding constraint for agricultural technology

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[4] Others have studied the role of liquidity and credit constraints for the take up of preventative health technologies (e.g., Yishay et al. 2017), where the delayed benefits come in the form of better health (and potentially higher earnings). This is in contrast with, for example, agricultural or energy efficiency technologies, where the benefits are in the form of higher revenue or cost savings.

adoption remains scarce, and recent RCT-based evidence suggests that it may present a barrier for at most a minority of farmers (e.g., Karlan et al. 2014, Beaman et al. 2014, Crépon et al. 2015).[5] Our study design helps separate the role of cash-on-hand liquidity constraints versus credit constraints or high discount rates.[6] Consistent with other recent RCTs, we find that both of these financial constraints play a relatively minor role in deterring the adoption of a profitable technology, and further show that modest treatment effects (above and beyond the effect of training) do not persist past the first year. In doing so, we provide novel evidence on the performance of conditional versus unconditional cash transfers, which have not been directly compared in an agricultural technology adoption context (Akresh et al. 2016, Benhassine et al. 2015, Baird et al. 2011). Our design rules out a problematic confound in most direct comparisons of UCT and CCT interventions: UCTs come before the desired outcome, while CCTs come after, making it difficult to separate the modality from the timing.

Second, numerous studies test the impact of informational interventions on technology adoption or other behavior change (e.g., Jensen 2010, Dupas 2011, Allcott and Rogers 2014), including in agriculture (Hanna et al. 2014, Glennerster and Suri 2015, Emerick and Dar 2020, Barrett et al. 2020).[7] Trainings are often used to deliver information, particularly in agriculture, and we extend the existing literature by benchmarking the effect of training against both a control group that receives no training, and treatment arms that combine training with cash transfers. Our findings are stark: training is what matters for adoption, particularly in the medium-term. This is in spite of a study population that is very poor and a technology that incurs substantial upfront costs. The magnitude of the effect of training on adoption is large relative to the existing literature. While we cannot fully disentangle the different ways that training may affect adoption, we provide a framework for considering alternative channels and find evidence that the bundled nature of the training may help explain its effectiveness.

The technology we study is most closely related to a class of agricultural practices and technologies that either mitigate the impacts of environmental shocks or reduce the environmental externalities from agriculture. These include drought-resistant crops (Emerick

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[5] Berkouwer and Dean (2019) provide evidence that credit constraints can fully explain the energy efficiency gap for an improved cookstove in Kenya. While access to short run credit more than doubles technology adoption at market prices, without subsidies on the price of the stove (or a longer-term loan), take up remains low (¡10 percent).

[6] Specifically, the UCT-early treatment will only increase adoption if the technology is privately profitable at current discount rates but a lack of cash on hand at the time of demi-lune construction deters adoption. The CCT treatment, on the other hand, is unlikely to affect short run liquidity and therefore will only increase adoption if the benefits are too heavily discounted relative to costs.

[7] A larger literature studies how farmers learn about new technologies, including learning by doing and learning from others (e.g., Foster and Rosenzweig 1995, Conley and Udry 2010, Besley and Case 1993).

et al. 2016), conservation agriculture (BenYishay and Mobarak 2014, Beaman et al. 2018, Barrett et al. 2020) and agroforestry (Oliva et al. 2020, Jack 2013). Despite the importance of technologies, relatively little is known about their profitability to farmers or the dynamics of adoption. Our study offers new evidence on the barriers to adoption of environmental technologies for smallholder farmers, and highlights the potential for trainings, rather than cash incentives, to increase adoption.

The rest of the paper proceeds as follows. Section 2 outlines the research setting and Section 3 describes the study design and implementation. Section 4 outlines the data and empirical strategy. Section 5 presents the results on demi-lune adoption and Section 6 the results on inputs and outputs. Section 7 discusses mechanisms including possible threats to identification. Section 8 concludes.

2. Context

2.1 Agriculture, Climate and Land in Niger

With a per capita income of USD 551 and an estimated 85 percent of the population living on less than USD 2 per day, Niger is consistently one of the lowest-ranked countries on the UN's Human Development Index (UN 2020). Agriculture dominates the economy and employs the majority of low income households, 70 percent of whom live and work in rural areas (Barry et al. 2008).

The primary staple crops cultivated in Niger are millet and sorghum, along with the cash crops of cowpea, peanuts, and sesame. A single annual rainy season occurs between June and September and harvest follows soon after (Barry et al. 2008). As a result, there is a marked seasonality to income, consumption, prices, and labor (see Figure A.1). The slack agricultural period coincides with a period of seasonal outmigration to neighboring countries, with 50 percent of households sending at least one seasonal migrant (Aker et al. 2020). The rainy season also overlaps with the "hungry period", the time when credit and liquidity constraints typically bind (Aker et al. 2020).

With limited surface water, agriculture in Niger is primarily rainfed; as a result, inter-annual fluctuations in rainfall are strongly correlated with agricultural output. The region witnessed some of its most serious climate-induced food shortages in 1970s and 1980s. Since then, Niger has been subject to frequent droughts, the most recent of which occurred in 2018 (CSAO/OECD 2015, OCHA 2018). Rainfall fluctuations have also led to shorter fallow periods (Jayne 2014).

Niger has some of the highest rates of soil degradation in the world, with approximately

50 percent of land experiencing soil erosion.[8] This is further compounded by population density: approximately 94 percent of the population lives on 20 percent of the land, and population growth is estimated at 3.8 percent per year. In our sample, 64 percent of farmers cited land quality as a primary constraint to agricultural production. While customary land tenure practices govern different types of land in Niger, most land ownership in our study area is private (Hughes 2014). Under customary law, women cannot own land; they only have access to it via male relatives in the household.

2.2 Rainwater Harvesting Techniques

The most appropriate type of water harvesting technique – micro and macro catchments, floodwater harvesting and storage reservoirs – depends upon average rainfall, soil type and geographic location (FAO 2001).[9] In the semi-arid areas of sub-Saharan Africa, micro-catchments – small structures constructed within a field to collect soil runoff and increase the nutrient content of the soil – are the most appropriate RWH technique for recuperating degraded soils. The most common micro-catchments used in the Sahel are *zaï* (soil pits), *demi-lunes* (half-moons) and *banquettes*, some of which are indigenous to West Africa (Barry et al. 2008).[10]

Demi-lunes are large, half-circle earthen bunds that are constructed on a plot of land. They are particularly appropriate for sloped land with severely degraded soil, known as *glacis*, which represents approximately 60 percent of all degraded land in Niger.[11] To maximize organic matter and moisture capture, the technical specifications of demi-lunes are important: size (2 meters by 4 meters), depth (15-30 centimeters) and spacing (2 meters between the bunds, to discharge excess runoff) (Figure A.3).[12] Following these dimensions, the Ministry of Environment recommends that 250-300 demi-lunes should be constructed

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[8] While there have been a number of land recuperation programs in Niger since the 1980s using RWH techniques, these programs have primarily focused on communal land, rather than private land.

[9] Conservation agriculture is poorly suited to the semi-arid areas of Africa, where soil cover materials compete with livestock fodder.

[10] This study focuses on demi-lunes, rather than a broader set of RWH techniques, for several reasons. First, demi-lunes are one of the most appropriate RWH techniques for the types of soils in Niger and other Sahelian countries. Second, the technology is specific and easy to observe (in terms of construction, complementary inputs and maintenance), which facilitates the measurement of adoption and dis-adoption. Third, the technology is a strategic priority for Nigerien, regional and international stakeholders, and related projects receive substantial investments each year.

[11] *Glacis* are soils that have developed an impermeable layer across the top of the soil that impedes infiltration of water, primarily due to wind and sun. Sandy soils are a second type of degraded land in Niger, which are not appropriate for demi-lunes.

[12] There are two types of *demi-lunes*, environmental and agricultural. The former seeks to restore forest cover, whereas the latter seeks to recuperate degraded agricultural land so that it can be cultivated. The technical dimensions of demi-lunes thus depend upon the specific type. This research focuses on agricultural demi-lunes.

per hectare to fully cover the plot and maximize restoration.[13] Technical norms also suggest that the timing of construction is important: demi-lunes need to be constructed after the harvest but before the rainy season, to collect wind-borne silt and organic matter (before the rains) and rainwater (during the rains). This suggests a window of approximately six months for construction. This window coincides with the slack agricultural season in Niger, so both the opportunity cost of family labor and local wages are low. This is also the start of the hungry season, and the exertion required for construction is substantial. Figure A.1 shows the timing of the agricultural calendar in Niger, along with the appropriate window for demi-lune construction.

Farmers can plant crops in and around the demi-lunes, primarily millet, sorghum, cowpea and sesame. While complementary inputs (such as manure or other fertilizers) can be added, they are not required for reaping soil moisture benefits. Once constructed, the demi-lune lasts for approximately three years without major maintenance, at which point the land in the demi-lune should be recuperated.[14]

Previous agronomic research suggests that the total costs of constructing 250-300 demi-lunes on one hectare are around USD 80, comprised mainly of labor (USD 75) and small tools (e.g., shovel and pickax).[15] Maintenance costs are significantly lower than construction costs, and primarily involve applying manure (Liniger et al. 2011). Decades of on-farm trials suggest that demi-lunes can significantly reduce soil degradation and the risk of crop failure, (Warren et al. 2001, Vohland and Boubacar 2009), as well as increase millet yields by over 300% if fertilizers and manure are used (Concern Worldwide 2011). Yet despite decades of investment in promoting demi-lunes in Niger, it is estimated that only 10% of farmers adopt demi-lunes on any part of their private land (authors' calculations).

3. Experimental Design

A number of barriers to adoption are associated with specific features of the technology.[16] The first is information: either farmers do not know about demi-lunes, or they do not know

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[13] It should be noted that there is little written about the justification of the technical norms, which appear to be largely mechanical: If each demi-lune is 2 X 4 meters, with 2 meters in between, then this would allow for 16 demi-lunes across 16 rows, so about 277 demi-lunes per hectare. This calculation assumes, of course, that the plot of land is a square, and that the slope is appropriate for demi-lunes.

[14] While soil quality in between demi-lunes may also improve, agronomists recommend constructing new demi-lunes in between the old ones in order to fully recuperate the land.

[15] Depending upon the hardness of the soil, studies indicate that an average of three demi-lunes can be constructed per day. Thus, fully covering one hectare with demi-lunes would take between 85-100 person-days. Labor costs are then estimated by applying the average wage rate.

[16] These are supported by qualitative evidence from farmers, quantitative evidence from a pilot study implemented by the authors, and anecdotal evidence from practitioners.

their technical specifications. The second is liquidity: given the nature of the seasonal calendar, as well as low rates of financial inclusion in Niger, farmers are cash-constrained at the time when demi-lunes are typically constructed.[17] The third is the delay between the upfront cost of adoption and the accumulation of benefits, which makes demi-lunes less privately profitable at higher discount rates. Our design targets these three primary barriers.

3.1 Interventions

In 2018, we collaborated with the Ministry of Environment and a data collection firm, Sahel Consulting, to implement four main treatments, summarized in Figure 1. In 2021, we also implemented a light-touch nudging intervention to investigate mechanisms behind the levels of adoption.

Training The first treatment offered an interactive training in February of 2018 to all selected farmers in a given treatment village. The training lasted half a day and covered the following topics: 1) an explanation of *demi-lunes* and their purpose; 2) the steps for constructing and maintaining demi-lunes, including how to plant in and around them; and 3) the technical norms for construction, including the appropriate land type, dimensions and orientation. The training was conducted by a Ministry of Environment agent, and visual aids were provided (see Appendix A.1). After the "classroom" portion of the training, the group practiced what they had learned by jointly constructing three demi-lunes on a plot of land volunteered by a village resident who was not part of the study.[18]

Unconditional Cash Transfer - Early (UCT-early) To address liquidity constraints during the construction window, the second treatment combined the training with an unconditional cash transfer of USD 20, paid in March, approximately one month after the training.[19] The value of the transfer was equivalent to 1/4 of the estimated cost of constructing demi-lunes on one hectare of land, based upon pilot research.[20] A key concern

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[17] If labor is hired, then cash constraints at this time will hinder adoption. If family labor is used, then food scarcity could affect the availability of labor for demi-lune construction.

[18] Our training differed from other demi-lune trainings in several ways. First, the training provided a booklet with text (in Hausa) and pictures on how to construct demi-lunes, which farmers could keep. Second, the training emphasized that demi-lunes could be constructed on individual plots of degraded land, in addition to communal land, the latter of which had been a primary focus of governmental and NGO trainings. And third, the training emphasized that demi-lunes could be constructed with readily available tools (e.g., shovel, pickax, etc), rather than specialized tools that needed to be specially ordered.

[19] If households are liquidity constrained and face other investment opportunities, this UCT would not necessarily change behavior. Rather, its impacts will depend on the relative value of allocating cash to *demi-lunes* versus other potential uses.

[20] The cash transfers were announced in all transfer arms after the training took place. Transfers were sent via mobile money to beneficiaries in the order of training implementation. If the transfer was not delivered,

with the *UCT-early* arm is that farmers could have interpreted the cash transfer as conditional on demi-lune construction (Benhassine et al. 2015). To minimize this effect, we emphasized the lack of conditionality when announcing the cash transfer via a script.[21]

Conditional Cash Transfer (CCT) To address the time delay in benefits relative to construction costs, the third treatment combined the training with a CCT worth approximately USD 0.40 for every demi-lune constructed of acceptable quality. Unlike the *UCT-early* treatment, the transfers were paid in June, before the rainy season and after verifying the number of demi-lunes constructed. All other modalities of the *CCT* transfers were the same as the *UCT-early* arm. The amount of the CCT was based upon prior pilot work, as well as the UCT amount; a household that constructed 50 demi-lunes would receive the same payment under the two treatment arms.[22]

Unconditional Cash Transfer - Late (UCT-late) The final treatment combined the training with a UCT of USD 20.50, timed to coincide with the CCT payout. The additional USD 0.50 was provided as compensation for the delay in payment relative to the *UCT-early*. This primary goal of this treatment arm was to distinguish between differences in the *UCT-early* and *CCT* arms, which differed both in their modality and timing.[23]

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beneficiaries were able to call a hotline to report non-receipt, and this was checked against mobile money records.

[21] The UCT-early transfers were introduced using the following script: "You have also been selected to receive a cash transfer of 10.000 CFA....We will send this money to you by late March. This money is for you; you are free to do with it what you wish. You do not need use it for anything related to demi-lunes. For example, if you need to spend it on food or clothing or medical expenses, you should. We will only be making this cash transfer one time, this year, and there will be no future cash transfers as part of this program. Please note that only those households who had a member who attended the training will be eligible for this."

[22] Similar to the *UCT-early* arm, the *CCT* arm was informed about the conditions, amount and timing of the cash transfer after the training. The script was the following: "You have been selected to receive a cash transfer of 250 CFA for every demi-lune that you construct that meets the norms outlined in the training....We will send this money to you by the end of May/early June, right before the rainy season and after we have verified how many demi-lunes that you constructed on your land. While you will be paid for every demi-lune constructed, this money is for you; you are free to do with it what you wish. You do not need use it for anything related to demi-lunes. We will only be making this cash transfer one time, this year, and there will be no future cash transfers as part of this program. Only those households who had a member who attended the training will be eligible for this."

[23] The *UCT-late* arm was introduced at the same time as the *UCT-early* arm, with an identical script. The only differences between the UCT-early and UCT-late treatments were the amount (20.50 USD rather than 20 USD) and the timing (after demi-lune construction rather than prior). The *UCT-late* arm also helped to address concerns about reciprocity or experimenter demand effects in the *UCT-early* arm, since these effects are likely to be similar across the two UCT treatments, while only the UCT-early addresses liquidity constraints.

Nudges In February 2021, we embedded a nudging intervention in the endline survey in an effort to better understand the mechanisms and magnitudes of adoption. The interventions included five treatments and one control, with each treatment designed to address a behavioral barrier to adoption. Within each village, we stratified by gender and assigned recipients to either a nudge or none. Each nudge was a phrase that was read at the end of the endline survey. The nudges addressed five topics: "permission-seeking" (i.e., seeking permission before building demi-lunes); procrastination (i.e., waiting too late in the dry season to construct demi-lunes); experimenter demand; the salience of cost and benefits; and the salience of inputs.[24]

3.2 Sample and Randomization

In December 2017, we identified 184 villages in the Zinder region of Niger. To be eligible, a village needed to: 1) have some households with degraded land appropriate for demi-lunes (e.g., *glacis*); 2) have no chieftancy disputes; and 3) be categorized as a administrative village, meaning that it had its own chief.

Following the initial village identification and prior to the baseline, a census of eligible recipients was conducted. The primary criteria for eligibility was access to degraded land: a household needed to have between 0.5 and 10 hectares of degraded land at their disposal. The same process for listing eligible recipients was used in all villages, yielding a total of 4,944 eligible recipients. During the listing exercise, we also collected information about recipients' age, gender, marital status, mobile phone ownership, household size, land ownership and experience with demi-lunes.

After this listing process, four villages were dropped, either because they were administratively part of another village or because they only had a few eligible recipients within the village. Within each village, we stratified by gender and randomly chose 16 individuals, 8 men and 8 women, from the list of eligible recipients.[25] This yielded a final sample of 180 villages and 2,861 participants. We also randomly drew a spillover sample from among the 2,083 eligible households who were not chosen to participate in the study. Within each village, we stratified by gender and randomly chose 4 participants per village, 2 men and 2 women, yielding a spillover sample of 670 participants.

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[24] The "permission seeking" intervention stated the following: "Just like preparing your fields for the rainy season, now is the best moment to begin recuperating your degraded land by building demi-lunes. If you think that demi-lunes are useful for you, don't wait for someone to tell you to start construction this year – your future is in your hands." Other nudges were written in a similar style. The full text for each nudge is available upon request.

[25] In a small number of villages, eight eligible females were not available, in which case all eligible females were enrolled. Over 94% of female participants were married.

The 180 study villages were stratified by sub-region before being randomly assigned to one of the four treatment arms (150 villages) or a control (30 villages). Treatment villages were assigned to either the *training* (40 villages), training plus *UCT-early* (40 villages), training plus *CCT* (40 villages) or training plus *UCT-late* (30 villages) arms. To ensure balance, we used the min-max T statistic method with village and household level characteristics, balancing on variables collected during the listing exercise, and choosing the assignment allocation that minimized the maximum t-statistic (Bruhn and McKenzie 2009).[26]

4. Data and Empirical Strategy

4.1 Data

The data we use in this paper come from three primary sources over a four-year period. First, we collected household-level survey data before the program in February 2018, as well as nine months after the intervention (February 2019) and two years later (February 2021). Second, we collected observational data on demi-lune construction in June of each year between 2018 and 2021. And finally, we collected household survey data from a spillover sample in February 2021. A summary of each dataset, the timing and the sample size is provided in Table 1.

Household Surveys The first data source includes information on household characteristics before the interventions took place (baseline), as well as after (midline and endline, study years 1 and 3 respectively). The baseline survey was conducted in all 180 villages in February 2018, approximately one month after the listing exercise, with follow-up surveys in February 2019 and 2021. Due to funding and time constraints, we were unable to interview all households within each village at baseline, and instead randomly sampled 12 (out of the 16) participants. We attempted to interview the full sample for the midline and endline surveys. Each survey collected detailed information on household demographics, assets, agricultural production, land and labor outcomes and demi-lune construction. Baseline data are primarily used to test for imbalance across the different treatments, while midline and endline data are used to estimate impacts of the program one and three years after the intervention, respectively.

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[26] After villages were assigned to their treatment condition, the balance on listing variables was tested using the a number of characteristics, including mobile phone ownership, number of hectares owned, number of degraded hectares owned, number of adult household members, gender, previous demi-lune experience, village population and administrative status. The procedure was repeated 10,000 times, and the assignment of treatments that minimized the maximum t-stats for individual and village level comparisons was selected as the final treatment allocation.

Demi-lune Construction The second data source is annual field observations of demi-lune construction in June of each year, between 2018 and 2021. For each data collection round, an enumerator and a Ministry of Environment field agent visited each participant's fields, counted the number of demi-lunes and noted which demi-lunes followed key technical norms, including as depth, dimension and spacing.[27] The enumerator also asked specific questions about demi-lune construction prior to verification, and took the GPS coordinates of the plot where demi-lunes were constructed.

For the 2020 and 2021 data collection rounds, the protocol was adjusted. In 2020, the enumerator conducted a census of all plots, visited all of them fields and took their coordinates. This ensured a consistent sample of field geo-coordinates and observations, regardless of adoption outcomes. In addition, enumerators were asked to observe the presence of any demi-lunes on adjacent fields across all villages. In 2021, enumerators only verified *new* demi-lune construction, in other words, construction that had taken place between February and June 2021. Since the 2021 round only verified new construction, we do not include it in our main analysis, and use it only to measure outcomes for the nudging interventions delivered at endline.

Spillover Sample Survey The final dataset is a household survey conducted with the spillover sample in February 2021. Similar to the household survey with the full sample, we collected information on asset ownership, agricultural production, land and labor outcomes, demi-lune knowledge and self-reported demi-lune construction. These data enable us to assess adoption and learning spillovers within villages.

4.2 Balance and Attrition

Baseline Balance Table 2 shows the balance of pre-program characteristics using the listing data, while Table 3 uses the baseline sample. In each table, Column 1 shows the mean and standard deviation for the control villages, and Columns 2-5 show the difference in means between each of the treatments and the control. The pairwise comparisons by treatment arm are shown in Tables A1 and A2.

Overall, differences in pre-program household characteristics are small. The average household size is 8.5 people (Table 3), with 4.4 adults. Households own approximately 4 hectares of land, almost half of which is degraded, although not necessarily *glacis*. Households have access to three plots of land (owned or rented), and grow millet, sorghum, cowpea and

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[27] In 2018, the verification data were also used to determine the amount of the cash transfer to be paid in the CCT treatment arm. Only farmers in the CCT treatment arm were explicitly informed that monitoring would take place; reference to future data collection details was left vague in the other treatment arms.

peanuts. Rates of food insecurity are high: 93 of households reported experiencing food insecurity over the course of the past agricultural season.

Across the 19 characteristics tested for balance in a total of 190 separate tests (each pairwise comparison), a total of 17 (or 8.9%) show imbalance at the 10% level. Of these, the potentially problematic variables pertain to households' previous experience with demi-lunes: households in treatment villages were more likely to have had prior experience with demi-lunes, and are about 4 percentage points more likely to have constructed demi-lunes in the past year.[28] The magnitude of the difference is small: baseline adoption along the extensive and intensive margins was low in all treatment arms. Nevertheless, we control for outcomes that are imbalanced at baseline as a robustness check during our analysis.

Attrition Table A3 tests whether there is differential attrition by treatment group across the different survey rounds. Attrition in the control group ranges from 1% in the demi-lune verification survey (Column 5) to 16% in the endline survey (Column 6). Differential attrition is most pronounced at midline (Panel A): households in treatment villages were 3 percentage points less likely to attrit than those in the control, with a statistically significant difference at the 10% level. This is potentially driven by labor reallocation as a result of treatment, as we discuss below. Analyzing differential attrition by treatment arm (Panel B), the UCT-late treatment is 5 percentage points less likely to attrit than the control group at midline and endline, and the CCT treatment is 4 percentage points less likely to attrit than the control group at endline. To correct for potential bias due to differential attrition, we bound our main treatment effects using Lee bounds for the midline and endline outcomes.[29] Attrition rates are low and not correlated with treatment in all of our verification rounds, which we use for measuring adoption.

Compliance To interpret the results, it is important to check that the experimental design was implemented as planned. Table A4 shows the statistics on training attendance and cash transfer receipt across all groups. Overall, participation in the program was high: 94 percent of households in the treatment group had at least one household member attend the training, 73% of households sent the targeted beneficiary, and an average of 15 participants attended per village (Panel A). In general, there are no statistically significant differences in training attendance across treatment arms, with the exception of the "any household member

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[28] Although we cannot distinguish between demi-lune experience on private or communal land, the government of Niger and NGOs have typically hired farmers to construct demi-lunes on communal land during the dry season, in order to provide off-seasonal jobs and regenerate pastureland.

[29] According to our Pre-Analysis Plan, if attrition rates are greater than 10 percent or we find evidence of differential attrition by treatment status, we will estimate Lee bounds. Thus, we focus our attrition corrections on the midline and endline data, rather than on the adoption outcomes.

attending" variable (Column 1). Yet the magnitudes of differences between the treatments is small (3-4 percentage points), and do not persist if we estimate the regression for treated villages only. [30] For the cash transfer arms, 94 percent of households in cash transfer villages received their cash transfer, with no statistically significant differences between the cash transfer arms (Column 5). There were also similar payouts between the UCT-early and CCT arms (Column 6).

4.3 Empirical Strategy

The random assignment of treatments across villages means that, in expectation, households in the control and the treatment groups have comparable background characteristics and agricultural constraints. We estimate the effect of being assigned to each of the treatment arms using the following specification:

$$Y_{iv} = \alpha + \sum_{j=1}^{4} \beta_j T_v^j + \gamma X_{i0}^{'} + \theta_v + \epsilon_{iv}.$$

where Y_{iv} it the outcome of interest for individual i in village v. Treatment T^j is defined by village-level assignment to the *training*, *UCT-early*, *CCT*, or *UCT-late* treatments; (θ_v) are strata and geographic fixed effects, and ($X_{i0}^{'}$) are the controls used to test balance during the randomization. In some cases, we also include the baseline measure of Y_{iv}.[31] We cluster our standard errors at the village level, the level of randomization. To correct our standard errors for multiple hypothesis testing, we also adjust the p-values to control for the false discovery rate (FDR) (Benjamini et al. 2006).

Each of the β_j coefficients represent the effect of treatment assignment relative to the control group. For most results, we show the pairwise tests between treatment arms to compare the relative impacts of each treatment. We also pool the treatments and estimate a single treatment coefficient.

5. Results: Adoption

We first analyze the impact of the treatments on the extensive and intensive margins of adoption, measured as the probability that a household adopted any demi-lunes and the

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[30] There are some slight differences by gender: Women were one percentage point less likely to have a family member attend the training, and four percentage points more likely to have a another household member attend.

[31] The baseline outcomes only include a subset of our observations, and thus reduce the total number of observations for the regression.

unconditional number of demi-lunes adopted.[32] We start by analyzing short-run effects, and then turn to adoption over time and heterogeneity in treatment effects on adoption.

5.1 Short-Run Adoption

Figure 2 depicts the extensive and intensive margins of demi-lune adoption in the first year, approximately three months after the initial training and UCT-early interventions. The impacts are substantial: while only 4 percent of households in control villages adopted demi-lunes on any part of their land, farmers in treated villages were 91 percentage points more likely to adopt demi-lunes (Figure 2, top panel). There are no statistically significant differences between the treatments. The treatments also significantly increased the intensity of adoption: households in treated villages adopted an additional 35 demi-lunes as compared with the control (Figure 2, bottom panel).

Table 4 presents the results from estimating equation (1) on a variety of adoption outcomes. Consistent with the figures, all treatments significantly increased the extensive and intensive margins of adoption, with treated farmers adopting 26-34 additional demi-lunes relative to the control (Panel A, Columns 2 and 3). The biggest effect across any two arms is associated with training only, as compared with the control. Relative to training alone, the UCT-early and CCT treatment arms adopted 26 and 42 percent more demi-lunes, respectively (Column 2). Other pairwise comparisons are not significantly different from zero.[33]

Farmers may have adopted demi-lunes without regard for quality (thereby reducing their effectiveness) or constructed demi-lunes without using them. Columns 4-6 show that this was not the case. First, the quality ratio (i.e., the ratio of demi-lunes that conform to technical norms relative to the total number of demi-lunes) is similar across groups: in the control group, 88 percent of demi-lunes met technical norms, with similar quality ratios across all treatment groups (Column 4).[34] Second, 80% of treated households planted crops in and around the demi-lunes, and approximately 20% of treated households applied manure to their demi-lunes, with few statistically significant differences between treatments. This suggests that demi-lunes were being used and maintained in the first year.[35]

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[32] There are a variety of ways to measure the intensive margin of adoption, including unconditional and conditional adoption, total adoption and adoption per hectare. In this paper, we primarily focus on the unconditional measure of total adoption, imputing a zero value for all households who did not adopt any demi-lunes, regardless of their treatment status.

[33] The 20 farmers in the control group who adopted any demi-lunes adopted a mean of 31 demi-lunes in the first year. Conditional on adoption, households in treated villages adopted an additional 13.2 demi-lunes relative to the control.

[34] The number of observations is lower in Column 4 because the quality ratio is only defined for farmers who adopted a positive number.

[35] The measure of planting and manure usage were only recorded the first year, as demi-lune verification was conducted immediately after the start of the rainy season, in order to give farmers sufficient time to

In addition to the treatment, several other characteristics were correlated with year 1 adoption (Table A5). While few of these characteristics explain the extensive margin of adoption, several are associated with the intensive margin of adoption. For example, households living in one sub-region (Kantche) adopted significantly fewer demi-lunes than did households in Takieta, perhaps due to less degraded land.[36] In addition, women adopted 3.5 fewer demi-lunes than did men. We assess heterogeneous treatment effects in more detail below.

5.2 Adoption Over Time

The short-term adoption of agricultural and environmental technologies may not persist in the medium- to long-term (Barrett et al. 2020). Our research design allows us to study disadoption – in other words, demi-lunes that are abandoned after the first year – as well as persistent and new adoption. However, unlike seeds and fertilizers, the decision to adopt demi-lunes is not made each agricultural season, since they can be used for three years with little maintenance. Yet if farmers completely neglect their demi-lunes after the first year, their quality is likely to deteriorate.[37]

To assess the dynamics of adoption over time, we use data from three rounds of demi-lune verification (2018, 2019 and 2020). Three main patterns emerge. First, the extensive margin of demi-lune adoption increased in the control group over time, from 4% of farmers in 2018 (year 1) to 17% in 2020 (year 3) (Figure 3, top panel). By 2020 (year 3), a total of 80 farmers in control villages (out of 470) had constructed at least one demi-lune on their plot of land. The pattern is similar for the intensive margin (Figure 3, bottom panel): farmers in control villages had adopted approximately 10 demi-lunes by the third year.[38]

Second, while the extensive margin of adoption remained stable across all treatment arms over time, the intensive margin of adoption increased slightly in the pooled treatment group, by 3-5 additional demi-lunes per year (Figure 3, bottom panel). Most notably, adoption levels converged across treatments: by the third year, the initial difference between the UCT-early and CCT arms (relative to the training arm) was eliminated (Table A6).[39] This

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adopt. In following years, the field visits were conducted immediately before (or at the start of) the rainy season, and so planting and manure application had not yet occurred for a majority of farmers.

[36] On average, households in Kantche owned 1 hectare less land than those in Takieta, and approximately 0.3 hectare less degraded land.

[37] We observe a small number of farmers whose demi-lunes disappeared over time. This could be explained by a failure to respect technical norms, disadoption or flooding. For example, if demi-lunes are constructed on heavily sloped land or sandy soils, they can be destroyed during the rainy season.

[38] Conditional upon adoption, control households adopted a total of 61 demi-lunes by the third year, with similar levels in the treatment group.

[39] By the third year, the *UCT-early* arm had fewer demi-lunes than both the training and CCT arms.

suggests that training had a persistent effect on adoption, but that the cash transfers did not have any additional longer-term effects on adoption relative to the training alone.

Third, regardless of adoption levels, in the third year (2020), farmers were still actively using their demi-lunes. While 16% of farmers in control villages had operational demi-lunes, farmers in treated villages were 74 percentage points more likely to have operational demi-lunes, for a total of 90% of farmers in treated villages (Column 5, Table A6). This is only slightly less than the percentage of farmers who had adopted any demi-lunes.

5.3 Heterogeneous Adoption

We would expect higher levels of adoption for sub-populations for whom the treatments alleviated key barriers. We therefore test for heterogeneous impacts of the treatment by a number of pre-specified characteristics, namely gender, household labor, land size, previous demi-lune experience and geographic location.[40] For this analysis, we pool across the treatment arms and estimate the interaction between each heterogeneity variable and an indicator for treatment, focusing on the intensive margin of adoption.

Table 5 presents the results. First, while the treatment had differential impacts along a number of dimensions in the short-term (Panel A), most of these differences did not persist in the longer-term (Panel B), with the exception of geographic sub-region.[41] Second with the exception of geography and previous experience, many of these heterogeneous effects are relatively small in magnitude, representing 5-13% of the main treatment effect. Perhaps most notable is the lack of persistent differential effects by gender: in the first year, women in treated villages adopted 5 fewer demi-lunes relative to men in treated villages (Panel A, Column 1). In a context where women do not have private land ownership and have limited access to financial services, the training still led to a large increase in adoption among female farmers.[42]

While the difference between the *UCT-early* and *CCT* arms is statistically significant at the 10 percent level, this is primarily driven by an outlier in the CCT arm, with one farmer adopting 1,673 demi-lunes. When these outcomes are winsorized, the difference between the UCT-early and CCT arms is no longer statistically significant.

[40] Our pre-analysis plan also included heterogeneity by mobile phone ownership as a proxy for wealth. Mobile phone ownership significantly increases the magnitude of the treatment effect in year 1 but not in year 3.

[41] We interpret these effects by sub-region with caution, as only 34 of the 180 villages were in the Takieta sub-region.

[42] Since *demi-lunes* can help to minimize the likelihood of crop failure, we also test whether demi-lune adoption varied by exposure to self-reported climatic shocks in the prior agricultural season. We find that exposure to a climatic shock increased the effect of treatment on the propensity to adopt, although it did not have an effect on the intensive margin of adoption.

5.4 Adoption Spillovers

The previous results show that the treatment induced adoption in the short- and medium-term among eligible farmers. However, with village sizes ranging from 250 to 1000 people, only a small fraction of the village was selected for treatment. We therefore test for adoption spillovers, using two separate measures. The first is an observational measure of neighbors' adoption, whereby enumerators noted whether a farmer had a neighboring plot that also had demi-lunes. The second is self-reported demi-lune adoption from the spillover sample.

Table 6 shows the impact of the training on adoption spillovers. Three years after the initial interventions, farmers in treated villages were 50 percentage points more likely to have neighbors who adopted demi-lunes than were farmers in control villages, with adoption observed on an additional 0.7 neighboring fields (Columns 1 and 2). Using the spillover sample, we find that eligible individuals living in treated villages – yet not selected for the sample – were 18 percentage points more likely to construct demi-lunes than the same sample in control villages, and constructed approximately 6 additional demi-lunes (Columns 3 and 4). While the impact on the intensive margin is not statistically significant, the magnitude is large, representing 53% of adoption in control villages. In addition, the spillover sample in treated villages cultivated an additional 0.15 ha of previously degraded land, and acquired new assets (Columns 5 and 6). None of these effects differ by treatment status. Overall, these results suggest that the treatments induced significant within-village adoption among eligible farmers and their neighbors, and were primarily driven by the training.

5.5 Interpreting Adoption Magnitudes

Despite the high rate of adoption in the treatment villages, in absolute terms, the number of demi-lunes constructed was below recommended levels of 250-300 per hectare. Using a baseline measure of total degraded land (although not necessarily *glacis*), farmers in treated villages adopted between 32-41 demi-lunes per hectare of degraded land by the third year, representing 11-16 percent of the Ministry's technical norms.[43] Do these adoption magnitudes signify underadoption? And if so, why?

The first – and most obvious – answer is that the recommended norms are based upon mechanical calculations that maximize coverage, rather than profits. Given the size of demi-lunes and the distance between them, this would suggest that 277 demi-lunes should be constructed on one square hectare of sloped and degraded land. Yet this ignores the *economic* costs and benefits from the farmers' perspective. If the cost of demi-lune construction is

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[43] The lower end of the range is based on the unconditional mean of 32 demi-lunes per ha for treated farmers and a norm of 300 demi-lunes per hectare; the upper end of the range is based on the conditional mean of 41 demi-lunes per ha and a norm of 250 demi-lunes per hectare.

increasing in the number of demi-lunes or if benefits are decreasing, then the recommendation to cover all degraded land may lead to negative profits on the margin, even if average profits are positive. Thus, adoption levels may maximize profits at a number that is less than "full" adoption.[44]

Second, our measures of land quality may suffer from measurement error, resulting in an underestimate of adoption (Abay et al. 2019). As outlined above, demi-lunes are appropriate for a common type of degraded land, *glacis*. While we have both self-reported and observational measures of soil quality, neither of these distinguish between *glacis* and other types of soils, nor do they account for the slope. If we are overestimating the size of *glacis* or the amount of land with the appropriate slope, then our measures may underestimate the rates of adoption per degraded hectare. There is some evidence that this is the case: during the field observations in 2020, Ministry agents calculated the amount of *glacis* land. On average, we found that farmers owned 0.35 ha of *glacis* land, representing approximately 20% of the degraded land size measured prior to the baseline.[45] Using this classification of *glacis* suggests that farmers are adopting at approximately 55-80% of the technical norms.

Third, market failures in complementary markets, such as labor, seeds or insurance, may persist despite our interventions, resulting in a constrained optimal level of adoption that is lower than the unconstrained optimum. Our data suggest that this is not the case. For labor, demi-lunes are constructed during the slack agricultural period, when labor availability is high, and there are no observed general equilibrium effects on wages (Table A7). Seed availability also does not appear to constrain adoption: while 25% of households cited seeds as an important constraint at baseline, 80% of households were still using their demi-lunes in the third year (Table A6). In addition, while risk aversion combined with missing insurance markets could lead to under-adoption, we observe no heterogeneous treatment effects with respect to baseline risk preferences.

Finally, it is widely recognized that behavioral frictions may deter adoption, including present bias, attentiveness and product salience (e.g., Bordalo et al. 2013, Gabaix 2019). To determine whether these factors may have affected adoption levels, we assess the impact of our nudging intervention on new adoption in 2021. Figure 4 presents these results. Overall, being assigned to any nudge led to a large but statistically imprecise increase in the number

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[44] The pattern of adoption results over time is also informative of the nature of the costs and benefits that drive adoption levels. While most agricultural inputs – such as labor – are associated with annual costs and benefits, land is not. The modest additional adoption over time, particularly given the positive average profit in the first year, is consistent with a time- invariant component to those costs that determine adoption levels. For example, adoption at a particularly steep part of the labor cost curve in one year could be deferred to the next year (and to a flatter part of the curve), while marginal costs that increase due to the difficulty in working increasingly degraded soils are unaffected by deferring adoption.

[45] The quantity of degraded land measured during the listing exercise was self-reported.

of new demi-lunes adopted as compared with the group assigned to no nudges. When looking at the impact of different nudging interventions, two of the nudges had the largest effect: providing information about the costs and benefits of demi-lunes, and reminding farmers that the Ministry may visit for observation. The magnitude of these effects ranged from 5-7 additional demi-lunes relative to no nudging intervention, and were statistically significantly different from the other nudges (although not from each other).[46] In general, this provides suggestive evidence that behavioral barriers may play a modest role in shaping the level of adoption.

Taken together, the above results suggest that while adoption levels are below full adoption, they are at or near the point where private returns are maximized.

6. Results: Inputs and Outputs

Given large effects on adoption, we next assess the impact of the interventions on households' input usage and outputs. Since differences across treatments dissipated by the third year, we focus on a pooled specification that compares farmers assigned to any treatment with those in the control group.[47] We interpret these impacts as driven by the training component common to all treatment arms.

6.1 Inputs to Demi-Lune Construction

Since demi-lune construction is labor intensive, labor costs are often cited as a potential barrier to adoption (Barry et al. 2008). Table 7 shows the impact of the treatments on households' allocation of labor over time. Most of the demi-lune construction took place in the first year, so we test for treatment effects on demi-lune specific labor investments in the short-run. (Panel A, Columns 1 and 2). In the first year, additional family labor was allocated to demi-lune construction: while households in the control group used two person-days of family labor to construct demi-lunes, households in the treatment group used an additional 15 person-days, with a statistically significant effect at the 1 percent level. Treated households also hired more non-family labor to construct demi-lunes, for a total of 6 additional person-days (Panel A, Column 2). On average, households in the treatment

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[46] In the endline, we asked a series of hypothetical questions about the returns to demi-lune adoption, comparing the costs and benefits of adopting demi-lunes with other technologies. Respondents in treatment villages had accurate beliefs about the returns to demi-lunes, which suggests that awareness of the returns was not a barrier. The nudge results are consistent with other research on product salience at the time of adoption (Bordalo et al. 2013).

[47] While we do not present the p-values of pairwise comparisons between treatments for these results, we note whether there are statistically significant differences between treatments for a given outcome.

group used approximately 24 person-days of labor for demi-lune construction, implying a mean productivity of approximately two demi-lunes per person per day.

This allocation of family labor to demi-lune construction was accompanied by a corresponding reduction in family labor supply, either through the number of household members involved in seasonal migration (Panel A, Column 3) or selling labor locally (Panel A, Column 4). These effects were significant, representing 17-35% of the mean of the control group, yet did not persist over time.[48] This is consistent with the fact that the labor reallocation was driven by the initial adoption in the first year. Yet while treated households sold less of their own labor, they were more likely to hire labor for other agricultural work in the short- and medium-term (Panels A and B, Column 5).[49]

Overall, households in treatment villages spent approximately USD 15 on demi-lune construction in the first year, with relatively similar expenditures across the treatment arms (Table A8, Column 1). This allocation of expenditures was almost equally divided between non-family and family labor, with slightly higher expenditures on family labor (Columns 2 and 3).[50] While the treatment increased households' expenditures on labor for the agricultural season, this did not crowd out expenditures on labor hired for non-demi-lune purposes (Column 4).

Beyond labor costs, demi-lunes also require small tools, such as shovels and pickaxes. Figure 5 shows that the treatments crowded in investment in these productive assets. Households in treated villages owned 17-26% more assets than those in control villages, primarily pickaxes and shovels, with no statistically significant difference by treatment arm. Higher asset ownership also persisted in the medium-term, suggesting that households initially purchased these tools to construct demi-lunes, but did not liquidate them after construction.

6.2 Agricultural Output

The agronomic literature suggests that demi-lunes can improve soil quality, reduce the risk of crop failure and increase agricultural productivity, especially with the use of complementary inputs. However, results from actual adoption decisions may differ from agronomic trials.

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[48] Treated households sold approximately 8 fewer person-days of family labor relative to the control, but this difference is not statistically significant at conventional levels.

[49] Estimating the impacts by treatment arm yields few statistically significant results between treatments, with the exception of the UCT-late treatment in year 1. Households in the UCT-late treatment resembled the control group in their household's migration patterns and their sale of family labor to the local labor market.

[50] Despite the fact that households used more family than non-family labor, expenditures across the two types of labor are similar. This is primarily because average daily wages for demi-lune family labor were USD 0.40, while average wages paid for non-family labor on demi-lunes was USD 1.20. These are both significantly less than wages paid for non-demi-lune labor, which are USD 1.60-2 (Table A7), and do not necessarily reflect the opportunity cost of family labor.

Table 8 shows the estimation results for equation (1) for agricultural outcomes, again pooling across treatment arms.

Households in the control group planted four crops, which was not affected by treatment (Column 1). While households in the treated villages had a 40% lower likelihood of crop failure than those in the control in the first year (Column 2, Panel A), this did not persist in the longer-term (Panel B). Yet the treatments led to a 0.12-0.15 standard deviation increase in both the quantity and value of agricultural production, with larger and more precise effects over time (Columns 3 and 4, respectively). Concretely, these effects translated into a 100-kg increase in the amount produced and an additional USD 40 in revenues *per year*.[51]

Figure 6 and Table A9 show the impacts by crop, pooling across treatment arms. The impacts on agricultural production were primarily driven by increased sorghum and sesame production: on average, households in treated villages produced 50 percent more sesame than those in control villages during the first year, with persistent effects in the medium-term (Table A9).[52] There were also sizable increases in millet and sorghum production, although these impacts were only statistically significant at the endline.[53]

It is possible that the short-term impacts on agricultural production could have been affected by channels other than demi-lune adoption, such as the cash transfers. Yet it seems unlikely that these transfers could have affected agricultural outcomes in the third year for two reasons. First, the cash transfers were relatively small in magnitude and unlikely to lead to persistent shifts in household incomes. Second, there was not a statistically significant difference in adoption between treatment arms by the third year.

6.3 Land Quality and Usage

Beyond the impacts on agricultural output, one of the touted benefits of demi-lunes is their effect on soil moisture and quality, and hence their contribution to reversing the process of land degradation. Table 9 shows the results of regressions of equation (1) on a number of self-reported measures of land usage and soil quality. In the first year (Panel A), there is little evidence of impacts (Columns 1-3), with the exception of self-reported soil quality, a

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[51] When looking at the differential effects by treatment arm, agricultural production was relatively higher in the *UCT-early* group relative to both the *training* and *UCT-late* groups in the first year, but did not persist over time. This is largely consistent with the patterns of demi-lune adoption.

[52] While millet, sorghum, cowpea and sesame can be planted in and around demi-lunes, planting peanuts is not recommended. As expected, we find no effects of the treatments on peanut production.

[53] While most of the impacts by crop were similar across treatments, the *UCT-early* group consistently produced more millet relative other treatments in the short-term, with the exception of the *CCT* treatment. This is consistent with the short-term adoption outcomes. These differences did not persist into the third year.

scale measure ranging from 1 (poor quality) to 5 (extremely fertile).[54] While households in control villages rated their average soil quality across all fields at 2.76, corresponding to "average" soil quality, those in treated villages rated it marginally higher.

By the third year, self-reported land usage significantly improved: households in treated villages were 34 percentage points more likely to cultivate previously uncultivable land, cultivating an additional 0.3 ha relative to the control (Columns 2 and 3, Panel B). In addition, they were 7 percentage points less likely to retire land from planting due to degradation, a significant decrease in terms of magnitude (Column 4). Figure 7 shows that a number of self-reported soil quality indicators also improved with treatment in year 3.

These results are also supported by *objective* measures of soil quality. Figure A.2 shows the impact of the treatments on soil quality in 2020, using data from field observations.[55] Overall, the distribution of the hectares of degraded land is shifted towards zero for the treated villages relative to the control, with a p-value from a Kolmogorov-Smirnov test of 0.12.

Taken together, these results provide suggestive evidence that demi-lune adoption slowed the land retirement process and improved soil quality in the medium-term, thereby allowing farmers to cultivate previously degraded land. This shift did not coincide with a shift in the land market: farmers did not change their ownership or rental patterns.[56]

6.4 Are Demi-Lunes Privately Profitable?

While we do not have detailed measures of all revenue and cost streams, we conduct back of the envelope calculations of the impact of demi-lunes on farmers' profits. As outlined in Table 8, treated households increased their agricultural revenues by USD 40 in the first year, while spending 20 USD on labor and materials and foregoing approximately 10 USD in off-farm family labor income.[57] Taken together, this suggests that the benefits outweighed the costs in the first year by USD 10. After the first year, the impacts on agricultural

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[54] While the impact of the treatment on the number of degraded hectares cultivated is not statistically significant in the short-term, the magnitude is important: households in treated villages reported cultivating an additional 0.12 ha of previously degraded land, which roughly coincides with the land area covered by the average number of demi-lunes constructed.

[55] These data were collected by trained enumerators and Ministry of Environment field agents during the demi-lune field verification exercise. For each plot of land, the agents estimated the total plot size, as well as the portion of land that was degraded.

[56] Beyond agriculture and land outcomes, Table A10 estimates equation (1) for a variety of proxies of well-being, including income, expenditures, livestock and food security. While assignment to treatment did not have an impact on most outcomes, households in treated villages had higher food security in the short-term and owned more assets.

[57] We estimate an increase in expenditure on construction equipment of USD 5, following the increase in ownership shown in Figure 5.

revenues persisted (Table 8), while the effects on labor expenditure and labor allocation did not (excluding any costs of additional adoption). Overall, this implies higher private net benefits after the initial year of approximately USD 40.

7. Mechanisms

Our results show treatments designed to relax barriers to adoption increased the extensive and intensive margin of adoption and led to improvements along a variety of margins. While there were some differential effects by treatment in the first year, these impacts were primarily driven by the training component. This therefore raises two questions: Why was the training *so* effective? And why were the cash transfer treatments not more effective in increasing longer-term adoption? We first discuss potential mechanisms underlying the training impacts, before turning to the cash transfers. Finally, we consider alternative explanations.

7.1 Why was the training so effective?

The impact of the training on demi-lune adoption over time suggests that it was successful in relaxing the binding constraint to demi-lune adoption in Niger. However, like most trainings, the training provided a bundled intervention that may have generated results through numerous channels. The first is a simple *awareness* channel: the training made farmers aware of the existence of demi-lunes, making adoption possible. The second is one of *technical advice*: the training provided information on how to construct demi-lunes (correctly), thereby making it easier to construct them and increasing their effectiveness. The third channel is one of *social learning*: by working together to construct demi-lunes during the training, farmers could learn from each other. The final channel includes *non-informational* effects: for example, the training may have motivated farmers by signaling interest and encouragement from an outside organization (i.e., the Ministry of Environment) or may have persuaded farmers to adopt. While we lack the data to fully distinguish among these channels, we provide suggestive evidence on each.[58]

Overall awareness of demi-lunes was relatively high at baseline: over 1/3 of households had prior experience constructing demi-lunes, either on private or communal land, and over 60% of farmers had heard about demi-lunes. By the endline, all farmers had heard about demi-lunes (Table 10, Column 1), primarily via the training (Column 2). Yet as was shown

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[58] While there are potentially other channels through which training could have affected adoption, these channels are based on the components of the training and qualitative interactions with farmers.

in Table A5, prior experience with demi-lunes was not correlated with adoption. Thus, while training almost certainly made some farmers aware of demi-lunes, it can account for (at most) a third of the impact of the training on the extensive margin.[59]

Second, technical knowledge about demi-lunes was also high: at the endline, the control group answered 1/3 of questions correctly on a demi-lune knowledge test.[60] Relative to the control group, farmers in treated villages had test scores that were 14% higher at endline (Table 10, Column 3). Yet the key nuance is *how* the training improved knowledge: farmers in treated villages were 8-21 percentage points more likely to know the correct dimensions, depth and number of demi-lunes relative to those in the control, as well as the fact that manure is not a required input (Figure 8). All of these elements are crucial for correctly constructing demi-lunes and reaping their benefits; a lack of knowledge about these elements appears to deter adoption, suggesting an important role for *technical advice*.[61] In the spillover sample, however, demi-lune knowledge did not improve suggesting that training was important for improving information (Table 6, Column 7).

Third, within-village adoption spillovers from trained to untrained farmers were prevalent in treated villages, suggesting that at least some degree of social learning took place. While we do not have a direct measure of this, we do have a proxy: farmers in treated villages were almost twice as likely to help others to construct demi-lunes, with a statistically significant effect at the 1 percent level (Table 10, Column 4). These types of social interactions and observations are important precursors to social learning, suggesting that may have also been an important element in the impact of training.[62]

Finally, the training may have affected adoption through a number of behavioral channels. Unfortunately, our study is not designed to distinguish between informational and non-informational explanations. That said, the nudging interventions can provide some insights.

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[59] We also note that the pattern of adoption over time is inconsistent with a learning by doing model, under which we would have expected modest adoption in the first year, followed by expansion in the second and third years.

[60] We tested all respondents on their demi-lune knowledge at the baseline, midline and endline. While the test covered the same topics in the midline and endline, the endline test was more difficult, as it was open-ended (rather than True/False), in an effort to more accurately gauge respondents' knowledge. Thus, we cannot directly compare the endline results with the baseline and midline results. While the control group had significant general knowledge at the baseline, they did not improve their knowledge over time.

[61] A key question is the gap between awareness and knowledge. As mentioned earlier, other NGO and government trainings focused on hiring farmers to construct demi-lunes on communal land. Thus, the focus was on hiring labor to construct demi-lunes, rather than disseminating knowledge. Our training used only readily available tools, and framed the technology as one that could be adopted on private or communal land. In focus groups, farmers report that the accessibility of both information and implementation strategies was important for their adoption decisions.

[62] Households in the spillover sample also reported primarily learning about demi-lunes via observation their neighbors' plots or another household within the village., as well as helping to build demi-lunes. About 20% of households in the spillover sample also reported learning about demi-lunes from a recent training.

Of the two nudging interventions that led to new adoption, one of the most effective was the "monitoring" treatment. While this is separate intervention, done three years after the training, we take it as suggestive evidence that encouragement provided by an outside organization during the training may have been relevant in spurring adoption.

Taken together, these results highlight the fact that effective trainings may work through a variety of channels. In our case, the training not only increased awareness and provided technical information, but also increased social interaction. Each channel may have been important for moving adoption outcomes for different farmers. For example, farmers with experience and higher reported awareness scored significantly better on the knowledge test than did those who were not aware of the technology or had no prior experience. On net, technical advice and the social learning appear to be the strongest channels, though we leave further unpacking of the relative importance of different aspects of trainings for future work.

7.2 Why did the cash transfers not have more of an impact?

While the *UCT-early* and *CCT* treatments led to initially higher levels of adoption as compared to the training alone, these impacts dissipated by the third year.[63] The UCT-early and CCT treatments were designed to relax cash-on-hand liquidity constraints and increase the short run benefits of adoption, respectively. The fact that we see little lasting effect of these treatments on adoption levels suggests that while they may lower adoption in the short run, they represent relatively minor barriers to adoption. This interpretation is supported by other results. For example, female farmers in Niger are more likely to face liquidity and credit constraints, yet we do not find strong or persistent differences in adoption by gender. In addition, baseline measures of access to borrowing show that over 85% of households reported borrowing money or food during the previous agricultural cycle. While farmers lack access to formal credit to finance agricultural investments, access to diversified borrowing opportunities will tend to both ease liquidity constraints and increase the profitability of investments with delayed benefits. Our study therefore joins a growing number of RCTs, summarized in Magruder (2018) that show modest overall effects of liquidity and credit constraints on agricultural technology adoption. Like Karlan et al. (2014), we find that farmers can – when the necessary barriers are relaxed – come up with the financial resources to cover agricultural investments.

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[63] We interpret the lack of impact of the *UCT-late* arm relative to the training as evidence that adoption in the *UCT-early* arm was not driven by reciprocity nor experimenter demand effects.

7.3 Threats to Identification

There are several potential confounds to interpreting our main results. First, given imbalance in some of our baseline characteristics, our results may be driven by these pre-existing differences. Table A.11 shows the ANCOVA specification for key outcome variables, where baseline data are available. Overall, most of our results are robust to controlling for baseline outcomes (and some are stronger), despite the lower number of observations.

A second potential confounding factor is differential attrition. The results on attrition in Table A3 show that attrition is higher in the control villages in the midline and endline surveys, but not in other data collection exercises, which implies that our main treatment effects on adoption are not affected. For the survey results, if households with lower agricultural outcomes are the marginal survey attriters, then this could overestimate our impacts of the treatments on labor, land and agricultural outcomes. We therefore use tightened Lee bounds to correct for potential bias due to differential attrition in the midline and endline surveys for all of the outcomes in the main tables (Table A.12). Unsurprisingly, almost all of the upper bounds are statistically significant (Columns 3 and 6, respectively). While the lower bounds are all the same sign as the original coefficients, some lose statistical significance (Columns 2 and 4). The key outcomes on land usage, labor allocation and asset ownership remain, as do our adoption outcomes. This implies that differential attrition is not driving the results measured at midline and endline.

A third potential threat is spillovers across villages. As mentioned previously, demi-lune adoption in the control group increased from 4 percent to 17 percent between 2018 and 2020. If adoption in the control group was driven by exposure to treatment, this would violate the stable unit treatment value assumption (SUTVA). We therefore test whether distance to the nearest treated village drives control group adoption, and find that there is no correlation between the two. In addition, the intra-cluster correlation of adoption in the control group was high (0.4), and adoption was primarily concentrated in six villages. This suggests that new adoption in control villages could have been driven by other NGO programs, rather than spillovers across villages.[64]

Finally, throughout this paper we have estimated the impact of the treatments on 37 different (primary) outcomes. Overall, we find that the intervention increased adoption, improved agricultural output and land quality and reallocated household labor. Given the number of comparisons in these tables, this may raise concerns that these effects cannot be attributed to the treatment, but are rather observed by chance amongst the different outcomes. Thus, for the outcomes reported in the tables in the main text, we report sharpened

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[64] Given that we estimate the ITT, adoption in the control group will lower the treatment effect on adoption and other agricultural measures.

q-values based on corrections for the false discovery rate (based on Benjamini et al. (2006)) in Table A.13.[65] Using these sharpened q-values, the effects of the pooled treatment remains statistically significant for all of the outcomes that were originally statistically significant.

8. Conclusion

Technologies that can address soil degradation are key for ensuring sustained yield improvements in the semi-arid areas of sub-Saharan Africa, especially the Sahel. Climate change exerts additional pressure on farmers and has the potential to accelerate land degradation and desertification. Despite decades of investment in promoting such technologies, their sustained adoption has been mixed, in part due to information barriers and liquidity or credit constraints.

This paper assesses the impact of training and cash transfer interventions on the adoption of one type of environmental technology in Niger. The treatment effects are striking: the training alone increased the probability of adoption by over 90 percentage points relative to the control, with no statistically significant differences between the treatments. Treatment also led to improvements in downstream outcomes, namely, agricultural production and land use, with persistent effects up to three years later. Training was more cost effective in increasing medium-run adoption as compared to the the cash transfer treatments, given that the latter had no additional impact on adoption intensity.

Our results are primarily driven by training alone, rather than the cash transfers, suggesting that the program is scalable and replicable. That said, scaling up may depend on hitting on the right bundle of awareness, technical information, social learning, and motivation. The effectiveness of the program in other contexts will also upon the suitability of the technology – in our case, the private profitability presumably contributed to the impacts – and the capacity of key partners to implement effective trainings. Nevertheless, given the widespread issue of land degradation, and the mandate of many Ministries to provide trainings, there are reasons to think that simple trainings could be effective in increasing adoption of rainwater harvesting and other technologies to address land degradation and increase resilience to climate shocks in other contexts.

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[65] We omit the heterogeneous treatment effects and spillovers results from these corrections.

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Tables and Figures

Table 1: Data Collection Summary

Survey round	Dates	Project year	Observations
Listing exercise	Jan - 18	Year 0	2,861
Baseline	Feb - 18	Year 0	2,029
Demi-lune verification 1	Jun - 18	Year 1	2,850
Midline	Feb - 19	Year 1	2,537
Demi-lune verification 2	June - 19	Year 2	2,817
Demi-lune verification 3	June - 20	Year 3	2,835
Endline	Feb - 21	Year 3	2,486
Spillover sample	Feb - 21	Year 3	670
Demi-lune verification 4	June - 21	Year 4	2,835

Notes: Data collection rounds. The project years reflect the agricultural calendar and time since the intervention. Verification involved physical inspection of the fields and could be completed with any household representative. See text for additional detail.

Table 2: Listing Balance: Full Sample

	(1) Control	(2) Training	(3) UCT early	(4) CCT	(5) UCT late	(6) P-value of joint F test	(7) N
Respondent is female	0.49	0.01	0.01	0.01	-0.00	0.49	2861
	(0.50)	(0.01)	(0.01)	(0.01)	(0.02)		
No. of adult household members	4.43	0.04	-0.12	-0.22	-0.02	0.85	2861
	(2.31)	(0.25)	(0.27)	(0.25)	(0.26)		
Owns a mobile phone	0.37	0.04	0.03	-0.02	-0.00	0.61	2861
	(0.48)	(0.05)	(0.05)	(0.04)	(0.05)		
No. of hectares owned	3.99	-0.18	-0.28	0.03	0.07	0.87	2861
	(2.29)	(0.36)	(0.42)	(0.41)	(0.41)		
No. of degraded hectares owned	1.78	0.04	-0.04	0.09	0.01	0.96	2861
	(1.05)	(0.16)	(0.18)	(0.17)	(0.16)		
Demi-lune experience	0.32	0.04	0.10	0.00	0.12	0.41	2861
	(0.47)	(0.08)	(0.08)	(0.08)	(0.08)		

Notes: The table includes household data from 2861 survey participants during a listing exercise conducted across 180 villages. Column 1 reports the unconditional mean of the control. Columns 2-5 report the coefficients on the binary treatment variables for Training, UCT-early, CCT and UCT-late, respectively. Column 6 reports the p-value from the joint F-test. Robust standard errors clustered at the village level are presented in parentheses. Asterisks denote a statistically significant difference at the 1% ***, 5% **, or 10% * levels.

Table 3: Baseline Balance: Baseline Sample

	(1) Control	(2) Training	(3) UCT early	(4) CCT	(5) UCT late	(6) P-value of joint F test	(7) N
Respondent age	42.44	-0.37	1.11	0.27	-0.66	0.53	2029
	(14.08)	(1.07)	(1.11)	(1.06)	(1.20)		
Respondent is Hausa	0.57	-0.00	-0.02	0.02	0.05	0.91	2029
	(0.50)	(0.08)	(0.08)	(0.08)	(0.08)		
Received some schooling	0.71	0.04	-0.00	0.03	0.03	0.70	2029
	(0.45)	(0.04)	(0.04)	(0.04)	(0.04)		
Household size	8.55	0.61*	0.72**	0.63*	0.36	0.23	2030
	(4.31)	(0.34)	(0.36)	(0.36)	(0.36)		
Asset index	-0.01	0.05	0.09	0.07	0.02	0.85	2029
	(1.00)	(0.09)	(0.09)	(0.10)	(0.10)		
No. of fields owned or rented	2.84	-0.06	-0.02	-0.12	-0.18	0.84	2029
	(1.56)	(0.17)	(0.17)	(0.16)	(0.18)		
No. of crops cultivated	3.93	-0.07	-0.04	0.03	-0.07	0.68	2029
	(0.81)	(0.09)	(0.08)	(0.09)	(0.09)		
Total quantity produced	902.96	-59.96	27.71	81.52	-54.26	0.15	2029
	(726.13)	(52.92)	(57.02)	(68.55)	(65.07)		
Household experienced hunger	0.93	-0.01	0.00	-0.00	-0.02	0.92	2029
	(0.26)	(0.02)	(0.02)	(0.02)	(0.02)		
Adult did not eat for an entire day	0.22	-0.01	0.01	-0.01	0.07**	0.20	2029
	(0.41)	(0.03)	(0.03)	(0.03)	(0.04)		
No. of household members who have migrated	0.58	0.03	-0.01	-0.03	0.04	0.87	2029
	(0.83)	(0.07)	(0.06)	(0.06)	(0.06)		
Built demi-lunes prior season	0.02	0.03*	0.04**	0.02**	0.04	0.03	2030
	(0.13)	(0.02)	(0.02)	(0.01)	(0.02)		
Demi-lune test score	5.40	-0.10	0.08	-0.05	0.24**	0.05	2030
	(1.50)	(0.11)	(0.09)	(0.10)	(0.12)		

Notes: The table includes household data from survey participants during the baseline data collection, conditional on being selected for the baseline sample. Column 1 reports the unconditional mean of the control. Columns 2-5 report the coefficients on the binary treatment variables for Training, UCT-early, CCT and UCT-late, respectively. Column 6 reports the p-value from the joint F-test. Robust standard errors clustered at the village level are presented in parentheses. Asterisks denote a statistically significant difference at the 1% ***, 5% **, or 10% * levels.

Table 4: Demi-lune Adoption, Year 1

	(1) Constructed any demi-lune	(2) No. of verified demi-lunes constructed	(3) No. of verified demi-lunes constructed per degraded ha	(4) Ratio of verified to total no. of demi-lunes constructed	(5) Sowed in demi-lunes	(6) Used manure in demi-lunes
Panel A						
Any treatment	0.91***	34.45***	25.94***	0.04	0.77***	0.20***
	(0.02)	(2.83)	(2.66)	(0.08)	(0.02)	(0.02)
Panel B						
Training	0.90***	28.24***	20.93***	0.06	0.74***	0.16***
	(0.02)	(2.88)	(2.76)	(0.08)	(0.04)	(0.03)
UCT early	0.93***	35.46***	27.54***	0.04	0.79***	0.22***
	(0.02)	(3.94)	(3.60)	(0.08)	(0.04)	(0.03)
CCT	0.89***	39.91***	30.44***	0.06	0.75***	0.20***
	(0.02)	(4.38)	(5.39)	(0.08)	(0.04)	(0.03)
UCT late	0.92***	34.22***	24.57***	0.02	0.82***	0.21***
	(0.02)	(4.92)	(3.85)	(0.08)	(0.04)	(0.03)
Mean in control	0.04	1.30	1.10	0.88	0.04	0.00
No. of observations	2850	2850	2850	2279	2850	2850
R squared	0.72	0.18	0.12	0.01	0.40	0.10
Training=UCT early	0.12	0.05	0.06	0.18	0.21	0.11
Training=CCT	0.71	0.00	0.08	0.93	0.78	0.31
Training=UCT late	0.48	0.21	0.33	0.08	0.09	0.17
UCT early=CCT	0.06	0.37	0.63	0.17	0.33	0.61
UCT early=UCT late	0.57	0.82	0.50	0.40	0.60	0.84
CCT=UCT late	0.31	0.32	0.32	0.07	0.15	0.76

Notes: Each column presents the results from a regression of the dependent variables on a binary variable for *any treatment* (Panel A) or binary variables for each treatment (Panel B), as well as stratification fixed effects and variables used to check balance in the min-max t-statistic method. Robust standard errors clustered at the village level are provided in parentheses. P-values from pairwise F-tests of the coefficients are provided below the regression results. The dependent variable in column (4) is only defined for households that constructed a positive number of demi-lunes. Asterisks denote a statistically significant effect at the 1% ***, 5% **, or 10% * levels.

Table 5: Heterogeneous Effects

Het var is:	Female respondent (1)	Adult HH members (2)	Degraded ha owned (3)	DL experience (4)	Kantche (5)
Panel A: Year 1					
Any treatment	36.59***	26.99***	27.75***	32.11***	50.72***
	(2.75)	(3.89)	(3.87)	(2.66)	(6.44)
Het variable	-0.74	-0.24	-0.59	-0.13	0.52
	(1.22)	(0.27)	(0.86)	(1.94)	(3.58)
Any treat × Het var	-5.31**	1.59**	3.44**	4.95	-20.47***
	(2.11)	(0.77)	(1.60)	(3.45)	(6.83)
Panel B: Year 3					
Any treatment	33.35***	28.33***	33.42***	32.15***	51.55***
	(6.50)	(8.10)	(8.30)	(6.17)	(7.74)
Het variable	-1.49	0.53	3.90	4.31	10.21
	(2.86)	(1.66)	(4.62)	(6.39)	(7.40)
Any treat × Het var	-4.97	0.59	-1.44	-4.02	-25.06**
	(4.00)	(1.95)	(4.96)	(7.45)	(10.10)

Notes: Each column presents the results from a regression of the dependent variable (the number of verified demi-lunes constructed) on a binary variable for *any treatment*, the heterogeneous characteristic from the listing exercise and an interaction term of the two. Panel A shows the results from the first demi-lune verification round (2018); Panel B shows the results from the third demi-lune verification round (2020). All regressions control for stratification fixed effects and variables used to check balance in the min-max t-statistic method. Robust standard errors clustered at the village level are provided in parentheses. Asterisks denote a statistically significant difference at the 1% ***, 5% **, or 10% * levels.

Table 6: Adoption Spillovers

	(1) Any demi-lunes adopted on neighbors' plots	(2) No. of fields where neighbors' adopted	(3) Adopted any demi-lunes	(4) Total no. of demi-lunes	(5) Ha. of new land cultivated	(6) Z-score of productive assets	(7) No. of correct answers on test
Panel A							
Any treatment	0.50***	0.69***	0.18***	5.89	0.15**	0.20*	0.00
	(0.05)	(0.06)	(0.05)	(5.34)	(0.07)	(0.11)	(0.17)
Panel B							
Training	0.48***	0.68***	0.19***	6.47	0.11	0.06	0.08
	(0.05)	(0.07)	(0.06)	(6.64)	(0.09)	(0.13)	(0.20)
UCT early	0.52***	0.69***	0.20***	4.42	0.14	0.22*	0.02
	(0.05)	(0.07)	(0.06)	(5.76)	(0.10)	(0.12)	(0.20)
CCT	0.50***	0.67***	0.16**	10.22	0.17	0.26**	-0.09
	(0.05)	(0.07)	(0.06)	(7.72)	(0.10)	(0.12)	(0.20)
UCT late	0.49***	0.75***	0.16**	1.58	0.19*	0.29*	-0.02
	(0.06)	(0.09)	(0.07)	(6.22)	(0.11)	(0.15)	(0.21)
Mean in control	0.17	0.20	0.12	11.07	0.28	-0.19	3.31
No. of observations	2834	2834	639	639	638	639	639
R squared	0.19	0.15	0.05	0.04	0.03	0.10	0.04
Training=UCT early	0.19	0.80	0.86	0.71	0.82	0.20	0.71
Training=CCT	0.49	0.88	0.59	0.62	0.59	0.10	0.32
Training=UCT late	0.70	0.37	0.68	0.41	0.49	0.12	0.56
UCT early=CCT	0.54	0.72	0.48	0.40	0.77	0.69	0.52
UCT early=UCT late	0.50	0.49	0.59	0.58	0.66	0.59	0.82
CCT=UCT late	0.87	0.33	0.97	0.22	0.87	0.82	0.71

Notes: Each column presents the results from a regression of the dependent variables on a binary variable for *any treatment* (Panel A) or binary variables for each treatment (Panel B), as well as stratification fixed effects and variables used to check balance in the min-max t-statistic method. Columns 1 and 2 are from enumerators' field observations of neighboring plots during the 2020 field verification round. Columns 3-7 are collected at endline from the sample of spillover households. Robust standard errors clustered at the village level are provided in parentheses. P-values from pairwise F-tests of the coefficients are provided below the regression results. Asterisks denote a statistically significant difference at the 1% ***, 5% **, or 10% * levels.

Table 7: Labor Outcomes

	(1) Person-days of DL family labor used	(2) Person-days of DL non-family labor used	(3) No. of migrants	(4) No. of family members selling labor	(5) Hired any non-family non-DL labor
Panel A: Year 1					
Any treatment	15.05***	6.03***	-0.21**	-0.12	0.06*
	(1.62)	(0.83)	(0.09)	(0.08)	(0.03)
Mean in control	2.35	0.65	1.12	1.08	0.36
No. of observations	2,535	2,535	2,536	2,535	2,535
R squared	0.12	0.05	0.05	0.03	0.04
Panel B: Year 3					
Any treatment			-0.05	-0.12	0.10***
			(0.07)	(0.11)	(0.03)
Mean in control			1.02	1.76	0.38
No. of observations			2,486	2,486	2,486
R squared			0.05	0.04	0.02

Notes: Each column presents the results from a regression of the dependent variables on a binary variable for *any treatment* for year 1 (Panel A) and year 3 (Panel B), as well as stratification fixed effects and variables used to check balance in the min-max t-statistic method. Robust standard errors clustered at the village level are provided in parentheses. P-values from pairwise F-tests of the coefficients are provided below the regression results. Asterisks denote a statistically significant difference at the 1% ***, 5% **, or 10% * levels.

Table 8: Agricultural Outcomes

	(1) No. of crops planted	(2) Percentage crops failed of crops attempted	(3) Z-score of production (kg) of crops	(4) Z-score of value (CFA) of crops
Panel A: Year 1				
Any treatment	0.06	-0.02*	0.12	0.12
	(0.07)	(0.01)	(0.08)	(0.08)
Mean in control	3.88	0.05	-0.00	-0.00
No. of observations	2,535	2,535	2,535	2,535
R squared	0.05	0.05	0.11	0.11
Panel B: Year 3				
Any treatment	0.00	-0.01	0.15**	0.12*
	(0.06)	(0.01)	(0.07)	(0.07)
Mean in control	4.01	0.10	0.00	-0.00
No. of observations	2,486	2,485	2,486	2,486
R squared	0.03	0.01	0.11	0.08

Notes: Each column presents the results from a regression of the dependent variables on a binary variable for *any treatment* for year 1 (Panel A) and year 3 (Panel B), as well as stratification fixed effects and variables used to check balance in the min-max t-statistic method. Robust standard errors clustered at the village level are provided in parentheses. P-values from pairwise F-tests of the coefficients are provided below the regression results. Asterisks denote a statistically significant difference at the 1% ***, 5% **, or 10% * levels.

Table 9: Land Usage and Soil Quality

	(1) No. of fields owned or rented	(2) Ha. of land cultivated	(3) Ha. of degraded land cultivated	(4) Self-reported soil quality	
Panel A: Year 1					
Any treatment	0.01	0.04	0.08	0.04*	
	(0.12)	(0.22)	(0.17)	(0.02)	
Mean in control	2.60	4.81	3.16	2.76	
No. of observations	2,535	2,535	2,535	2,535	
R squared	0.07	0.08	0.06	0.01	
	(1) No. of fields owned or rented	(2) Renewed cultivation on any land	(3) Ha. of renewed cultivation	(4) Stopped cultivating any land	(5) Ha. of land no longer cultivated
Panel B: Year 3					
Any treatment	-0.08	0.33***	0.29***	-0.07***	-0.04
	(0.12)	(0.04)	(0.05)	(0.03)	(0.03)
Mean in control	2.86	0.39	0.35	0.21	0.19
No. of observations	2,486	2,486	2,486	2,486	2,486
R squared	0.06	0.08	0.05	0.01	0.01

Notes: Each column presents the results from a regression of the dependent variables on a binary variable for *any treatment* for year 1 (Panel A) and year 3 (Panel B), as well as stratification fixed effects and variables used to check balance in the min-max t-statistic method. Robust standard errors clustered at the village level are provided in parentheses. P-values from pairwise F-tests of the coefficients are provided below the regression results. Asterisks denote a statistically significant difference at the 1% ***, 5% **, or 10% * levels.

Table 10: Training Mechanisms

	(1) Knows about demi-lunes	(2) Knows about DL from training	(3) Demi-lune test score	(4) Helped build DL in village
Any treatment	0.01*	0.37***	0.47***	0.07***
	(0.01)	(0.03)	(0.07)	(0.02)
Mean in control	0.99	0.24	3.31	0.10
No. of observations	2,486	2,473	2,486	2,473
R squared	0.01	0.09	0.04	0.03

Notes: Each column presents the results from a regression of the dependent variables on a binary variable for *any treatment* , as well as stratification fixed effects and variables used to check balance in the min-max t-statistic method. The data are from the endline household survey (year 3). Robust standard errors clustered at the village level are provided in parentheses. P-values from pairwise F-tests of the coefficients are provided below the regression results. Asterisks denote a statistically significant difference at the 1% ***, 5% **, or 10% * levels.

T0 Control	T1 Training	T2 Training + Unconditional cash transfer (early)	T3 Training + Conditional cash transfer	T4 Training + Unconditional cash transfer (late)
		$20.00	$0.40 per demi-lune	$20.50
	February	March	June	June

Figure 1: Study design

Notes: Treatment arms, assigned at the village level, including information on the transfer value and timing.

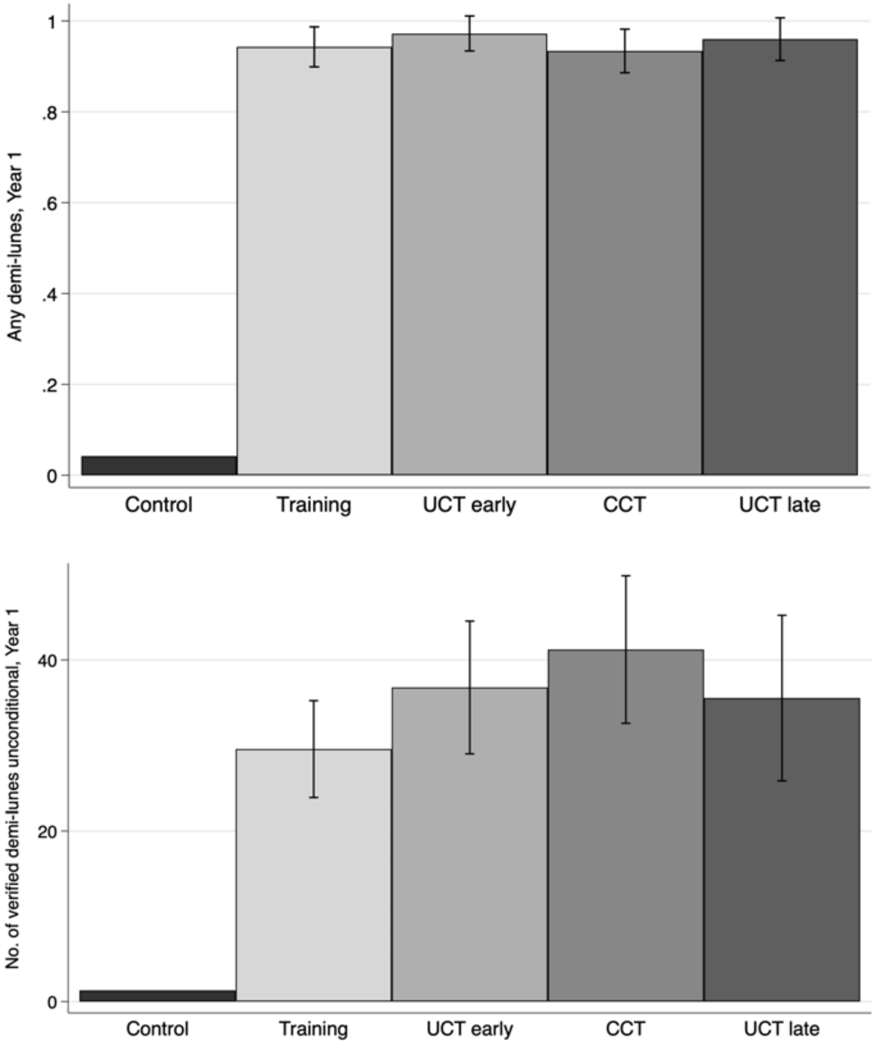

Figure 2: Demi-lune Adoption, Year 1

Notes: Results from a regression of measures of the extensive and intensive margin of demi-lune adoption on binary variables for each treatment variable and strata fixed effects, using data from the June 2018 field observations of demi-lune construction. Standard errors are clustered at the village level.

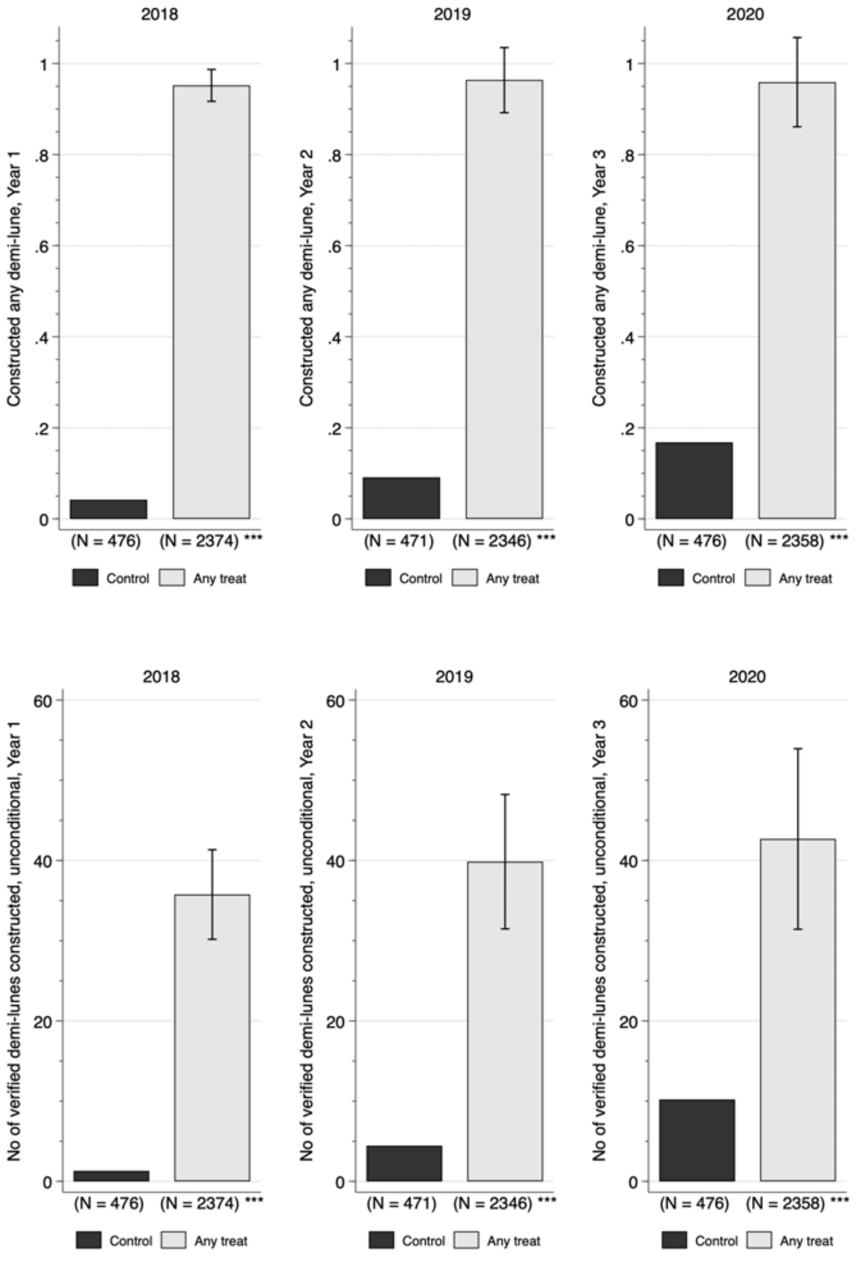

Figure 3: Demi-Lune Adoption over Time

Notes: Results from a regression of adoption outcomes on a binary variable for *any treatment* and stratification fixed effects. Data are from the field verification rounds in 2018, 2019 and 2020 (years 1, 2 and 3). Standard errors are clustered at the village level.

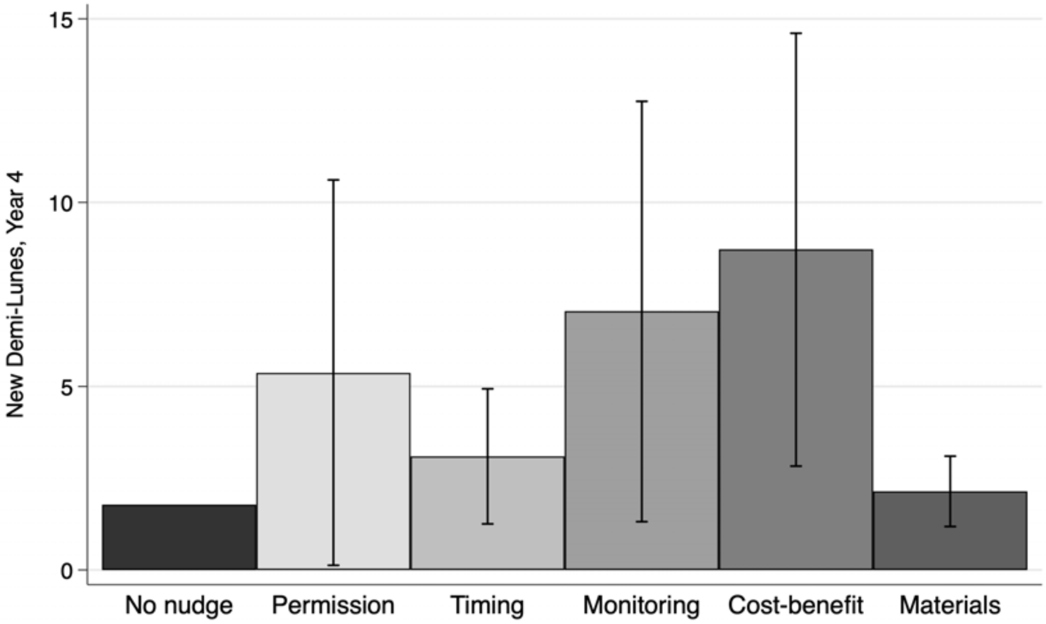

Figure 4: Impact of Nudges on New Adoption

Notes: This graph shows the point estimates are from a regression of new verified demi-lune construction between January and June 2021, binary variables for each nudging intervention and strata fixed effects. The data are conditional on being in a treated village. Standard errors are clustered at the village level.

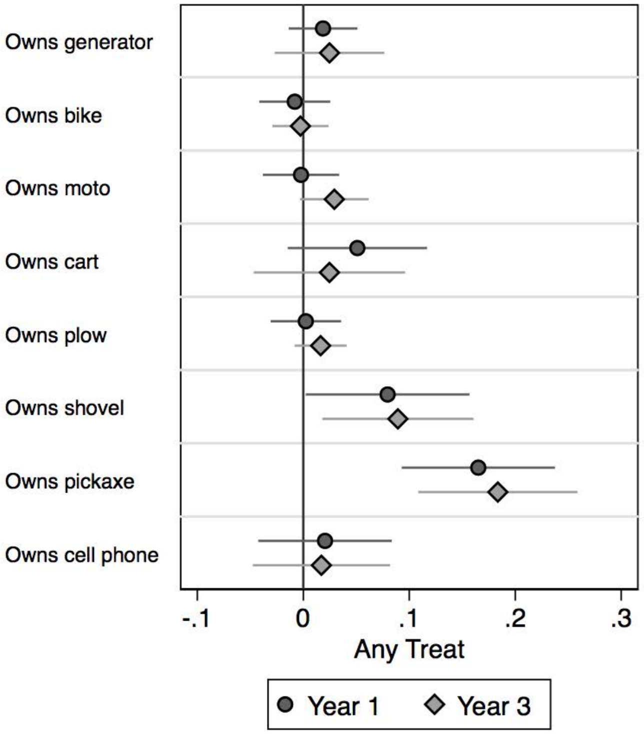

Figure 5: Asset Ownership

Notes: The point estimates are from a regression of each variable for asset ownership on a binary variable for *any treatment* and strata fixed effects. Data on asset ownership were collected in the midline (year 1) and endline (year 3) surveys. Standard errors are clustered at the village level.

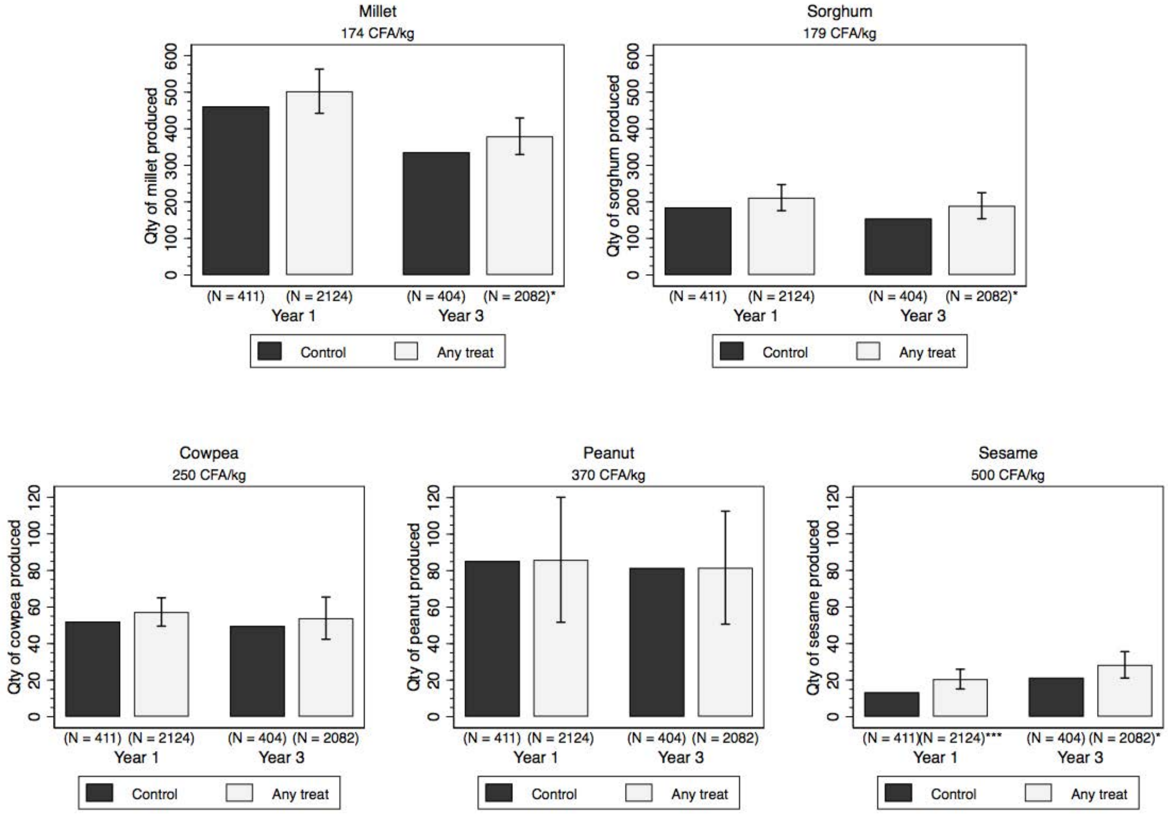

Figure 6: Agricultural Production (in kg) by Crop

Notes: These figures show the results of a regression of production of different crops (in kg) on a binary variable for *any treatment* and strata fixed effects, using data from midline (year 1) and endline (year 3) surveys. Standard errors are clustered at the village level.

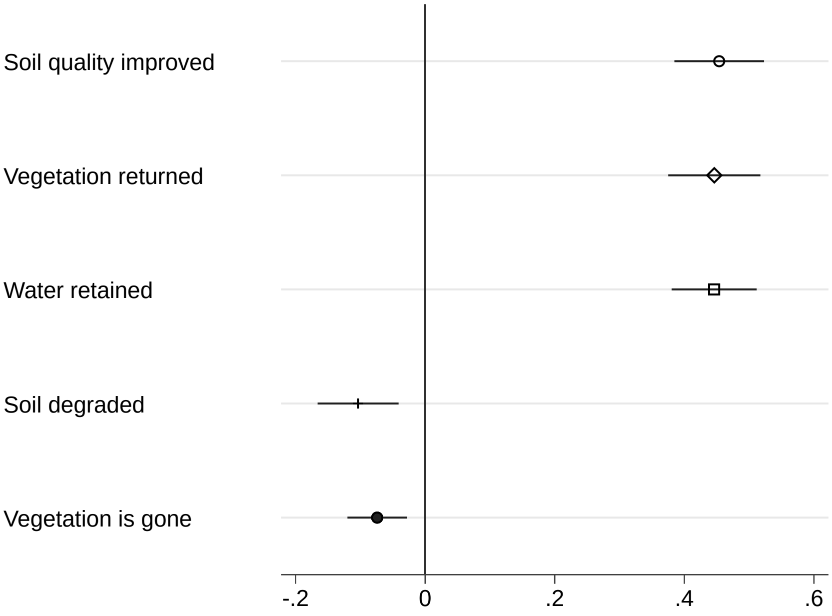

Figure 7: Land Quality, Year 3

Notes: This figures shows the results of a regression of a number of variables on a binary variable for *any treatment* and stratification fixed effects, using data from the endline survey. Standard errors are clustered at the village level.

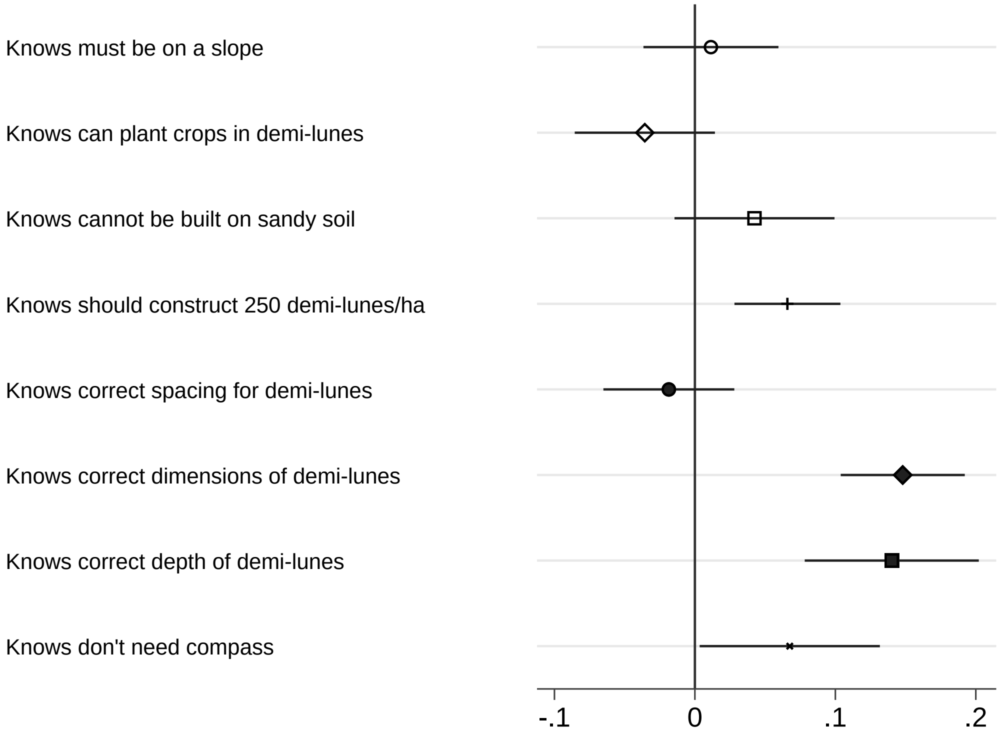

Figure 8: Test Scores, Year 3

Notes: Results from a regression of each variable on a binary variable for *any treatment* and stratification fixed effects, using data from the endline survey. Standard errors are clustered at the village level.