Eliciting Supplier Collaboration for a Firm's Decarbonization Strategy:

A Field Experiment in an Agricultural Supply Chain in India

Sukti Ghosh

INSEAD

sukti.ghosh@insead.edu

Jasjit Singh

INSEAD

jasjit.singh@insead.edu

January 10, 2024

Acknowledgments. We thank to our partner firm for the access and support they provided for this research. We thank Aline Gatignon, Anna Szerb, Bala Vissa, Chiara Spina, Hyunjin Kim, Ilze Kivleniece, Kate Odziemkowska, Jiao Luo, Laurence Capron, Lite Nartey, Lucia Del Carpio, Maria Guadalupe, Matthew Lee, Phanish Puranam, Phebo Wibbens, Rem Koning, Rupali Kaul, Vibha Gaba and Victoria Sevcenko for helpful inputs. This research has also benefited from feedback at the 2023 meetings of the Academy of Management and the Strategic Management Society as well as at the NMSRC Doctoral Conference and the INSEAD STR/EFE Research Seminar. Finally, we are grateful to the INSEAD R&D Committee and the Kurt Björklund Research Fund for financial support. Any errors remain our own.

ABSTRACT

Firms are increasingly under pressure to cut greenhouse gas emissions not just within their own operations but across their overall value chain. This requires cooperation from all value chain partners, especially the suppliers, which faces the dual challenge of the partners often lacking capabilities relevant for decarbonization as well as the incentives for pursuing it. Given the impracticality of achieving supplier cooperation purely through contractual means in many contexts, especially in emerging markets, we propose that a potential solution is to make long-term investments that simultaneously develop supplier capabilities and deepen their relational engagement with the firm through creation of mutual benefits. To empirically test this, we collaborated with a Fortune 500 firm seeking to decarbonize its agricultural supply chain in India. We designed a field experiment to examine the effectiveness of two interventions to provide the firm's supplier farmers with knowledge and training around decarbonization practices at the same time as making further investment in addressing their unmet needs related to agricultural advisory for boosting their overall agricultural productivity. We find that that, relative to a base program where no such investment was made, the two interventions improved outcomes related to farmer retention as well as adoption of climate friendly practices, with the higher-investment intervention leading to greater impact in terms of outcomes achieved per dollar. More generally, our study draws attention to the important strategic issue of achieving stakeholder cooperation for firms to make faster progress towards decarbonization.

Keywords: Sustainability; Nonmarket Strategy; Decarbonization Strategy; Climate Change; Greenhouse Gas Emissions; Agricultural Supply Chain; Emerging Markets; Social Impact; Field Experiment

1. INTRODUCTION

Effectively contributing towards addressing humanity's grand challenges requires firms to coordinate collective action across varied stakeholders (George, Howard-Grenville, Joshi & Tihanyi, 2016; Henderson & Serafeim, 2020; Lumpkin & Bacq, 2019; McGahan, 2021). Addressing the climate crisis, one of the biggest challenges humanity has ever faced (Richardson et al., 2023), is no exception. Further, business activities associated with firms are widely recognized as a critical contributor to this crisis (TIME, 2022). It is therefore no surprise that firms are under pressure to implement credible decarbonization strategies to cut greenhouse gas (GHG) emissions. One source of this pressure is the ongoing tightening of environment-related regulation worldwide in response to urgency of the issue (Rennert et al., 2022; Rockström et al., 2017). However, the pressure for firms to be more socially responsible in general also appears to be rising from other stakeholders, including a firm's customers (Bertini, Buehler, Halbheer & Lehmann, 2022; The Wall Street Journal, 2021), employees (Bode & Singh, 2018; Burbano, 2016), communities (Dorobantu & Odziemkowska, 2017; Henisz, Dorobantu & Nartey, 2014), or investors (Flammer, Toffel & Viswanathan, 2021; Reid & Toffel, 2009). As a result, in the process of increasingly integrating societal priorities into their business strategies, more and more firms are in particular pledging to goals for reducing their GHG emissions and designing long-term decarbonization programs to achieve them.

Another notable trend is that firms are increasingly expected to lead efforts to reduce emissions not just within their own operations but across their overall value chains. However, a key challenge remains that a large fraction of a firm's value chain emissions lies beyond its control as they are the result of upstream or downstream activities (Blanco, Caro & Corbett., 2016; CDP, 2022; WRI, 2022). Addressing such emissions critically depends on cooperation of the value chain partners (Hardy & Sandys, 2022; Hsu & Rauber, 2021; CDP, 2021), a challenge accentuated by these partners often lacking either sufficient understanding about decarbonization or sufficient incentives to make decarbonization a priority. For example, low-income producers of a raw material in an emerging economy might have limited knowledge about how their activities produce emissions that contribute to climate change or may be more concerned about their daily livelihood than the long-term impact of their emissions. Further, these challenges can often not be resolved by contractual mechanisms, making it important to engage partners through a relational approach (Baker, Gibbons & Murphy, 2002; Gibbons & Henderson, 2012).

There is limited empirical research on effective approaches for engaging value chain partners in a firm's decarbonization strategy, a gap that this study hopes to fill. We examine one potential solution for addressing the dual challenge of missing capabilities and misaligned incentives mentioned above: making long-term relational investments that simultaneously develop partner capabilities for decarbonization and enhance their overall economic well-being, so that a partner is both able and willing to cooperate in implementing a firm's decarbonization strategy. Focusing in particular on the supplier side of the value chain, we use a field experiment to present evidence related to how the extent and nature of a firm's relational investment in supplier capabilities and overall well-being can impact their continued engagement and cooperation in its decarbonization efforts. [1]

Our empirical context is a Fortune 500 firm that relies on supplier farmers in India to source an agricultural crop (henceforth referred to as "Crop X") critical for its products.[2] In the years leading up to our research collaboration (launched in 2022), the firm had been running a farmer engagement program to support farmers with some (but limited) access to knowledge, tools and resources for growing Crop X productively in line with the firm's quality requirements. However, there had thus far not been any systematic effort to move farmers towards more climate-friendly agricultural practices. Our research was launched in the context of an interest in linking this program with the firm's decarbonization ambition, which provided us with an opportunity to examine the effectiveness of a relational approach towards influencing suppliers to adopt more climate-friendly practices.

---

[1] Our study in some ways builds on McGahan & Pongeluppe (2023), who examine how the cosmetics company Natura engaged with its suppliers to make progress on its rainforest preservation goals in the Amazon. However, our specific context, hypotheses and analysis are quite distinct as we execute a field experiment for evaluating cost effectiveness of alternative interventions engaging farmer suppliers in a decarbonization effort in an agricultural supply chain in India.
[2] Since our partner firm is one of the few major firms with deep engagement in this specific crop's supply chain in India, we have not mentioned the name of the specific crop in this study in order to protect the firm's identity.

Our investigation started with in-depth field work. Our first observation was the farmers were generally not even aware of the issue of emissions reduction, though they did care about localized climate-related issues they saw as affecting their welfare - such as achieving climate resilience or preserving soil health. A large fraction of the farmers came from low-income segments, and their most important concern was their own productivity and economic well-being. We also noticed considerable barriers to adoption of new practices due to a perception of uncertain returns and a lack of reliable knowledge and resources appropriate for a farmer's specific agricultural context. While the farmers appreciated the support the firm's field staff were already providing, they also expressed a need for more comprehensive and personalized agricultural advisory tailored to their context. Additionally, farmers also expressed a desire for support not just for Crop X they grew for the firm but also for broader agricultural matters pertaining to other crops. Overall, our qualitative research suggested that just providing farmers training around climate-friendly agricultural practices might have limited impact, and that a more promising direction was for this training to be bundled with additional services targeting the unmet needs of the farmers. Advisory services with personalization (i.e., tailored to the farmer's needs and context) and provision for comprehensive agricultural support (i.e., on broader matters beyond just Crop X) thus emerged as two potential extensions for the success of a program that had a goal of getting farmers to adopt climate-friendly practices.

We next started using the insights from our field work for considering possible interventions where training about decarbonization practices (the only component of a "base program" to be used as a control group) would be bundled with also providing supplier farmers with long-term support to improve their overall capabilities as well as deepen their relational engagement with the firm. Our discussions with our partner firm finally converged on two specific interventions: (i) Intervention A, which would only cater to the first of the above two needs (and hence be less expensive to implement) by adding personalized crop-specific advisory services in the form of a free-soil testing service and accompanying advisory (but still restricted to Crop X) and, (ii) Intervention B, which would cater to both of the above two needs (and hence be more expensive to implement) by adding not only the personalized crop-specific advisory services but also broader agricultural advisory provided by an expert agronomist visit related to overall agricultural productivity (covering all crops being grown).

Our next step was to design a field experiment to examine the impacts and cost effectiveness of our Intervention A as well as Intervention B relative to a base program. The experiment was implemented using a pool of 2,605 supplier farmers belonging to 362 villages (taken as the unit of randomization). Intervention B generated greater impact relative to the base program as well as Intervention A for both business and environmental outcomes. In a cost-benefit analysis that also accounts for the additional cost that Intervention B entailed, Intervention B still turns out to be the more cost effective intervention in terms of meeting the firms strategic goals for the program. With a caveat that there might be limits to generalizability, the higher investment approach (Intervention B) in our context thus trumped the lower investment approach (Intervention A), which in turn trumped the minimal investment approach (the base program). In other words, given the impracticality of formal contractual solutions for this in our context, making significant and appropriate relational investments seemed worthwhile for eliciting supplier cooperation for the decarbonization strategy.

In terms of overall contribution, this paper is one of the few large-scale empirical studies (and the first field experiment to our knowledge) in the management literature to examine the phenomenon of decarbonization of a firm's overall value chain, and how it can be facilitated by a relational approach towards investing in the capabilities as well as overall well-being of the value chain partners. Another unique aspect of our study is an attempt to quantify the costs and benefits of decarbonization-related interventions from the point of view of the firm itself as well as society at large. More generally, we also hope to contribute towards climate action by providing practical implications at the intersection of social and environmental impact in the context of emerging economies.

2. DECARBONIZATION STRATEGY IN FIRMS

2.1. Climate change and the role of firms

It is well established in the scientific literature that human activity, much of it related to business around the world, has been behind the alarming rise in environmental challenges in recent decades. Six of the nine so-called "planetary boundaries" have already been breached, implying that the overall earth system is now well outside of its "safe operating zones" (Richardson et al., 2023; Rockström et al., 2017). Although the boundaries are inter-related, the one drawing the most attention in terms of the need for critical business action is the boundary associated with GHGs in the atmosphere, the key driver of global warming and climate change. GHG emissions, including carbon dioxide, continue to cause an alarming rise in the earth's temperature, which is increasing the risk of severe climate-related impacts like sea-level rises, floods, droughts, and extreme weather events (IPCC, 2022). This has led to urgent calls for decarbonization (i.e., reducing GHG emissions and limiting atmospheric GHG levels), including global negotiations leading to the Paris Climate Agreement of 2015 where all nations agreed to a global goal of limiting global warming to under two degrees Celsius (and an aspiration of limiting it to closer to 1.5 degrees Celsius) relative to pre-industrial levels. However, scientists remain concerned that the progress has not been rapid enough to meet these goals (Richardson et al., 2023; United Nations Environment Programme, 2023).

Firms are increasingly under pressure to take a lead in reducing not just direct emissions arising within their own boundaries but also indirect emissions involving the activities of their partners in the value chain. These pressures seem to have escalated with the widespread diffusion of emission measurement standards like the GHG protocol (which classifies emissions from a firm's value chain partners as its "Scope 3 emissions") and emission reduction standards like the SBTi (Science Basted Target Initiative, an organization that helps firms formalize science-based "net zero" strategies).[3] In fact, indirect emissions, including those attributable to either direct suppliers or suppliers that are further upstream, are often significantly larger in magnitude than a firm's direct emissions. Firms are therefore under growing pressure not just from policy makers but also from customers, employees and society at large to undertake serious efforts to decarbonize their overall value chains (Reid & Toffel, 2009; Jira & Toffel, 2013). The firms are, in response, increasingly

[3] The GHG Protocol uses the term "Scope 1 emissions" for direct emissions from a firm's own activities, "Scope 2 emissions" for emissions associated with its acquired electricity, steam, heat or cooling, and "Scope 3 emissions" for emissions from its value chain partners (https://ghgprotocol.org/). Scope 3 emissions are the hardest to manage, and yet often represent a large majority of a firm's total emissions (Stenzel & Waichman, 2023; Tidy et al., 2016).

setting specific emission reduction targets and implementing decarbonization strategies for measuring and reducing emissions not just within their own boundaries but also across their entire value chains.

2.2. Decarbonizing a firm's value chain

Engagement with relevant stakeholders is critical for firms to meaningfully engage on societal issues (Bridoux & Stoelhorst, 2016; McGahan, 2021), and making sufficient progress on the issue of climate change is no exception (McGahan & Pongeluppe, 2023). However, engaging value chain partners for decarbonization poses the dual challenges of a common lack of awareness of climate-related issues among these partners and their interests of not being aligned with the goals of the firm (Koh, Jia, Gong, Zheng & Dolgui, 2023). Such challenges can be further aggravated for global firms with complex cross-border value chains with numerous and varied stakeholders (Verbeke, 2021).

Despite the challenges, global firms are well positioned to contribute to emissions reduction. To begin with, they have an opportunity to redesign their cross-border supply chains. For instance, sourcing more raw materials locally as opposed to importing raw materials can result in lower emissions (while also improving their supply chain resilience). Ultimately, the impact of reducing emissions anywhere in the world is global, which presents an opportunity for pursuing mitigation wherever it is most cost effective to do so (Glennerster & Jayachandran, 2023). Firms often command significant resources and the latest knowledge regarding low-carbon technologies and practices and have a global reach that positions them well to engage millions of suppliers worldwide (Steenbergen & Saurav, 2023). In the process, they can also have meaningful social impact by engaging deeply with the primary producers and suppliers belonging to low-income segments of the global population (Howard-Grenville, Buckle, Hoskins & George, 2014; McGahan & Pongeluppe, 2023).

However, engaging suppliers in decarbonization, especially in the context of emerging economies, requires four important considerations. First, the suppliers may not have much knowledge of climate change or might lack appropriate knowledge and resources for being able to undertake decarbonization efforts, making it critical for firms to provide intensive support for developing supplier capabilities (Gatignon & Capron, 2023; McGahan & Pongeluppe, 2023). Second, protecting the environment versus ensuring local economic sustenance can entail trade-offs; for instance, in poorer households, an owner of forested land could face the choice between conserving a forest or earning income by cutting down trees. This makes it important for decarbonization efforts to also take into account local livelihoods (Jayachandran, 2023; Samii et al., 2014). Third, emissions mitigation often entails significant upfront costs, a challenge made worse by inefficient access to capital in places with an underdeveloped financial sector (Glennerster & Jayachandran, 2023). Recognizing such financial constraints of the local stakeholders is important for designing solutions. Finally, contractual arrangements to protect the environment are often not effective due to limited legal recourse or the difficulty of enforcement (Jack, Jayachandran, Kala & Pande, 2022; Jack & Jayachandran, 2019). This makes it paramount for firms to align interests through relational mechanisms, previously shown to often be better suited in certain contexts (Dorobantu, Kaul & Zelner, 2017; Marquis & Raynard, 2015; Teodorovics, Lazzarini, Cabral & McGahan, 2023).

3. RESEARCH CONTEXT AND HYPOTHESES

3.1. Empirical setting: A global firm's agricultural supply chain in India

Our research partner is a Fortune 500 firm in the Food & Beverage industry, and our research context was the firm's agricultural supply chain in India. About one-fifths of the global GHG emissions arise from the agricultural sector (Rivera, Movalia, Pit & Larsen, 2022; WRI, 2023). Although a substantial fraction of these come from agriculture-related activities in emerging economies (Glennerster & Jayachandran, 2023), and the impact of climate change is also expected to fall disproportionately on the low-income farmers within these countries, local emission mitigation efforts through more climate-friendly agricultural practices remain limited. The first reason for this is a lack of sufficient institutional infrastructure, such as access to requisite tools and knowledge for adoption of optimum practices (Cole & Fernando, 2021; Jack, 2013). The second reason is the difficulty of getting farmer buy-in for making emissions reduction a priority, which typically requires ensuring that their livelihoods are not made worse off by them adopting climate-friendly practices.

Even before our research collaboration started, our partner firm had for several years been running a farmer engagement program as a part of their long-term sourcing strategy for Crop X. Our research started in the context of discussions on how this program could be extended to also promote more climate-friendly agricultural practices. Before we describe the potential extensions of the original program that we examined as a means for effectively securing farmer cooperation for the firm's decarbonization goals, it is useful to review the details of the original program itself.

3.2. The firm's original farmer engagement program

The firm's original program was intended to nurture a long-term relationship with participating farmers to have an assured supply of Crop X. Cultivating Crop X in line with the stringent quality standards of the firm entails the farmer adopting specific agricultural practices, such as particular seed varieties, precise activities for land preparation, and exact timing of sowing. If a farmer's produce failed to meet the firm's quality parameters, the prospect of finding an alternative buyer and securing a good price was uncertain. This uncertainty could deter farmers from working with the firm in the first place or from devoting enough land to Crop X, an issue that the firm did not think could be addressed simply through formal contractual arrangements or binding financial inducements: limitations of the legal infrastructure, marginal land holdings and ambiguity in land ownership made enforceability of contracts impractical (Shrimali, 2022). The firm's original farmer program had therefore tried to overcome this challenge by relying on relational investments to build trust and ensure that the farmers were both able and willing to grow Crop X at the desired scale and quality. Instead of relying on formal contracts, the program focused on investing in building and strengthening long-term informal relationships with the farmers.[4]

[4] The firm's program built upon experiences of past government and development programs seeking to boost farmer productivity through in-person support, though often with mixed success (Birner & Anderson, 2007; FAO, 2017; Glendenning, Babu & Aseno-Okyere, 2010). Insufficient institutional capacity, dispersed populations and limited infrastructure generally made it hard for such so-called "extension services" to be delivered in a reliable and timely manner (Glendenning et al., 2010). Another challenge had been the suitability of the knowledge, which was often either too generic to address context-specific issues or too technical for the illiterate or semi-literate farmers to optimally use (Cole & Fernando, 2021). Many such technologies had also been developed and tested in laboratory conditions very different from farmers' actual context, introducing further uncertainty in benefits from their adoption (Alidaee, 2023; Suri, 2011).

The firm's program was implemented through a network of its field officers, who carried out regular visits to assure the farmers that growing Crop X for firm was an attractive option, and nurtured a long-term relationship built on mutual trust rather than formal contracts. The farmers were provided with access to certified seeds, information on best practices, digitized quality check on the crop produced, and an informal assurance that the firm would buy Crop X at a price commensurate with the investment a farmer made for assuring its quality. Figure 1 summarizes the organization structure of the program, which was implemented in North India in the states of Haryana and Rajasthan. Within these states, the field officer network spanned across 16 geographic centers (corresponding to "Agricultural Produce and Livestock Market Committee" locations as per the Government of India's nomenclature). The farmers accessed inputs and sold their produce at the center closest to them, with the firm's field officer at each center serving as the point of contact between the firm and the farmers.[5]

[Insert Figure 1 here]

3.3. Insights from pre-experiment field interviews

Before starting work on designing potential extensions to the original program to meet our partner firm's decarbonization goals, we first carried out qualitative field research to understand firsthand how the original program itself was being perceived. This involved 57 semi-structured interviews: 43 with farmers (from 15 villages across seven centers) who had already participated in the original program, seven with field officers (from the same seven centers), and seven with managers (two state-level managers also serving as agronomists, one R&D manager, and four program managers). The interviews took place during April-May 2022 and October-November 2022, lasted about 45-90 minutes each, and were carried out in either English or a local dialect (with field staff serving as translators where necessary). Table 1 provides illustrative quotes from the interviews.

[Insert Table 1 here]

[5] The operations in each center were carried out with the help of a different field officer, the only exceptions being one large center that had two field officers and two small and proximal centers that were managed by the same field officer.

In several interviews (e.g., interview [1] in Table 1), the farmers informed us that they found the regular one-to-one visits of the field officers (usually once a month during the cultivation season) beneficial for receiving timely information on issues relevant at the different stages of growing Crop X. The farmers viewed their engagement with the firm as a long-term relational partnership that was mutually beneficial, with a particular appreciation for the firm investing in arranging frequent field staff visits to build and continue the relational aspect of the engagement (e.g., interviews [2] and [3] in Table 1). The interviews also revealed farmer needs not currently addressed due to the lack of sufficient farmer-specific customization in the original program as well as its focus only on Crop X.

The first set of unmet needs related to agricultural issues unique to a farmer's context and priorities, as available information was often too generic to be useful (e.g., interviews [4] and [5] in Table 1). There was a latent need for more personalized advisory that would take into account farmer-level considerations like the agricultural routines they practiced, their agricultural inputs (like the specific seeds and fertilizers), and the idiosyncrasies of their growing conditions (like soil nutrients).[6] Access to a timely and reliable soil testing service that could enable personalization of agricultural practices was mentioned several times as a concrete service that the farmers would find particularly useful as an extension to the original program. Although soil testing services were in principle provided by the government in some locations, these were not always reaching farmers in time for them to implement appropriate actions, and the information provided in a soil test report was often too technical to be useful for a large majority of the farmers that were illiterate or semi-literate.

The second set of unaddressed farmer needs related to support that would cover not just Crop X but also the other crops a farmer grew, a point that came through in our interviews with the farmers themselves (e.g., interviews [6] and [7] in Table 1) as well as with the firm's employees (e.g., interview [8]). This included the need for more comprehensive advice on agriculture-related matters, such as weather patterns, crop diseases and pests, and access to inputs like good quality seeds even

[6] The importance of considering a farmer's localized context has also been previously documented by prior work on adoption and effectiveness of agricultural technologies and practices (Alidaee, 2023; JPAL, 2023; Suri, 2011). In particular, access to scientific tools like soil tests, combined with farmer-friendly information sharing to help interpret the results from such tests, has been documented as a particularly impactful service (Cole & Sharma, 2017).

for crops other than Crop X. Based on their positive experience with the firm's program, the farmers hoped that the firm might also be able to provide them with such access to expert agricultural knowledge and tools beyond what its field staff specializing only in Crop X was equipped to provide.

We also asked farmers about their understanding and attitude towards environmental issues. They generally did not have much awareness of global environmental debates like climate change but did seem sensitive to local environmental issues they could relate to– such as soil health, water availability, unpredictability of weather, and new kinds of pests and diseases. They also seemed somewhat open to adopting climate-friendly practices, but only if doing so did not involve a compromise on their own productivity and economic well-being (e.g., interview [9] in Table 1).

On the whole, our interviews suggested that getting the farmers to adopt climate-friendly practices would be easier if the extension to the original program included not just information and training about decarbonization practices but also more personalized and/or more comprehensive agricultural services that created immediate and visible economic value in their eyes.

3.4. Proposed program extensions and formal hypotheses

Subsequent to our field interviews, we worked with our partner firm to design possible interventions that could get the farmers to adopt more climate-friendly practices to reduce two kinds of agricultural emissions - carbon dioxide (CO_2) and nitrogen dioxide (N_2O). The first intervention was simply a "base program" that involved just a small extension of the original program wherein the field officers would make the farmers more aware of their environmental externalities and train them on climate-friendly agricultural practices. In line with scientific recommendations from agronomy (Diacono & Montemurro, 2011; Mangalessary et al., 2014; Menegat, Ledo & Tirado, 2022; Stylianou et al., 2023), the focus would be on two kinds of practices: reducing tillage of their land (i.e., number of times they turn the soil in advance of sowing) and optimizing fertilizer usage (i.e., reducing use of inorganic fertilizers and increasing use of organic fertilizers). [7]

[7] In Table A1 in supplementary appendix, we provide a detailed overview of the linkage between the climate-friendly practices recommended by the firm and GHG emissions reduction as derived from the agronomy literature.

The base program was intended for use as a control group in our subsequent field experiment, which is why we did not include any additional effort to meet the farmers' unmet needs that were revealed in from our field interviews. In reality, our expectation was that ensuring farmer cooperation for adopting climate-friendly practices would be facilitated by also taking their perspectives and needs into account through additional extensions to the base program. The next step was therefore to extend the base program in a way that not only considered the firm's decarbonization goals but also created more immediate and visible value for the farmers by meeting some of their unmet needs. This formed the basis of two additional interventions that we call "Intervention A" and "Intervention B".

Recall from our discussion of field interviews that one specific support that the farmers were keen to get was more personalized advisory enabled through a timely and reliable soil testing service. Other than its incremental cost, adding this service to the firm's existing program was not hard as the firm already had close ties with external partners who could provide the service reliably, and its existing network of field officers could further tailor their support for growing Crop X based on the results from such a soil test. This therefore formed the basis of our Intervention A, which would include everything in the base program but additionally also include a free-soil testing service.

Our field interviews had also revealed a latent need for more comprehensive support on general agricultural matters beyond just growing Crop X. Providing this could, however, involve significant resource investment and changes to the firm's processes, as the firm's existing field officers were qualified and equipped only to support Crop X. While extending too far in this direction could be too costly and risky, the firm was open to experimenting with making progress within the existing structure by leveraging relevant knowledge and agronomist expertise it had available internally. In particular, it could be feasible to provide the farmers with general agricultural advisory (beyond just Crop X) in the form of limited one-on-one visits by the firm's expert agronomists, who would provide customized guidance to the farmers based on their local conditions and priorities. This formed the basis of our design of Intervention B, which would include not only everything already in Intervention A but also add one visit per season for each farmer by one of their expert agronomists.

To summarize, the base program would extend the original program by only adding training around climate-friendly practices. Intervention A would further add the *personalized crop-specific agricultural advisory services* in the form of a free-soil testing service and accompanying advisory services personalized to their agricultural conditions, but still restricted to Crop X. Intervention B would be an even higher-investment version that also included *personalized crop-specific as well as broader agricultural advisory* covering land management and agricultural practices not restricted to Crop X. The hope was that the investment made in either Intervention A or Intervention B would enhance the supplier farmers' overall capabilities as well as their relational commitment to the firm by providing them additional immediate value beyond what the base program did (Figure 2). This, in turn, was expected to improve their continued participation in the firm's program going forward as well as their ability and willingness to adopt the recommended climate-friendly practices.

[Insert Figure 2 here]

The above arguments lead us to two sets of formal hypotheses, which we pre-registered prior to testing them through our field experiment.[8] The first set of hypotheses pertains to a business outcome ("retention") that captures the farmers' continuation in the firm's program going forward:

Hypothesis 1a. When the firm provides inducement to its supplier farmers in the form of personalized crop-specific advisory (Intervention A), farmer ***retention*** *in the program will be greater than when they do not receive this inducement (Base Program).*

Hypothesis 2a. When the firm provides inducement to its supplier farmers in the form of personalized crop-specific as well as broader advisory (Intervention B), farmer ***retention*** *in the program will be greater than when they do not receive this inducement (Base Program).*

Hypothesis 3a. When the firm provides inducement to its supplier farmers in the form of personalized crop-specific as well as broader advisory (Intervention B), farmer ***retention*** *in the program will be*

[8] Our research design and hypotheses were pre-registered with Open Science Framework (OSF, https://osf.io/registries) before launching our field experiment (documentation available upon request). While we also carry out and report the findings from some post hoc analyses beyond the pre-registered hypotheses, we follow the best practice of ensuring that our reported findings have a "clear demarcation between preregistered and post hoc results" (Levine, Schilke, Kacperczyk & Zucker, 2023).

greater than when the inducement is only in the form of personalized crop-specific advisory (Intervention A).

The second set of hypotheses is analogous to the ones from the first set above, but pertains to the environmental outcome ("adoption") that captures the farmers' adoption of the climate-friendly agricultural practices that the firm recommended:

Hypothesis 1b. When the firm provides inducement to its supplier farmers in the form of personalized crop-specific advisory (Intervention A), farmer ***adoption*** *of the climate-friendly practices will be greater than when they do not receive this inducement (Base Program).*

Hypothesis 2b. When the firm provides inducement to its supplier farmers in the form of personalized crop-specific as well as broader advisory (Intervention B), farmer ***adoption*** *of the climate-friendly practices will be greater than when they do not receive this inducement (Base Program).*

Hypothesis 3b. When the firm provides inducement to its supplier farmers in the form of personalized crop-specific as well as broader advisory (Intervention B), farmer ***adoption*** *of the climate-friendly practices will be greater than when the inducement is only in the form of personalized crop-specific advisory (Intervention A).*

4. FIELD EXPERIMENT DESIGN AND EXECUTION

4.1. Sample construction, randomization approach and data collection

Our study sample consisted of the 2,605 supplier farmers who signed up for the firm's farmer engagement program for the 2022-2023 season. Following prior field experiments related to adoption of agricultural practices among farmers in emerging economies (Barrett, Islam, Mohammad Malek, Pakrashi & Ruthbah, 2018; Cole & Fernando, 2021), we used villages as our unit of randomization.[9] Further, given that the 362 villages in our sample belonged to 16 different centers (Figure 1), we adopted a stratified randomization strategy, wherein all the villages under a given center were randomly assigned to one of three groups: the base program (the control group), Intervention A or

[9] The reason for not using farmer-level randomization in such studies was two-fold. First, it was usually impractical to carry out different interventions for farmers living in the same village. Second, even if this could be reliably carried out, there was a significant risk of spill overs given that farmers in a village generally know each other and are frequently in touch.

Intervention B. This led to 127 villages being allocated to the base program, 120 villages to Intervention A, and 115 villages to Intervention B (Figure 3).[10]

[Insert Figure 3 here]

All intervention-related activities were implemented during the 2022-2023 growing season, which lasted from December 2022 to May 2023. Our partner firm provided us with access to their proprietary data on farmer characteristics, their activity records, and their formal transactions with the firm. We merged these data with village-level data on socio-economic indicators (Asher et al., 2021) as well as two rounds of primary survey data collection: baseline data collected pre-experiment (November-December 2022) and endline data collected post-experiment (July-August 2023).

4.2. Variable definition

For testing our Hypotheses 1a, 2a and 3a, we define two business-related outcome variables that capture a farmer's likely engagement in the firm's program going forward. The first is *Retention*, a binary indicator of the farmer's intention to continue next year (coded as 1 if the farmer intends to stay in the program and 0 otherwise). The second is *Land allocated*, the farmer's land allocation for Crop X for the next year's program (measured in hectares and set to 0 if the farmer does not intend to continue at all). Unlike *Retention*, which is only measured post-experiment, *Land Allocated* is also measured for the current year, allowing not just post-comparison but also a comparison of post-versus-pre changes (i.e., "difference-in-differences") across experimental groups.

For testing Hypotheses 1b, 2b and 3b, we define two environment-related outcome variables that capture a farmer's adoption of climate-friendly practices the firm recommends (as detailed in Table A1). The first is *Tillage*, which measures the extent of turning of soil practiced by the farmer during preparation (a count variable). The second is *Inorganic fertilizer*, which measures the intensity of inorganic fertilizer by taking the average of two kinds of inorganic fertilizers - urea and DAP –

[10] Figure A1a in the supplementary appendix depicts the geographic location for these centers, and Figure A1b provides the distribution of the villages belonging to the base program, Intervention A or Intervention B across these centers.

that the farmer uses per unit of land (in kilograms per hectare).[11] Both *Tillage* and *Inorganic fertilizer* are measured pre-experiment as well as post-experiment, again allowing not just post-experiment comparison of levels but also post-versus-pre changes across the experimental groups.

Given the randomized design, using control variables in comparing across groups is not critical. Nevertheless, to improve estimation efficiency, we employ village-level as well as farmer-level controls in our multivariate regression analysis. Table 2a provides the definition and summary statistics for our village-level controls: *Total population, Village area, Literacy rate, Rural poverty rate*, *Agriculture main income*, *Daily hours power* and *Night light*. Table 2b similarly provides the definition and summary statistics for our farmer-level controls: *Age, Household size, No formal education*, *Only primary education*, *Land area*, *Land ownership* and *Agriculture primary of income*.

4.3. Summary statistics and balance check

As Table 2a shows, the average village in our sample has about 3,064 people, is 844 hectares in size, has a literacy rate of 63%, has a poverty rate of 18%, has 44% of its residents relying on agriculture as their main source of income, and has 8 hours per day access to electricity. The summary statistics provided in Table 3b yield further insight into the farmer population itself. The average farmer is 42 years old, has a household size of seven, has a 19% likelihood of having primary education or less, works on land area that is 4.74 hectares in area, is likely to own 84% of the land, and has an 88% likelihood of having agriculture as their primary source of income.

[Insert Tables 2a and 2b here]

As our unit of randomization for the field experiment is the village, a balance check is also required at the village level. Comparing averages of the village-level characteristics for the three experimental groups (as reported in Table 2a) suggests that the samples are quite balanced. As a more formal statistical test for the balance check, we also carried out pairwise t-tests for each of the variables for Intervention A as well as Intervention B relative to the base program. We found that the

[11] Table A2 in the supplementary appendix provides fine-grained analysis separately reporting the findings for these two kinds of inorganic fertilizers and also presents additional analysis of use of organic fertilizer (omitted in our main tables and text for brevity). As the notes accompanying Table A2 explain in detail, our main insights remain unchanged.

equality of means could not be rejected in any of the cases at conventional levels (p=0.05), indicating once more that our sample was well balanced and that our randomization had worked as expected.

5. ANALYSIS OF PRIMARY BUSINESS AND ENVIRONMENTAL OUTCOMES

5.1 Univariate analysis

In Figure 4a and 4b, respectively, we depict univariate statistics for the primary business outcomes (*Retention* and *Land allocated*) as well as the two environmental outcomes (*Tillage* and *Inorganic fertilizer*) for the three experimental groups. We start by reporting the results of a post-experiment comparison for all four outcomes, and then present the findings from a difference-in-differences calculation (also summarized in Table 3a) for the three outcomes for which this is feasible.

As panel (i) in Figure 4a shows, the post-experiment mean for *Retention* is not meaningfully different from zero for Intervention A (p=0.68). The corresponding statistic for Intervention B is 6.17 percent points greater than that for the base program (p=0.00), which represents an 8.17% increase. As panel (ii) in Figure 4a similarly shows, the post-experiment mean for *Land Allocated* for Treatment A is again not meaningfully different from that for the base program (p=0.98). The mean for Intervention B is 0.57 hectares greater than that for the base program (p=0.00), which represents a 38% increase. A direct statistical comparison of the impacts of Intervention A and Intervention B further confirms that the latter is significantly stronger (p=0.00).

[Insert Figure 4a here]

Further, as panel (i) in Figure 4b shows, the post-experiment mean for *Tillage* for Treatment A is statistically indistinguishable from that for the base program (p=0.28). The mean for Intervention B is -0.36 lesser than that for the base program (p=0.00), representing an 8.16% decrease. Panel (ii) in Figure 4b similarly shows that the post-experiment mean for *Inorganic fertilizer* for Treatment A is just -4.16 kgs/hectare lesser than that for the base program (p=0.00), while that of Intervention B is -8.77 kgs/hectare lesser than that for the base program (p=0.00). This represents a 3.20% decrease for Intervention A relative to the base program, and a 6.75% decrease for Intervention B relative to the base program. For *Tillage* as well as *Inorganic* fertilizer, a direct comparison of Intervention A and Intervention B confirms that the impact for the latter is again significantly stronger (p=0.00).

[Insert Figure 4b here]

Moving beyond just a post-experiment comparison of outcomes, Table 3a provides a comprehensive difference-in-differences (DID) calculation for three of the four outcomes for which this is feasible: *Land allocated*, *Tillage* and *Inorganic fertilizer*. The DID effect for *Land allocated* for Intervention A is practically indistinguishable from zero (p=0.77), while the same effect for Intervention B is 0.46 hectares (a 30.67% increase over the base program pre-experiment mean; p=0.00). A similar DID calculation for *Tillage* reveals an effect of -0.09 (a 2.02% decrease over the base program pre-experiment mean; p=0.00) for Intervention A, and an effect of -0.39 (an 8.76% decrease over the base program pre-experiment mean; p=00) for Intervention B. Finally, a DID calculation for *Inorganic fertilizer* reveals an effect of -3.67 kg/hectare (a 2.73% decrease over the base program pre-experiment mean; p=0.00) for Intervention A, and an effect of -7.97 kg/hectare (a 5.94% decrease over the base program pre-experiment mean; p=0.00) for Intervention B.

[Insert Table 3a here]

Overall, the above results lead us to the following conclusions. For Intervention B, we see an unambiguous treatment effect for all four primary outcomes. In contrast, for Intervention A, we find some (but weaker) treatment effect for the primary environmental outcomes and no treatment effect for the primary business outcomes. A direct comparison confirms that Intervention B has a greater impact than Intervention A for all four outcomes. For the business outcomes, we therefore have strong support for Hypothesis 2a and 3a but not for Hypothesis 1a. For the environmental outcomes, we likewise have strong support for Hypothesis 2b and 3b but mixed support for Hypothesis 1b. We now turn to multivariate regressions to further validate and dig deeper into these findings.

5.2. Multivariate regression analysis

We carry out our regression analysis at the level of the farmer, as doing so fully uses all available data and improves the precision of the econometric estimation (Angrist & Pischke, 2009).

However, we employ village-level clustering for calculating our standard errors since a conservative approach requires clustering the standard errors at the level at which the randomized treatment takes place (Abadie, Athey, Imbens & Wooldridge, 2023; Bertrand, Duflo, Mullainathan, 2004; Cameron & Miller, 2015; Roth, Sant'Anna, Bilinski & Poe, 2023).

We use two linear model specifications to evaluate the impact of our interventions. The first is a cross-sectional specification that compares just the post-experiment level of the given outcome, which is a simple yet econometrically valid approach given our randomized research design (Glennerster and Takavarasha, 2013; Mian & Sufi, 2014).[12] Our first estimation equation is thus:

$$Y_{v,i} = \alpha + \beta_A A_v + \beta_B B_v + \gamma X_{v,i} + \delta W_v + \tau_{center(v)} + \varepsilon_{v,i} \qquad (1)$$

where v indexes the village, i indexes the farmer within the village, Y represents any of the outcomes, A and B are indicators for Intervention A and Intervention B (always zero for the base program), X is the vector of farmer-level controls (as in Table 2b), W is the vector of village-level controls (as in Table 2a), τ is the center's fixed effect (corresponding to the center the village v belongs to) and ε is the error term. For evaluating the treatment effects, the coefficients of interest are β_A and β_B.

Our second model also includes pre-experiment information to employ a DID approach. Given that we have just two time periods (pre and post), this can be implemented as a cross-sectional model where the dependent variable is the *change in outcome* between the pre-experiment and post-experiment periods (Angrist & Pischke, 2009; Card, 1992).[13] Our second estimation equation is thus:

$$\Delta Y_{v,i} = \alpha + \beta_A A_v + \beta_B B_v + \gamma X_{v,i} + \delta W_v + \tau_{center(v)} + \varepsilon_{v,i} \qquad (2)$$

where ΔY represents the difference between post-experiment and pre-experiment values for the outcome. The coefficients β_A and β_B are now to be interpreted as DID estimates.

Table 3b reports estimates for three of the four primary outcome variables using estimation equation (1) as well as equation (2). The exception is *Retention*, for which only equation (1) can be used as there is no pre-experiment data. While Table 3b shows all our results, for brevity we present

[12] A recent application of this estimation approach in the management literature is Dimitriades & Koning (2022).
[13] See Boulogne, Durand & Flammer, (2023) and Flammer & Ioannou (2021) for recent applications of this approach.

here detailed interpretation for the most preferred yet practical model for each of the outcomes, which is equation (1) for *Retention* and equation (2) for *Land Allocated*, *Tillage*, and *Inorganic Fertilizer*.

As column (1) in Table 3b shows, the coefficient for *Retention* for Intervention A is statistically indistinguishable from zero (p=0.68). The corresponding coefficient for Intervention B is 0.068 (p=0.01), implying that 6.84% more farmers were interested to continue in the program after Intervention B relative to those after the base program. A direct comparison between the impacts of Intervention A and Intervention B further confirms that the latter is significantly stronger (p=0.00).

Column (4), which uses DID estimation equation (2) for *Land allocated*, the estimated effect for Intervention A is practically indistinguishable from zero (p=0.45). The corresponding estimate for Intervention B is 0.48 hectares (p=0.00), indicating that the farmers in Intervention B plan to allocate 0.48 hectares more land to grow Crop X than do farmers in the base program. A comparison between the impacts of Intervention A and Intervention B confirms that the latter is again significantly stronger (p=0.00). These findings are qualitatively similar in column (3), which uses equation (1).

Column (6) reports the DID estimates for our first environmental outcome, *Tillage*. The coefficient for Intervention A is -0.11 (p=0.01), while that for Intervention B is -0.40 (p=0.00). This implies that the farmers in Intervention A reduced tillage count by 0.11 and those in Intervention B reduced it by 0.40 relative to those in the base program. A direct comparison between the impacts of Intervention A and Intervention B again confirms that the latter is much stronger (p=0.00). These finding are qualitatively similar in column (5), which employs equation (1) instead of equation (2).

Finally, as column (8) shows, the estimated DID effect for *Inorganic fertilizer* for Intervention A is -2.79 kgs/hectare (p=0.01), while the same for Intervention B is -8.16 kgs/hectare (p=0.00). This implies that farmers in Intervention A reduced inorganic fertilizer usage by 2.79 kgs/hectare and those in Intervention B reduced it by 8.16 kgs/hectare when compared to farmers in the base program.[14] A direct comparison between the impacts of Intervention A and Intervention B further confirms that the

[14] Table A2 in the supplementary appendix reports further analysis related to how the overall reduction in inorganic fertilizer use arises through a combination of a more efficient use of the both kinds of inorganic fertilizers (urea and DAP) based on the specific soil needs for each farmer and a partial substitution of some inorganic fertilizer use by organic fertilizers that are more climate-friendly and also better for long-term soil health (as explained in Table A1).

latter is significantly stronger (p=0.00). Once more, these findings remain qualitatively similar in column (7), which employs equation (1) instead of equation (2)

[Insert Table 3b here]

Overall, the findings from our multivariate regression are very similar to those from our univariate analysis, except that now Hypothesis 1b also has unambiguous support. In line with our expectations, the null hypothesis is rejected (in the respective preferred models) for Hypotheses 2a, 3a, 1b, 2b and 3b, but it could not be rejected in any of the regression models for Hypothesis 1a. In other words, for Intervention A we observe a clear treatment effect in line with our hypotheses for both of our primary environmental outcomes but neither of our primary business outcomes. In contrast, for Intervention B, we observe a clear treatment effect for both of our primary business outcomes as well as both of our primary environmental outcomes. Further, Intervention B has significantly greater impact than Intervention A for all four of these outcome variables.

6. FURTHER ANALYSIS

Having analyzed the impact of Intervention A and Intervention B relative to the base program in terms of our primary outcomes, we carry out three sets of further investigation. The first brings the cost side of the interventions in order to carry out a more comprehensive cost-benefit analysis. The second extends our analyses beyond our primary outcomes to additional outcomes that shed further light on the various impacts and the mechanisms underlying them. Finally, we present key insights from post-experiment field interviews regarding the farmers' direct experience with our interventions.

6.1. Cost-benefit analysis of the interventions

While our analyses so far demonstrate that both Intervention A and Intervention B were generally more impactful than the base program, and that Intervention B was more impactful than Intervention A, comparing their cost effectiveness requires a more comprehensive cost-benefit analysis. Considering the benefits accruing to the farmer first, Table 4a reports the incremental cost savings per farmer generated by Intervention A as well as Intervention B relative to the base program. In particular, we estimate farmer cost savings from reduced usage of inorganic fertilizers (urea and

DAP), reduced diesel usage due to less land tillage, and a soil testing service that is now provided to the farmer for free. As detailed in Table 4a, this implies that Intervention A generated a total cost saving of 1,035 INR (USD 12.47[15]) per farmer relative to the base program, while Intervention B generated a total cost saving of 1,752 INR (USD 21.12) per farmer relative to the base program.[16]

[Insert Table 4a here]

Table 4b shows the firm's cost-benefit calculation for the GHG emissions reduction achieved in each intervention. On the cost side, the firm's incremental cost for Intervention A relative to the base program is the 700 INR (USD 8.43) it pays for the soil test per farmer. In Intervention B, the firm also incurs the additional cost of expert agronomist visits, which amounts to a total incremental cost per farmer of about 1,300 INR (USD 15.67).[17] In either case, the emissions reduction comes from reduced usage of inorganic fertilizers (urea and DAP) and reduced diesel burning due to reduced tillage. For Intervention A, the incremental emission reduction is 19.67 CO_2-equivalent kgs per farmer, i.e., a reduction of 2.33 kgs per USD spent over and above the base program. For Intervention B, the incremental emission reduction is 52.02 CO_2-equivalent kgs per farmer, i.e., a reduction of 3.32 CO_2-equivalent kgs per USD spent over and above the base program. Put differently, Intervention A costs about USD 429 per ton of CO_2-equivalent emissions (henceforth referred to as tCO_2) reduced, while Intervention B costs about USD 301 per tCO_2 reduced.

[Insert Table 4b here]

With a caveat that the above calculations should be taken as indicative rather than definitive, it is useful to note that the estimated cost of USD 301 per tCO_2 reduction using Intervention B is within the range of social cost of carbon being suggested in many scientific studies (even though cost figures currently in use by policy makers generally lag behind these scientific recommendations). For

[15] All USD figures are meant just to ease interpretation and are based on the Dec 2023 exchange rate of 83 INR/USD.

[16] We should note that these calculations of farmer cost savings are conservative estimates of the overall social impact generated for the farmer. For example, the calculations for either intervention do not capture the time savings for the farmer from reduced tillage or the productivity gain from higher-quality customized advisory provided based on the soil test. In addition, the calculation for Intervention B also does not capture the benefits from expert agronomist advice.

[17] Agronomists have multiple duties and often also travel to the field for reasons unrelated to our interventions. The cost calculation for their cost is therefore sensitive to how the costs are allocated, which in term varies with the opportunity cost of time and travel plans for a given agronomist. Our calculations should therefore be taken as approximate.

example, Rennert et al. (2022) suggest using a preferred estimate of USD 185 per tCO_2, with a 5%-95% range of USD 44 to USD 413 per tCO_2 (depending in part on the discount rate used). Importantly, emissions reductions achieved within a firm's value chain are considered more credible and therefore count towards SBTi-backed science-based "net zero" targets, something that is not allowed if the firm simply chooses to buy cheaper voluntary carbon offsets externally (SBTi, 2023).

To summarize, Intervention B is more cost effective than Intervention A in terms of environmental benefits per dollar invested (Table 4b). Bringing in our earlier finding that Intervention B is also better for social impact on the farmer (Table 4a), Intervention B is clearly better also in terms of overall societal impact per dollar. Additionally bringing in our business-related result that Intervention B is also better for farmer retention (Tables 3a and 3b), there seems to be a strong case for the firm to prioritize scaling up of Intervention B going forward (perhaps after further testing).

6.2. Analysis of additional outcome variables

The analysis so far has been based on just our four primary outcome variables. We now extend this investigation with examination of a range of additional outcomes to help dig further into different aspects of the impacts we observe and possible mechanisms underlying them. Table 5 presents a comparison across our experimental groups for these outcomes, which capture various aspects of farmers' relational engagement with the firm (columns (1) to (5)) as well as their willingness and ability to adopt the climate-friendly practices recommended by the firm (columns (6) and (7)).

Column (1) presents the analysis for the endline survey-based outcome *Willingness to pay for firm provided services*, which measures the farmers' stated willingness to contribute an annual monetary amount for the services received from the firm. Relative to the base program, the estimated treatment effect for Intervention A is 34 INR/annum (p=0.00), while that for Intervention B is more than twice of that at 87 INR/annum, representing an 88.43% increase over the base program (p=0.00).

Unlike the other variables in Table 6, which are derived from the post-experiment endline surveys, column (2) presents analysis based on the outcome *Sold Crop X to other buyers* derived from data that the firm collects at its procurement centers as an indicator for whether a given farmer sold

Crop X also to other sellers or stayed exclusively with the firm. Analysis for this outcome reveals that, relative to the base program, the fraction of farmers who sold to other buyers is practically indistinguishable in Intervention A (p=0.61), while 4% less farmers sold to other buyers in Intervention B (p=0.08). In other words, farmers in Intervention B are more likely than those in the base program to sell exclusively to the firm, but this does not seem to be the case for Intervention A.

Columns (3) through (5) employ three additional outcomes derived from seven-point Likert scale questions in the endline survey in order to capture various aspects of farmer perception of their relationship with the firm. As per column (3), the treatment effect for farmer's *Satisfaction with the program* is 0.72 for Intervention A (p=0.00), while the same effect is 2.17 for Intervention B (p=0.00). Similarly, as per column (4), the treatment effect for *Would recommend program to others* is 0.63 for Intervention A (p=0.00), while the same effect is 1.73 for Intervention B (p=0.00). Finally, as per column (5), the treatment effect for *Perception of firm investment in relationship*, the treatment effect is 0.74 for Intervention A (p=0.00), while the same effect is 1.99 for Intervention B (p=0.00). In all cases, farmer perception of their relationship with the firm is therefore better after Intervention B than after Intervention A, and better after Intervention A than after the base program.

Column (6) is based on the outcome *Willingness to adopt recommended practices* derived from another seven-point Likert scale question in the endline survey. The treatment effect is 0.39 for Intervention A (p=0.00) and 1.89 for Intervention B (p=0.00). Finally, column (7) is based on the outcome *Knowledge test score* derived as a count of the number of benefits from adopting climate-friendly practices that a farmer was able to correctly identify in a question in the endline survey. The treatment effect is 0.59 for Intervention A (p=0.00) and 1.68 for Intervention B (p=0.00). In other words, the farmer's willingness to adopt climate-friendly practices that the firm recommends as well as the farmer's knowledge of the benefits resulting from these practices is greater after Intervention B than after Intervention A, and greater after Intervention A than after the base program.

[Insert Table 5 here]

6.3. Insights from post-experiment field interviews

In order to gain direct understanding of how our interventions were perceived by the farmers, we conducted 40 semi-structured interviews with farmers after the experiment. Each interview lasted about 30-45 minutes. Table 6 provides illustrative quotes from this part of our field work.

[Insert Table 6 here]

Our interviews informed us that the supplier farmers had indeed found the interventions beneficial in line with our expectations as summarized in Figure 2. Several farmers noted that the interventions had led them to reduce the extent of inorganic fertilizer they applied to a more appropriate level, and in the process helped them reduce costs (e.g., interviews [1] and [2] in Table 7). Some also noted that the free soil test they were provided in Intervention A (and Intervention B) had improved their knowledge of soil nutrients (e.g., interview [2] in Table 7). A few specifically mentioned their relationship with the firm as being valuable and the reason for them to be more open to adopting climate-friendly practices that it recommended (e.g., interviews [3] and [4] in Table 7).

Several farmers that had been a subject of Intervention B noted a resulting improvement in their knowledge of climate-friendly as well as general practices, including detailed understanding of soil nutrient management, the implication of these practices on the long-term health of the soil, and appropriate methods for application of different kinds of fertilizers (e.g., interviews [5], [6] and [7] in Table 7). The farmers' perception of a strong relational engagement with the firm also came through particularly strongly in several interviews with farmers from Intervention B. They expressed appreciation for the firm's efforts to build a deep relationship with them and noted how beneficial its support had been, and also stated that as a result they shared a greater trust in the firm and therefore were more open to adopting the practices it recommended (e.g., interviews [7] and [8] in Table 7).

To summarize, our interviews suggest that our findings of the increased inclination of farmers to continue in the program as well as adopt climate-friendly practices were indeed driven by a combination of greater value they derived from the firm-provided support as well as an improvement in their knowledge as a result of the support. On the whole, greater investments from the firm were indeed leading to stronger relational engagement also from the farmers, an effect that seemed to come through more strongly for Intervention B than Intervention A, even in the interviews.

7. DISCUSSION AND CONCLUSION

With increasing global sensitivity towards the climate crisis and the calls for business to do its part towards climate mitigation, businesses are increasingly pursuing decarbonization strategies in their value chains. Achieving these goals requires cooperation with a wide range of stakeholders, yet achieving this cooperation through purely contractual means is often impractical. As a potential solution to help resolve this dilemma specifically in the context of a firm's suppliers, we have proposed making relational investments in suppliers in order to boost their capabilities as well as willingness to help in decarbonization. To test the effectiveness of this approach, we designed a field experiment that randomized the extent of such relational investments by a Fortune 500 firm in its supplier farmers in India. The base program (used as a control group) provided farmers basic training around decarbonization practices, while two other interventions (Intervention A involving greater investment than the base program, and Intervention B involving an even greater investment) involved making relational investments to also address the unmet needs of farmers in terms of advisory even beyond decarbonization practices. The experimental findings revealed that the higher-investment intervention (Intervention B) was especially impactful for improving farmer retention in the program as well as their adoption of the recommended climate-friendly practices, with a cost-benefit analysis revealing that it produced greater benefits than the lower-investment intervention (Intervention A) not just in terms of the absolute level of impact but also in terms of benefits achieved per dollar.

Our study contributes to the conversations in the strategy literature on climate action by providing practical implications for firms pursuing decarbonization strategies for their value chains, and especially those doing so in the understudied context of emerging economies where issues related to social and environmental impact are often tightly intertwined. While a majority of emissions in past decades have arisen from developed markets, emissions growth is coming largely from emerging economies – with China and India alone already comprising 21% of the global GHG emissions as of

2022 (Ritchie, Rosado & Roser, 2023). We highlight that mitigating emerging economy emissions requires an understanding of and sensitivity to contextual uniqueness. Small and low-income suppliers in emerging economies contribute significantly to a sector's global emissions in aggregate, yet often lack both the capabilities and the incentives to participate in firm-led decarbonization efforts in a value chain. For example, in the agriculture sector that we study, the average land per farming household in emerging economies is less than five hectares, yet such smallholder-dominated regions contribute more than half of the global production for several major food crops (Samberg, Gerber, Ramankutty, Herrero & West, 2016). Our study highlights this unique challenge and documents the effectiveness of one possible solution.

Our study can also be seen as an empirical contribution to the growing literature on the New Stakeholder Theory, which "relies primarily on economic and legal arguments that stakeholders will sustain their connection to an organization only if they expect and ultimately receive appropriate returns on their contributions" (McGahan, 2021, p. 1735). In line with the calls in this literature, our study has tried to integrate questions about stakeholder prominence in the firm's value creation and distribution processes (Barney, 2018; Bridoux & Stoelhorst 2014, 2016; Garcia-Castro & Aguilera, 2015; Jones, Harrison & Felps, 2018; Klein, Mahoney, McGahan & Pitelis, 2019; McGahan, 2021), and focused on an empirical examination of important socially relevant dependent variables beyond financial performance (McGahan, 2023). Our work presents evidence on an especially relevant managerial context today – engaging stakeholders in implementing a firms decarbonization goals that extend beyond its firm boundaries.

While relying on a field experiment in the context of a real decarbonization initiative of a major firm makes our study both rigorous and relevant, we should acknowledge some limitations of our study. In line with many prior field experiments involving similar contexts (e.g., in development economics), we tried to overcome data availability challenges by significantly relying on survey-based data collection using pre and post-experiment surveys. While biases due to measurement errors are likely reduced by our randomized design, survey data still have many limitations. Like most experimental studies, our study also faces limits on external generalizability, e.g., in extending insights beyond our specific sector, firm or geography. Also, while the higher-investment intervention performed better than the lower-investment intervention in our specific field experiment, this should not be interpreted as a "more investment is always better" result: there is likely a threshold beyond which further investment would not be cost effective. We can also not rule out that a qualitatively different intervention we did not consider might have produced even greater benefits per dollar. Finally, in terms of mechanisms, we are limited in our ability to disentangle the extent to which our findings reflect a supplier capability enhancement effect versus an incentive alignment effect, since the two were bundled together. While our analyses of additional outcomes as well as post-experiment field work suggest that both of these two mechanisms likely played an important role in producing the overall treatment effects, disentangling these two components of the relationship could be a fruitful direction for future research on how firms can most effectively decarbonize their value chains.

It is tempting to think that society's grand challenges – such as climate change – should be addressed just through stringent policy solutions. For example, textbook solutions often suggest that the best way to tackle global warming is for the governments around the world to coordinate and set a high enough global carbon tax. Practical experience has shown, however, that relying only on policy solutions might in practice lead to progress that is too slow and insufficient. While acknowledging the importance of ensuring that corporate initiatives are not just greenwashing and that corporate action does not crowd out policy solutions, we agree with management scholars who insist that proactive business action has an important role in ensuring adequate societal progress. Firm-driven efforts can often play a pivotal role in helping address collective action problems, sometimes even by driving more effective action in the public interest than can occur through government policy or public institutions (Gatignon & Capron, 2023; Luo & Kaul, 2019). We hope our study motivates further work on how tackling of humanity's grand challenges can be facilitated through decentralized experimentation by firms with the relevant expertise and aspiration to contribute towards addressing problems in line with broader societal goals (Agarwal, Kim & Moeen, 2021).

REFERENCES

Abadie, A., Athey, S., Imbens, G. W., & Wooldridge, J. M. (2023). When should you adjust standard errors for clustering? *The Quarterly Journal of Economics*, 138(1), 1-35.

Abdul Latif Jameel Poverty Action Lab (J-PAL). 2023. Improving agricultural information and extension services to increase small-scale farmer productivity. *J-PAL Policy Insights*.

Adewoyin, A. O., & Ajav, E. A. (2013). Fuel consumption of some tractor models for ploughing operations in the sandy-loam soil of Nigeria at various speeds and ploughing depths. *Agricultural Engineering International: CIGR Journal*, 15(3), 67-74.

Agarwal, R., Kim, S., & Moeen, M. (2021). Leveraging Private enterprise: incubation of new industries to address the public sector's mission-oriented grand challenges. *Strategy Science*, 6(4), 385-411.

Akbarnia, A., & Farhani, F. (2014). Study of fuel consumption in three tillage methods. *Research in Agricultural Engineering*, 60(4), 142-147.

Alidaee, H. (2023). How Uncertainty About Heterogeneity Impacts Technology Adoption. Working Paper.

Angrist, J. D., & Pischke, J. S. (2009). Mostly harmless econometrics: An empiricist's companion. *Princeton University Press*.

Asher, S., Lunt, T., Matsuura, R., & Novosad, P. (2021). Development research at high geographic resolution: an analysis of night-lights, firms, and poverty in India using the shrug open data platform. *The World Bank Economic Review*, 35(4), 845-871.

Baker, G., Gibbons, R., & Murphy, K. J. (2002). Relational Contracts and the Theory of the Firm. *The Quarterly Journal of Economics*, 117(1), 39-84.

Barney, J. B. (2018). Why resource-based theory's model of profit appropriation must incorporate a stakeholder perspective. *Strategic Management Journal*, 39(13), 3305-3325.

Barrett, C. B., Islam, A., Mohammad Malek, A., Pakrashi, D., & Ruthbah, U. (2022). Experimental evidence on adoption and impact of the system of rice intensification. *American Journal of Agricultural Economics*, 104(1), 4-32.

Bertini, M., Buehler, S., Halbheer, D., & Lehmann, D. R. (2022). Carbon Footprinting and Pricing Under Climate Concerns. *Journal of Marketing*, 86(2), 186-201.

Bertrand, M., Duflo, E., & Mullainathan, S. (2004). How much should we trust differences-in-differences estimates? *The Quarterly Journal of Economics*, 119(1), 249-275.

Bhan, S., & Behera, U. K. (2014). Conservation agriculture in India–Problems, prospects and policy issues. *International Soil and Water Conservation Research*, 2(4), 1-12.

Birner, R., & Anderson, J. R. (2007). How to make agricultural extension demand driven? The case of India's agricultural extension policy (Vol. 729). *International Food Policy Research Institute.*

Blanco, C., Caro, F., & Corbett, C. J. (2016). The state of supply chain carbon footprinting: analysis of CDP disclosures by US firms. *Journal of Cleaner Production*, 135, 1189-1197.

Bode, C., & Singh, J. (2018). Taking a hit to save the world? Employee participation in a corporate social initiative. *Strategic Management Journal*, 39(4), 1003-1030.

Boulongne, R., Durand, R., & Flammer, C. (2023). Impact Investing in Disadvantaged Urban Areas. *Strategic Management Journal*, 45(2), 238-271.

Bridoux, F., & Stoelhorst, J. W. (2014). Microfoundations for stakeholder theory: Managing stakeholders with heterogeneous motives. *Strategic Management Journal*, 35(1), 107-125.

Bridoux, F., & Stoelhorst, J. W. (2016). Stakeholder relationships and social welfare: A behavioral theory of contributions to joint value creation. *Academy of Management Review*, 41(2), 229-251.

Burbano, V. C. (2016). Social responsibility messages and worker wage requirements: Field experimental evidence from online labor marketplaces. *Organization Science*, 27(4), 1010-1028.

Cameron, A. C., & Miller, D. L. (2015). A practitioner's guide to cluster-robust inference. *Journal of Human Resources*, 50(2), 317-372.

Carbon Disclosure Project (CDP) (2021). Collaboration is Mission Critical to Successful City Climate Action.

Carbon Disclosure Project (CDP) (2022). Climate Change Questionnaire. Technical Note: Relevance of Scope 3 Categories by Sector.

Card, D. (1992). Using regional variation in wages to measure the effects of the federal minimum wage. *ILR Review*, 46(1), 22-37.

Cole, S. A., & Fernando, A. N. (2021). 'Mobile'izing agricultural advice technology adoption, diffusion and sustainability. *The Economic Journal*, 131(633), 192-219.

Cole, S., & Sharma, G. (2017). The promise and challenges of implementing ICT in Indian agriculture. *India Policy Forum* (pp. 11-12).

Diacono, M., & Montemurro, F. (2011). Long-term effects of organic amendments on soil fertility. *Sustainable Agriculture*, 2, 761-786.

Dimitriadis, S., & Koning, R. (2022). Social skills improve business performance: Evidence from a randomized control trial with entrepreneurs in Togo. *Management Science*, 68(12), 8635-8657.

Dorobantu, S., Kaul, A., & Zelner, B. (2017). Nonmarket strategy research through the lens of new institutional economics: An integrative review and future directions. *Strategic Management Journal*, 38(1), 114-140.

Dorobantu, S., & Odziemkowska, K. (2017). Valuing stakeholder governance: Property rights, community mobilization, and firm value. *Strategic Management Journal*, 38(13), 2682-2703.

Eggelston, H., L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (2006). Guidelines for national greenhouse gas inventories. *IPCC National Greenhouse Gas Inventories Programme*, Hayama, Japan. Volume 4, 475–505.

FAO (2017). Sulaiman, V. R. Enabling advisory services for climate-smart agriculture. Key elements to foster farmers' adoption of CSA practices.

Flammer, C., Toffel, M. W., & Viswanathan, K. (2021). Shareholder activism and firms' voluntary disclosure of climate change risks. *Strategic Management Journal*, 42(10), 1850-1879.

Flammer, C., & Ioannou, I. (2021). Strategic management during the financial crisis: How firms adjust their strategic investments in response to credit market disruptions. *Strategic Management Journal*, 42(7), 1275-1298.

Garcia-Castro, R., & Aguilera, R. V. (2015). Incremental value creation and appropriation in a world with multiple stakeholders. *Strategic Management Journal*, 36(1), 137-147.

Gatignon, A., & Capron, L. (2023). The firm as an architect of polycentric governance: Building open institutional infrastructure in emerging markets. *Strategic Management Journal*, 44(1), 48-85.

George, G., Howard-Grenville, J., Joshi, A., & Tihanyi, L. (2016). Understanding and tackling societal grand challenges through management research. *Academy of Management Journal*, 59(6), 1880-1895.

Gibbons, R., & Henderson, R. (2012). Relational contracts and organizational capabilities. *Organization Science*, 23(5), 1350-1364.

Glendenning, C. J., Babu, S., & Asenso-Okyere, K. (2010). Review of agricultural extension in India: Are farmers' information needs being met? (No. 1048). *International Food Policy Research Institute (IFPRI).*

Glennerster, R., & Jayachandran, S. (2023). Think globally, act globally: opportunities to mitigate greenhouse gas emissions in low-and middle-income countries. *Journal of Economic Perspectives*, 37(3), 111-135.

Glennerster, R., & Takavarasha, K. (2013). *Running Randomized Evaluations: A Practical Guide*. Princeton University Press.

Hardy, J., & Sandys, L. (2022). Anticipating customer-centred zero-carbon energy business models. *Nature Energy*, 7(5), 383-385.

Henderson, R., & Serafeim, G. (2020). Tackling climate change requires organizational purpose. *AEA Papers and Proceedings*, 110, 177-80.

Henisz, W. J., Dorobantu, S., & Nartey, L. J. (2014). Spinning gold: The financial returns to stakeholder engagement. *Strategic Management Journal*, 35(12), 1727-1748.

Howard-Grenville, J., Buckle, S. J., Hoskins, B. J., & George, G. (2014). Climate change and management. *Academy of Management Journal*, 57(3), 615-623.

Hsu, A., & Rauber, R. (2021). Diverse climate actors show limited coordination in a large-scale text analysis of strategy documents. *Communications Earth & Environment*, 2(1), 1-12.

IPCC (2022). *Summary for Policymakers*. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3-33.

Islam, M., & Beg, S. (2021). Rule-of-thumb instructions to improve fertilizer management: Experimental evidence from Bangladesh. *Economic Development and Cultural Change*, 70(1), 237-281.

Jack, B. (2013). Market inefficiencies and the adoption of agricultural technologies in developing countries. UC Berkeley: Center for Effective Global Action.

Jack, B. K., & Jayachandran, S. (2019). Self-selection into payments for ecosystem services programs. *Proceedings of the National Academy of Sciences*, 116(12), 5326-5333.

Jack, B. K., Jayachandran, S., Kala, N., & Pande, R. (2022). Money (Not) to Burn: Payments for Ecosystem Services to Reduce Crop Residue Burning. NBER Working Paper 30690.

Jayachandran, S. (2023). The inherent trade-off between the environmental and anti-poverty goals of payments for ecosystem services. *Environmental Research Letters*, 18(2), 025003.

Jira, C., & Toffel, M. W. (2013). Engaging supply chains in climate change. *Manufacturing & Service Operations Management*, 15(4), 559-577.

Jones, T. M., Harrison, J. S., & Felps, W. (2018). How applying instrumental stakeholder theory can provide sustainable competitive advantage. *Academy of Management Review*, 43: 371–391.

Klein, P. G., Mahoney, J. T., McGahan, A. M., & Pitelis, C. N. (2012). Who is in charge? A property rights perspective on stakeholder governance. *Strategic Organization*, 10(3), 304-315.

Klein, P. G., Mahoney, J. T., McGahan, A. M., & Pitelis, C. N. (2019). Organizational governance adaptation: Who is in, who is out, and who gets what. *Academy of Management Review*, 44(1), 6-27.

Koh, S. L., Jia, F., Gong, Y., Zheng, X., & Dolgui, A. (2023). Achieving carbon neutrality via supply chain management: position paper and editorial for IJPR special issue. *International Journal of Production Research*, 61(18), 6081-6092.

Lal, R., Monger, C., Nave, L., & Smith, P. (2021). The role of soil in regulation of climate. *Philosophical Transactions of the Royal Society* B, 376(1834), 20210084.

Levine, S. S., Schilke, O., Kacperczyk, O., & Zucker, L. G. (2023). Primer for Experimental Methods in Organization Theory. *Organization Science*, 34(6), 1997-2025.

Lumpkin, G. T., & Bacq, S. (2019). Civic wealth creation: A new view of stakeholder engagement and societal impact. *Academy of Management Perspectives*, 33(4), 383-404.

Luo, J., & Kaul, A. (2019). Private action in public interest: The comparative governance of social issues. *Strategic Management Journal*, 40(4), 476-502.

Mangalassery, S., Sjögersten, S., Sparkes, D. L., Sturrock, C. J., Craigon, J., & Mooney, S. J. (2014). To what extent can zero tillage lead to a reduction in greenhouse gas emissions from temperate soils? *Scientific Reports*, 4(1), 4586.

Marquis, C., & Raynard, M. (2015). Institutional strategies in emerging markets. *The Academy of Management Annals*, 9(1), 291-335.

McGahan, A. M. (2021). Integrating insights from the resource-based view of the firm into the new stakeholder theory. *Journal of Management*, 47(7), 1734-1756.

McGahan, A. M. (2023). The new stakeholder theory on organizational purpose. *Strategy Science*, 8(2), 245-255.

McGahan, A. M., & Pongeluppe, L. S. (2023). There is no planet B: Aligning stakeholder interests to preserve the Amazon rainforest. *Management Science*, 69(12), 7860-7881.

Menegat, S., Ledo, A., & Tirado, R. (2022). Greenhouse gas emissions from global production and use of nitrogen synthetic fertilisers in agriculture. *Scientific Reports*, 12(1), 14490.

Mian, A., & Sufi, A. (2014). What explains the 2007-2009 drop in employment? *Econometrica*, 82(6), 2197–2223.

Reid, E. M., & Toffel, M. W. (2009). Responding to public and private politics: Corporate disclosure of climate change strategies. *Strategic Management Journal*, 30(11), 1157-1178.

Rennert, K., Errickson, F., Prest, B. C., Rennels, L., Newell, R. G., Pizer, W., ... & Anthoff, D. (2022). Comprehensive evidence implies a higher social cost of CO_2. *Nature*, 610(7933), 687-692.

Richardson, K., Steffen, W., Lucht, W., Bendtsen, J., Cornell, S. E., Donges, J. F., ... & Rockström, J. (2023). Earth beyond six of nine planetary boundaries. *Science Advances*, 9(37), eadh2458.

Ritchie, H., Rosado, P., and Roser, M. (2023). CO_2 and Greenhouse Gas Emissions. Published online at OurWorldInData.org.

Rivera, A., Movalia, S., Pit, H., & Larsen, K. (2022). Global Greenhouse Gas Emissions: 1990-2020 and Preliminary 2021 Estimates. Rhodium Group, 19.

Rockström, J., Gaffney, O., Rogelj, J., Meinshausen, M., Nakicenovic, N., & Schellnhuber, H. J. (2017). A roadmap for rapid decarbonization. *Science,* 355(6331), 1269-1271.

Roth, J., Sant'Anna, P. H., Bilinski, A., & Poe, J. (2023). What's trending in difference-in-differences? A synthesis of the recent econometrics literature. *Journal of Econometrics*.

Samberg, L. H., Gerber, J. S., Ramankutty, N., Herrero, M., & West, P. C. (2016). Subnational distribution of average farm size and smallholder contributions to global food production. *Environmental Research Letters*, 11(12), 124010.

Samii, C., Lisiecki, M., Kulkarni, P., Paler, L., Chavis, L., Snilstveit, B., ... & Gallagher, E. (2014). Effects of payment for environmental services (PES) on deforestation and poverty in low and middle income countries: a systematic review. *Campbell Systematic Reviews*, 10(1), 1-95.

Science Based Targets Initiative (SBTi) (2023). Net-Zero Standard.

Shrimali, R. (2022). Contract farming, capital and state: Corporatisation of Indian agriculture. Palgrave Macmillan, Singapore.

Steenbergen, V., & Saurav, A. (2023). The Effect of Multinational Enterprises on Climate Change: Supply Chain Emissions, Green Technology Transfers, and Corporate Commitments. World Bank Publications.

Stenzel, A., & Waichman, I. (2023). Supply-chain data sharing for scope 3 emissions. *npj Climate Action*, 2(1), 7.

Stylianou, M., Papamichael, I., Voukkali, I., Tsangas, M., Omirou, M., Ioannides, I. M., & Zorpas, A. A. (2023). LCA of Production: A Case Study from Cyprus. *International Journal of Environmental Research and Public Health*, 20(3), 2417.

Suri, T. (2011). Selection and comparative advantage in technology adoption. *Econometrica*, 79(1), 159-209.

Teodorovicz, T., Lazzarini, S., Cabral, S., & McGahan, A. M. (2023). Investing in general human capital as a relational strategy: Evidence on flexible arrangements with contract workers. *Strategic Management Journal*, 1–37.

The Wall Street Journal. (2021). Hutcheon, M. Consumers Expect Brands to Address Climate Change.

Tidy, M., Wang, X., & Hall, M. (2016). The role of Supplier Relationship Management in reducing Greenhouse Gas emissions from food supply chains: supplier engagement in the UK supermarket sector. *Journal of Cleaner Production*, 112, 3294-3305.

TIME (2022). Planet Earth's Future Now Rests in the Hands of Big Business.

Tubiello, F. N., Karl, K., Flammini, A., Gütschow, J., Obli-Laryea, G., Conchedda, G., ... & Torero, M. (2022). Pre-and post-production processes increasingly dominate greenhouse gas emissions from agri-food systems. *Earth System Science Data*, 14(4).

United Nations Environment Programme (2023). Emissions Gap Report 2023: Broken Record – Temperatures hit new highs, yet world fails to cut emissions (again).

Verbeke, A. (2021). The long-term energy transition and multinational enterprise complexity: A BJM–JIBS Joint Initiative. *Journal of International Business Studies*, 52(5), 803-806.

World Resources Institute (WRI) (2022). Trends show companies are ready for Scope 3 reporting with US Climate Disclosure Rule.

World Resources Institute (WRI) (2023). World Greenhouse Gas Emissions in 2020. *Climate Watch*.

Table 1: Illustrative quotes from pre-experiment field interviews

The farmers' experience with the firm's original program	
[1]	"When <Field Officer> first visited and checked my field and told me I should water my <Crop X> only certain fixed times during the season, I did not believe him...But I listened to his advice over the years because he has studied on these matters plus, he was traveling this distance, to visit and inspect my field 4-5 times during the season and only then give advice. That has saved me so much water, not to mention better yield and quality over the years now." (Farmer #10)
[2]	"I had grown <Crop X> a few times before but did not get good yield, also when I sold at the mandi (center) buyers never worried much about quality. Prices were not great as it was volume selling. But since I became a [program] member I got guidance on when to sow, how to prepare land, how much seed to use, when to water, even right time to harvest and especially advice on pest problems on time at critical <Crop X> growing stage, when <Field Officer> comes and visits…Now the yield and quality of <Crop X> has improved a lot…Last year another company offered to buy my <Crop X> because of good quality but I did not sell to them, I sold to the <Firm> because it was their advice that helped me and they gave good price too." (Farmer #05)
[3]	"The company cannot benefit unless we farmers benefit - it's a relationship where we walk together. The company is good at understanding this so helps its member farmers to grow better <Crop X> and also keep costs low by using less seeds, water…The advice they give is useful…sometimes I ask <Field Officer> to check my other crops in the neighboring fields when he comes for visit but his focus is the <Crop X>…Some companies these days offer advice on phones but how will they know what my agricultural problems are unless I have shown them on my field." (Farmer #17)
The farmer's needs unmet by the firm's original program	
[4]	"Agriculture takes many years of experience to get it right. I have been doing this for more than 45 years and still learn new things sometimes…Every field is different, my farm is different from my neighbor's and from my brother's – nature of soil is different, water flow is different…Agricultural advice is only useful if you tell things specific to my field and soil conditions. Otherwise, the government also gives lots of common advice, sometimes on radio and sometimes in village meetings…What is true in textbooks does not work in the field; unless you visit my field, see and touch my crops, check my soil, then that advice is useful for me. Otherwise, it's just a friendly chat over a cup of tea but no good for agricultural activities." (Farmer #06)
[5]	"The government extension officer took my soil sample last year, but I never got a report back telling me what they found. It [the service] was no good…it would only help if someone can bring the report and explain to me what I should do, what does my soil need, to produce good crops…I studied only till class 5. When I was born it was usual for farmer to start helping on farms and not waste time in school. I have seen a relative's soil test report, but we don't understand how to use it." (Farmer #03)
[6]	"Last few years it's not been easy to be a farmer – the weather changes suddenly often bringing rains when it's bad for crops. Last year my neighbor lost one entire crop because of badly timed rain. And pests are a big issue. These days we see new types of pests on crops, and we don't always know what to do...I learnt farming from my father and he from his. But they had not seen these problems then." (Farmer #02)
[7]	"New things are always coming up – new tools, new farming techniques, and the seasons are unpredictable but worst of all new pests and insects keep coming…So agricultural advice is useful especially as I don't meet the government's district extension officer many times in a year…In the past the <Firm> once brought knowledgeable doctors [agronomy experts] from <Agricultural Institution> who visited my village, came to my field and told me many useful things about how to do better agriculture…he was not trying to sell me anything so I trust his advice….I showed him all my growing crops and he checked the growth and recommended good fertilizer practice that would work for my farm and the crops I was growing…getting good knowledge on all my crops from somewhere trustworthy is important for the advice to be useful." (Farmer #14)
[8]	"When my field officers conduct field visits, farmers often request them to look at their other crops growing at the same time as <Crop X> on their other plots. But our field officers are not trained with knowledge of wide range of crops beyond <Crop X> matters as knowing about multiple other crops requires significant training, knowledge and experience. We are careful to not give farmers wrong advice, so we ask field officers not to discuss matters beyond the <Crop X>…On many occasions they have asked the field officers either for advice or requested them to ask the firm to provide advisory on other crops. We know and understand that farmers lack systematic access to scientific practices, newer agricultural technologies and need more support to increase their productivity without damaging their soil in the long term." (Regional manager #1)
The farmers' attitude towards adoption of climate-friendly practices	
[9]	"One must always respect the environment, but I have to sustain myself too…It is always good for me to know good practices that don't harm the environment, but you must first explain how it relates to my land and soil… I must think about the effects and how it will affect my income today or tomorrow…Farming is my primary family income so I can't change everything overnight and suffer large productivity loss…first <Firm> must check and advise how it will affect my land and crops." (Farmer #04)

Table 2a. Village-level summary statistics (and balance check)

Village Level Variables	**Description**	**Base Program**	**Intervention Group A**	**Intervention Group B**	**Full Sample**
Total population	Village level population based on Govt. of India's 2011 census data	3,379.73 (3,806.62)	3,056.79 (3,696.86)	2,723.33 (3,230.86)	3,064.19 (3,595.41)
Village area	Total area of village in hectares based on Govt. of India's 2011 census data	908.49 (704.69)	844.46 (527.97)	771.91 (521.11)	843.53 (594.90)
Literacy rate	Share of total population that is literate (had some schooling and can read and write with some understanding) based on Govt. of India's 2011 census data	0.63 (0.06)	0.62 (0.06)	0.63 (0.06)	0.63 (0.06)
Rural poverty rate	Share of total population below 31 INR poverty line based on Govt. of India's 2012 SECC data	0.17 (0.12)	0.18 (0.13)	0.17 (0.12)	0.18 (0.12)
Agriculture main income	Share of the total population with agriculture as the main source of income, based on Govt. of India's 2012 SECC data and 2011 census data	0.44 (0.21)	0.45 (0.19)	0.44 (0.20)	0.44 (0.20)
Daily hours power	Daily hours of power for all types of uses (average of daily summer and winter hours of power) based on Govt. of India's 2011 census data	17.33 (4.59)	17.47 (4.76)	18.25 (5.67)	17.67 (5.02)
Night light	DMSP-OLS based on 2013 satellite data that gives annual measures of night light luminosity	119.57 (104.23)	119.68 (108.83)	111.85 (94.23)	117.17 (102.54)
Number of villages		**127**	**120**	**115**	**362**

Notes. Standard deviations in parentheses. This table has been generated using village-level socioeconomic census data from Asher et al (2021). Villages for which a particular variable's value was missing (about 3% of the cases on average) were excluded in calculating its mean. As a formal statistical test for the balance check, we also carried out pairwise t-tests for each of the variables for Intervention A as well as Intervention B relative to the base program (our control group). Among the 14 t-tests following this procedure (7 variables x 2 pairs of groups), the equality of means could not be rejected in any of the cases at p=0.05, indicating that the sample was well balanced and that the randomization worked as expected.

Table 2b. Farmer-level summary statistics

Farmer Level Variables	Description	Base Program	Intervention Group A	Intervention Group B	Full Sample
Age	Age of the farmer in years pre-experiment	41.73 (8.13)	41.76 (7.77)	42.90 (8.79)	42.08 (8.22)
Household size	Total members in the farmer's household pre-experiment	7.10 (2.70)	6.88 (2.61)	7.22 (2.61)	7.05 (2.64)
No formal education	Indicator variable for whether the farmer completed any formal schooling	0.05 (0.21)	0.10 (0.30)	0.05 (0.23)	0.07 (0.25)
Only primary education	Indicator variable indicating whether the farmer completed primary education (Class 1-5)	0.10 (0.31)	0.12 (0.33)	0.12 (0.33)	0.12 (0.32)
Land area	Total land in hectares used by the farmer for all agricultural purposes	4.48 (3.26)	4.88 (3.78)	4.88 (4.70)	4.74 (3.92)
Land ownership	Fraction of the farmer's agricultural land that is fully owned by them	0.84 (0.24)	0.84 (0.24)	0.84 (0.25)	0.84 (0.24)
Agriculture primary source of income	Indicator variable for whether agriculture is the primary source of income for the farmer's household	0.86 (0.35)	0.90 (0.30)	0.88 (0.32)	0.88 (0.33)
Number of farmers		**914**	**926**	**765**	**2,605**

Notes. Standard deviations in parentheses. This table has been generated using our baseline data collection just before the experiment. Instances in which a particular variable was missing for a farmer (only 4 cases) were excluded in calculating the means.

Table 3a. Summary statistics for the primary outcomes

	Primary Business Outcomes								Primary Environmental Outcomes							
	Retention (indicator)				*Land allocated* (hectares)				*Tillage* (count)				*Inorganic fertilizer* (kg/hectare)			
	Pre	Post	First Difference	DID	Pre	Post	First Difference	DID	Pre	Post	First Difference	DID	Pre	Post	First Difference	DID
Base Program (Control Group)	-	0.84 (0.012)	-	-	1.50 (0.046)	1.47 (0.047)	-0.03 (0.050)	-	4.45 (0.036)	4.41 (0.036)	-0.04** (0.016)	-	134.25 (0.716)	129.91 (0.752)	-4.30*** (0.399)	-
Intervention A (Lower investment)	-	0.85 (0.012)	-	-	1.53 (0.048)	1.47 (0.052)	-0.05 (0.045)	-0.02 (0.067)	4.61 (0.038)	4.47 (0.038)	-0.13*** (0.020)	-0.09*** (0.026)	133.83 (0.731)	125.75 (0.757)	-7.97*** (0.525)	-3.67*** (0.661)
Intervention B (Higher investment)	-	0.91*** (0.010)	-	-	1.60 (0.066)	2.04 (0.069)	0.43*** (0.065)	0.46*** (0.081)	4.48 (0.039)	4.05 (0.043)	-0.43*** (0.033)	-0.39*** (0.035)	133.49 (0.782)	121.14 (0.826)	-12.27*** (0.631)	-7.97*** (0.724)

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Notes: Standard errors are show in parentheses. For three of the four primary outcomes, *Land allocated*, *Tillage* and *Inorganic fertilizer*, the DID statistics are reported for Intervention A as well as Intervention B relative to the base program (the control group). For the fourth primary outcome, *Retention*, the pre-experiment, first difference and DID statistics cannot be calculated as it was only measured post-experiment.

Table 3b. Regression analysis for the primary outcomes

	(1) *Retention* (Post)	(2) *Δ Retention* (Post – Pre)	(3) *Land Allocated* (Post)	(4) *Δ Land Allocated* (Post – Pre)	(5) *Tillage* (Post)	(6) *Δ Tillage* (Post – Pre)	(7) *Inorganic Fertilizer* (Post)	(8) *Δ Inorganic Fertilizer* (Post – Pre)
Intervention A	0.00999	-	-0.0770	-0.0674	-0.103	-0.108***	-4.143**	-2.794**
	(0.0244)	-	(0.0858)	(0.0896)	(0.0819)	(0.0402)	(1.793)	(1.106)
Intervention B	0.0684***	-	0.442***	0.484***	-0.496***	-0.403***	-10.06***	-8.158***
	(0.0244)	-	(0.102)	(0.110)	(0.0883)	(0.0629)	(1.911)	(1.134)
Constant	0.852***	-	0.262	0.535	4.387***	-0.203	122.6***	-7.573
	(0.178)	-	(0.856)	(0.986)	(0.657)	(0.480)	(15.93)	(8.591)
Observations	2,416	2,416	2,416	2,416	2,416	2,416	2,416	2,416
Farmer and village level controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Center FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Notes: Robust standard errors clustered at the village level (the unit of randomization) are reported in parentheses. The sample size used here is 2,416 farmers instead of 2,605 farmers (in our original sample) due to two reasons for why a total of 189 observations (7% of the original sample) get dropped. First, 24 farmers could not be surveyed post-experiment due to their unavailability (although there is no statistical difference in attrition across the experimental groups). Second, there were missing values for one or more of the control variables in 165 cases (although the findings remain very similar if we simply exclude control variables with missing observations in order to use a more complete sample).

Table 4a: Farmer cost savings in Intervention A and Intervention B (versus the base program)

	Intervention A	Intervention B	Data source, assumptions and additional comments
Reduction in urea used per hectare of land (kgs)	3.12	6.70	Treatment effects (relative to the base program) as calculated based on farmer-reported data as per the pre-experiment and post-experiment surveys.
Reduction in urea used for the average farmer (kgs)	4.80	10.32	Quantity of reduced usage per farmer over average plot size of 1.54 hectare.
Cost saving from reduction in urea use for the average farmer (INR)	*29.90*	*64.20*	Calculated using price of one bag of urea as 280 INR and size of one bag as 45 kgs.
Reduction in DAP used per hectare of land (kgs)	4.22	9.24	Treatment effects (relative to the base program) as calculated based on farmer-reported data as per the pre-experiment and post-experiment surveys.
Reduction in DAP used for the average farmer (kgs)	6.50	14.23	Quantity of reduced usage per farmer over average plot size of 1.54 hectare.
Cost saving from reduction in DAP use for the average farmer (INR)	*155.97*	*341.51*	Calculated using price of one bag of DAP as 1200 INR and size of one bag as 50 kgs.
Reduction in tillage carried out by the average farmer (count)	0.09	0.39	Treatment effects (relative to the base program) as calculated based on farmer-reported data as per the pre-experiment and post-experiment surveys.
Cost saving from reduction in tillage for the average farmer (INR)	*149.06*	*645.91*	Cost saving resulting from reduced diesel use from reduced tillage for the average plot size of 1.54 hectare. Calculated using diesel price of 90 INR/liter and assuming diesel burning averted per hectare of 12 liters (https://www.farmingforabetterclimate.org/wp-content/uploads/2023/04/Practical-Guide-Optimising-Tractor-Fuel-Use-2022.pdf) (Adewoyin & Ajav, 2013).
Cost saving from the soil testing service for the average farmer (INR)	*700.00*	*700.00*	This was a conservative estimate based on the firm's internal cost for providing a soil test to the farmer. If the farmer were to procure the soil testing service externally, it would likely cost more than 700 INR, but it was provided to the farmer for free in both intervention A and intervention B.
Total incremental cost saving for the average farmer (INR)	***1,035***	***1,752***	Sum total of the four kinds of cost savings listed above for the two interventions relative to the base program: those from reduced usage of two kinds of inorganic fertilizers (urea and DAP), those from reduced tillage, and those from the free soil test service the firm provided.

Notes: This table documents the benefits accruing to the farmers in the form of different kinds of cost savings that the average farmer in Intervention A or Intervention B achieves relative to the base program. The calculation reveals that Intervention A generated 1,035 INR (USD 12.47) in cost savings for the average farmer, while Intervention B generated 1,752 INR (USD 21.12) in cost savings for the average farmer.

Table 4b: GHG emission reduction per dollar invested in Intervention A or Intervention B (versus the base program)

	Intervention A	Intervention B	Data source, assumptions and additional comments
Reduction in urea used for the average farmer (kgs)	4.80	10.32	See Table 4a.
GHG emission saving from reduction in urea use per farmer (CO_2-equivalent kgs)	*7.55*	*16.21*	This calculation has two components. The first component is reduction in nitrous oxide emissions, which is calculated by taking nitrogen content in urea as 46%, the emission factor of nitrogen (i.e., fraction at risk of leaking from inorganic fertilizers) as 0.01 (Eggelston et al., 2006; https://www.epa.gov/air-emissions-factors-and-quantification/basic-information-air-emissions-factors-and-quantification), and CO_2 equivalence of nitrous oxide (i.e., global warming impact relative to CO_2 on a per kilogram basis) as 298 (https://climatechangeconnection.org/emissions/CO2-equivalents/). The second component is CO_2 emissions savings calculated using CO_2 emission factor of 20% (Islam & Beg, 2021).
Reduction in DAP used for the average farmer (kgs)	6.50	14.23	See Table 4a.
GHG emission saving from reduction in DAP use per farmer (CO_2-equivalent kgs)	*7.80*	*17.08*	This calculation is analogous to that described for urea above, except that the nitrogen content in DAP is 18%.
Reduction in tillage carried out by the average farmer (count)	0.09	0.39	See Table 4a.
GHG emission saving from reduction in tillage per farmer (CO_2-equivalent kgs)	*4.32*	*18.74*	Calculated by taking average diesel burning averted per hectare as 12 liters and weight of CO_2 generated per liter of diesel as 2.6 kgs (https://www.farmingforabetterclimate.org/wp-content/uploads/2023/04/Practical-Guide-Optimising-Tractor-Fuel-Use-2022.pdf) (Adewoyin & Ajav, 2013)
Total incremental GHG emissions reduction per farmer (CO_2-equivalent kgs)	***19.67***	***52.02***	Sum total of the three kinds of GHG emission savings listed above for the two interventions relative to the base program: those from reduced usage of two kinds of inorganic fertilizers (urea and DAP) and those from reduced tillage.
Cost to firm for providing free soil testing per farmer (INR)	*700.00*	*700.00*	Providing the soil test costs 700 INR per farmer as per the firm's records, but the farmer was provided this service for free in both intervention A and intervention B.
Cost to firm for the agronomist support per farmer (INR)		*600.00*	Assumes a cost allocation of 400 INR from salary and 200 INR from travel expenses per farmer visit by the agronomist.
Total incremental cost to firm per farmer (INR)	***700.00***	***1,300.00***	Sum total of the four kinds of cost savings listed above for the two interventions relative to the base program: those from reduced usage of two kinds of inorganic fertilizers (urea and DAP), those from reduced tillage, and those from the free soil test service the firm provided.
Total incremental GHG emissions reduction per unit cost (CO_2-equivalent kgs per INR)	***0.028***	***0.040***	
Total incremental GHG emissions reduction per unit cost (CO_2-equivalent kgs per dollar)	*2.33*	*3.32*	This calculation uses the Dec 2023 exchange rate of approximately 83 INR/USD.
Effective cost of achieving GHG emission reduction (dollars per CO_2-equivalent tons)	***429***	***301***	

Notes: This table documents three kinds of value chain emissions reduction that are achieved in Intervention A as well as Intervention B. For Intervention A, the incremental GHG emission reduction relative to the base program was 19.67 CO_2-equivalent kgs per farmer and the incremental cost was 700 INR (USD 8.43) per farmer, implying an emissions reduction of 0.028 kgs per INR incrementally spent on Intervention A. For Intervention B, the incremental GHG emission reduction relative to the base program was 52.02 CO_2-equivalent kgs per farmer and the incremental cost was 1,300 INR (USD 15.67) per farmer, leading to a GHG emission reduction of 0.040 kgs per INR incrementally spent on this intervention.

Table 5: Regression analysis for additional outcomes of interest

	(1) *Willingness to pay for firm provided services* (INR/annum)	(2) *Sold Crop X to other buyers* (indicator variable)	(3) *Satisfaction with the program* (rating 1-7 scale)	(4) *Would recommend program to others* (rating 1-7)	(5) *Perception of firm investment in relationship* (rating 1-7)	(6) *Willingness to adopt recommended practices* (rating 1-7)	(7) *Knowledge test score (0-4)*
Intervention A	33.70***	0.0120	0.717***	0.628***	0.740***	0.396***	0.590***
	(3.841)	(0.0234)	(0.115)	(0.0822)	(0.109)	(0.108)	(0.0679)
Intervention B	86.86***	-0.0408*	2.168***	1.726***	1.985***	1.897***	1.677***
	(4.581)	(0.0229)	(0.128)	(0.109)	(0.105)	(0.108)	(0.0725)
Constant	98.22***	-0.0189	4.904***	4.041***	4.173***	3.750***	1.409***
	(35.13)	(0.194)	(0.947)	(0.782)	(0.776)	(1.125)	(0.501)
Observations	2416	2439	2416	2416	2416	2416	2416
Farmer and village level controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Center FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Notes: Robust standard errors clustered at the village level (the unit of randomization) are reported in parentheses. *Willingness to pay for firm provided services* was measured using an endline survey question that asked respondents to state an annual monetary fees (in INR) they would be willing to pay for the services they received through the program (the lowest choice being "50 INR or less" and the highest being "250 INR per annum" given the range of values that the firm considered as possible options for the future). *Sold Crop X to other buyers* was an indicator variable defined using our partner firm's proprietary data that captured whether or not a given farmer sold part of their Crop X produce to other buyers beside the firm. *Satisfaction with the program rating* was a 1-7 Likert scale variable constructed using the endline survey to capture how satisfied a farmer was with the firm's program (1 being not satisfied at all and 7 being very satisfied). *Would recommend program to others* was a 1-7 Likert scale variable constructed using the endline survey to capture how likely a farmer would be to recommend the firm's program to other farmers (1 being not likely at all and 7 being very likely). *Perception of firm investment in relationship* is a 1-7 Likert scale variable constructed using the endline survey to capture the extent to which a farmer thought the firm had invested in building a relationship with them (1 being did not invest at all and 7 being invested a lot). *Willingness to adopt firm recommended practices* was a 1-7 Likert scale variable constructed using the endline survey to capture how willing a farmer would be to adopt climate-friendly practices recommended by the firm (1 being not willing at all and 7 being very willing). *Knowledge test score* was a 0-4 scale variable captured using the endline survey by counting the number of climate-friendly practices (among a list of four) that the farmer understood the environmental benefits for.

Table 6: Illustrative quotes from post-experiment field interviews

The farmers' experience with the firm's program following Intervention A	
[1]	"Productivity and quality of my <Crop X> has improved a lot. The soil test report this year in particular helped me add to my soil the required balanced nutrients and add fertilizers in appropriate quantities...My knowledge of <Crop X> improved and I am more aware of climate friendly practices...The added facilities from the company are very helpful as I was able to reduce fertilizer costs...Through the <Field Officer> the company has built good relations but I will hesitate to adopt practices if it reduces my crop productivity by a large amount...May be I will adopt for a year on a trial basis because of the good relations with the company..." (Farmer #16)
[2]	"The <Field Officer's> visits are planned for critical crop growing stages. This year he also got my soil sample as the company offered the soil testing service for free. As a result the <Field Officer> was able to show me what my soil was lacking and also his advice for <Crop X> was more relevant, tailored for my soil conditions...I also added more farm yard manure (organic fertilizer) to the soil based on the soil test report and <Field Officer's> advice...<Crop X> productivity was the best this year compared to other crops and I am always assured that I will get the best price from the <Firm> compared to other buyers in the market." (Farmer #20)
[3]	"I will try and consider adopting the climate-friendly practices that the company recommends. Their advice based on the soil report is useful but for me the trust I have on the <Firm> because of the relationship built by the field staff - that is more fundamental." (Farmer #21)
[4]	"The <Field Officer's> advice on the quantity of <Crop X> seed required to be applied for my fields has saved me both cost of seed purchased as well as quality because of how I was able to manage soil nutrients. I have seen the result myself as well as the regularity of the support I have received. I feel assured that the company cares about farmers and I am more open to the climate friendly practices they recommended..." (Farmer #22)
The farmers' experience with the firm's program following Intervention B	
[5]	"This time <Agronomist> came and advised me on my agricultural matters - I have faith in what they say. If any person from a company, I am not familiar with turns up and offers advice for my agricultural matters I would suspect the information he provides whereas I now readily listen to <Field Officer> or <Agronomist> advice as I know the company has built a good relationship with us over time that has proven to be beneficial for us in the past. I value that the company invested in sending knowledgeable, trained and expert staff to visit us and trust their advice reliably much more than any advice I would receive from my peers or neighbors." (Farmer #03)
[6]	"The <Agronomist's> visit was especially helpful. I was able to ask questions to understand my soil's nutrients and its health in more details such as nitrogen, magnesium and zinc content. I no longer had to guess work how much fertilizers I need to add, and I saved costs by adding the appropriate quantity of fertilizer for productivity. The company's initiative to not only provide soil testing service but also send the <Agronomist> to provide us information and advice showed it wants to invest in us farmers...I also reduced tillage because the <Agronomist> advised that excess tillage does not benefit productivity but increases cost and harms my soil in the long term...I trust his advice and adopted reduced tillage even though I have been practicing higher tillage since I started farming." (Farmer #01)
[7]	"I reduced tillage and also started using farmyard manure (organic fertilizer) according to proper methods. I was not aware before that higher tillage harms the soil nor did anyone point out the appropriate method for adding organic inputs...The <Agronomist> visit gave me the opportunity to ask about these things in detail. But just knowledge and awareness is not enough. I have to be sure that the advisory comes from a trustworthy source...The company has been providing good seeds and <Crop X> sale price last few years and now I trust the <Firm's> staff completely...Unlike other <Competitor firm> who only sends its officers to sell their seeds for its own profit without ongoing support for or investing in farmers and the relationship, <Field Officer> and <Agronomist> have provided so much support that there is a strong relationship - I can rely on any advice they give as the <Firm> provided support has benefitted before..." (Farmer #04)
[8]	"Every year for the past few years the <Firm> has been providing continuous support for <Crop X>. I have seen the ongoing commitment to building this relationship with farmers. This year I received additional support from <Field Officer> and <Agronomist>...The support is timely and reliable and I do not hesitate to take up their advice because in my experience the company wants to profit but by creating more benefit for farmers...The company recommends various practices because it wants farmers to be more productive...The <Agronomist> visit was not targeted at just <Crop X> but also for other crops, so the company is not focusing on just its own <Crop X> profits but also on things that will benefit the farmer in the long term for the ongoing relationship...I have adopted their recommendations for climate-friendly practices and will see what the results are at the end of the season...I have recommended other farmers to join this program." (Farmer #11)

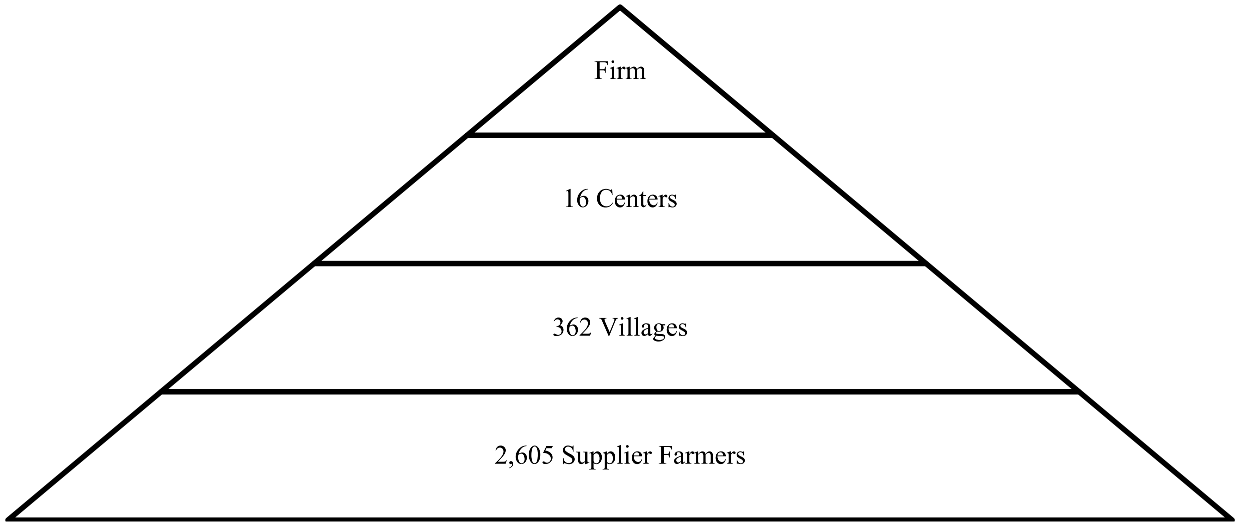

Figure 1. Organization structure of the firm's farmer engagement program

Note. Each farmer used the center closest to their village as the place for buying agricultural inputs and selling their agricultural produce (to our partner firm as well as any other sellers). The operations in each center were carried out with the help of a different field officer, the only exceptions being one large center that had two field officers and two small and proximal centers that were managed by the same field officer.

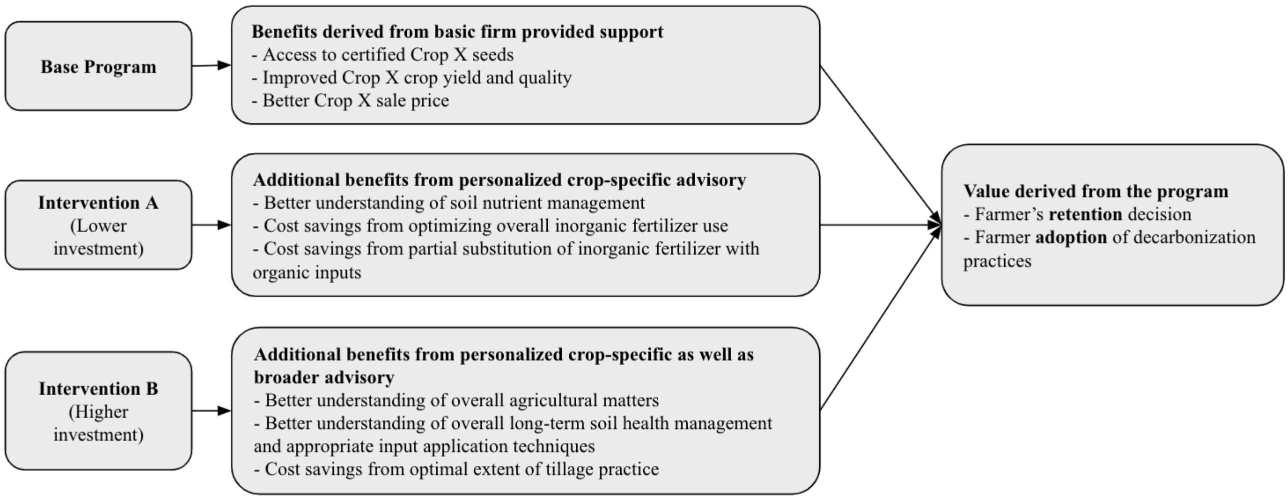

Figure 2. Rationale behind the proposed interventions

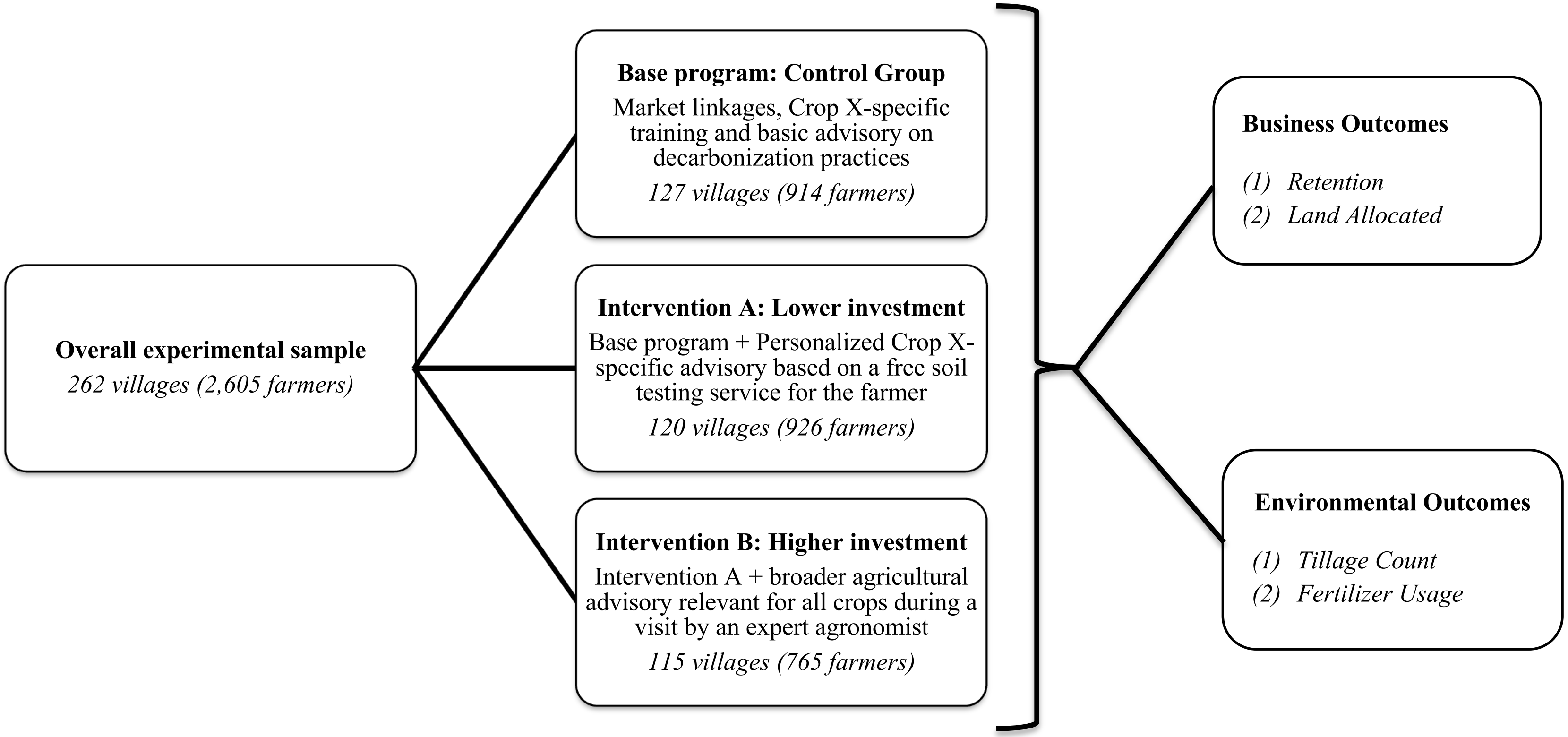

Figure 3. Design of our field experiment

Notes. Our research design used a stratified randomization strategy wherein the program villages within each of the program centers were randomly assigned to one of three experimental groups: the base program (the control group), Intervention A (a lower-investment intervention that extended the base program by adding personalized Crop X-specific advisory based on a soil testing service provided to the farmer for free) and Intervention B (a higher-investment intervention that, in addition to including everything that Intervention A included, also included a visit by an expert agronomist to provide broad agricultural advisory relevant for all of the crops a given farmer grew). Although the unit of randomization was the village, all activities associated with a given intervention as well as with both the baseline and endline surveys were carried out one-on-one at the level of the individual farmers.

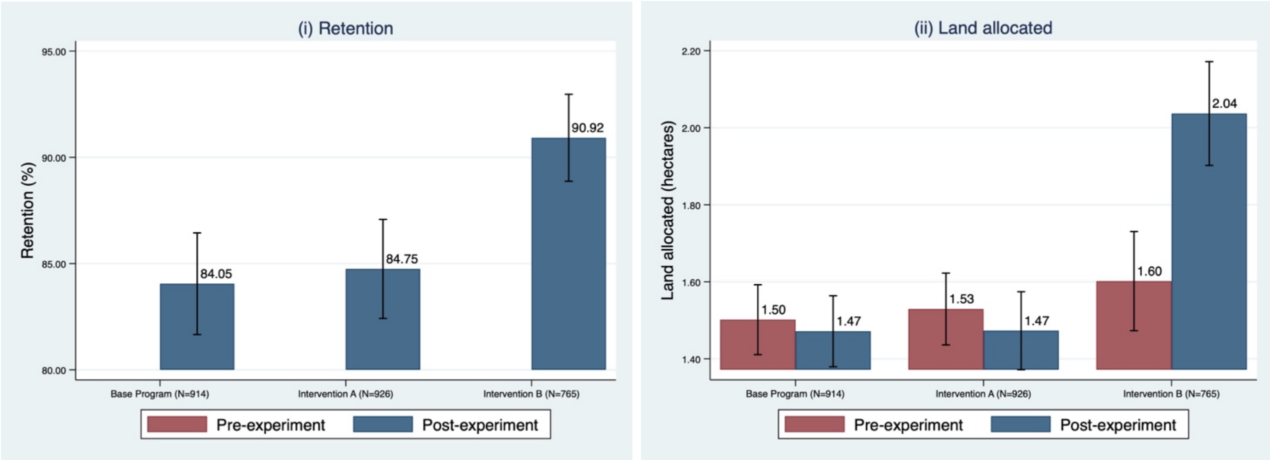

Figure 4a. Treatment effect for the primary business outcomes

Notes: Vertical bars indicate 95% confidence intervals. Note that *Retention* was measured only post-experiment but *Land allocated* was measured pre-experiment as well as post-experiment.

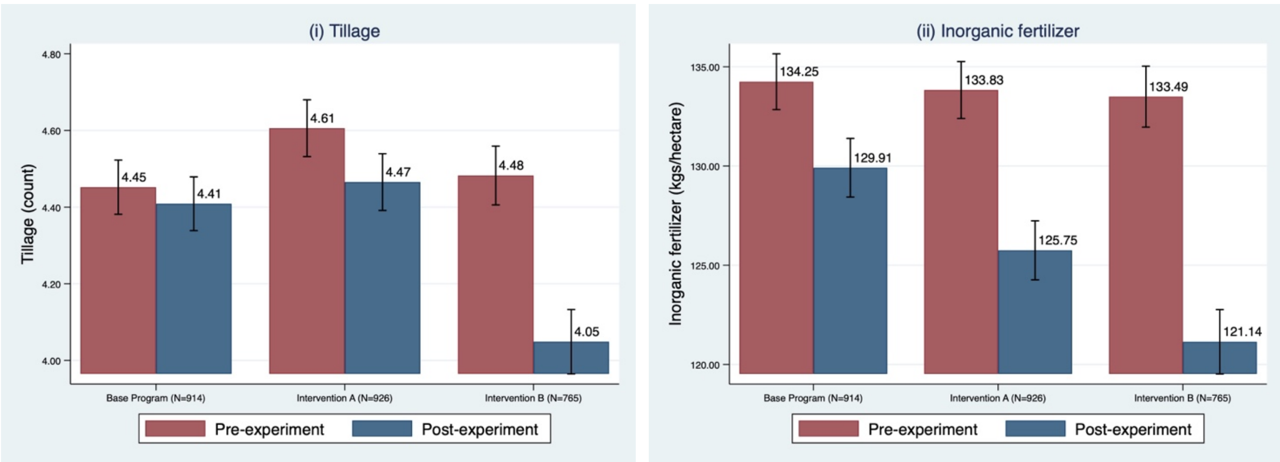

Figure 4b. Treatment effect for the primary environmental outcomes

Notes: Vertical bars indicate 95% confidence intervals. Note that *Tillage* and *Inorganic fertilizer* were both measured pre-experiment as well as post-experiment.

SUPPLEMENTARY APPENDIX

Table A1. Decarbonization practices for the agricultural supply chain

Decarbonization Practice	Linkage to GHG emissions
1. Reduced land tillage	Tillage refers to turning over of the soil to prepare it for crop cultivation, and is measured as the number of times that a farmer ploughs a given plot of land. In the absence of awareness and prioritization of its environmental impacts, farmers have a tendency to do too much tillage relative to what is appropriate. • Tillage has a short-term impact on CO_2 emissions as ploughing of soil is generally done using tractors and agricultural machinery that runs on diesel duel. Reducing tillage reduces burning of diesel, which leads to a significant reduction in overall agriculture-related GHG emissions (Akbarnia & Farhani, 2014; Bhan & Behera, 2014; Stylianou et al., 2023). • Tillage also has a longer-term impact on the soil's structure and organic carbon content. Reducing tillage can thus also improve the soil's organic content and ultimately fertility, while also enhancing the soil's ability to sequester carbon over multiple sowing seasons by improving its biological activity (Mangalessary et al., 2014).
2. Optimized fertilizer use	Fertilizers are of two kinds – inorganic or organic – with inorganic fertilizers being much worse from the point of view of GHG gas emissions. In the absence of awareness and prioritization of environmental impacts of fertilizer use, farmers have a tendency to use too much of inorganic fertilizers (as they are easily and cheaply available, especially due to government subsidies) and too little of organic fertilizers (as their readily available amounts are limited by livestock ownership and also as they are less convenient to apply) relative to what is appropriate. • Inorganic fertilizers are responsible for a substantial fraction of agriculture-related GHG emissions in the form of N_2O (Tubiello et al., 2022). It is often possible to reduce these emissions without compromising on farm productivity (Lal et al., 2021), e.g., through better tailoring of inorganic fertilizer use to a specific farm's soil requirements. • Further reduction in inorganic fertilizer use can often be achieved by using an organic fertilizer (e.g., farmyard manure) to substitute for some of the soil nutrients (Menegat et al., 2022). This also has the additional long-term benefit of enhancing soil fertility and sequestering more organic carbon in soil over time (Diacono & Montemurro, 2011)

Table A2: Delving deeper into fertilizer use

	(1) *Inorganic Fertilizer (DAP – kgs/ha)*	(2) *Inorganic Fertilizer (Urea- kgs/ha)*	(3) *Organic Fertilizer (farmyard manure-MT/ha)*	(4) *Inorganic Fertilizer (DAP- kgs/ha)*	(5) *Inorganic Fertilizer (Urea-kgs/ha)*
Intervention A	-4.008***	-4.279*	0.394*	-2.746	1.379
	(1.459)	(2.373)	(0.224)	(2.060)	(4.188)
Intervention B	-10.42***	-9.701***	1.442***	-3.387	-3.595
	(1.757)	(2.442)	(0.323)	(2.345)	(3.921)
Organic Fertilizer				-0.690***	-0.110
				(0.257)	(0.426)
Intervention A x *Organic Fertilizer*				-0.176	-0.985
				(0.380)	(0.616)
Intervention B x *Organic Fertilizer*				-0.879***	-0.853
				(0.328)	(0.605)
Constant	126.6***	118.5***	5.284**	131.0***	120.9***
	(14.59)	(19.92)	(2.180)	(13.92)	(20.33)
Observations	2416	2416	2416	2416	2416
Farmer and village level controls	Yes	Yes	Yes	Yes	Yes
Centre FE	Yes	Yes	Yes	Yes	Yes

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Notes: Robust standard errors clustered at the village level (the unit of randomization) are reported in parentheses. Supplier farmers in our context use two kinds of inorganic fertilizers: DAP and urea. Digging further into the analysis of their average use as reported in Table 3b, this table provides detailed analysis of the two kinds of inorganic fertilizers separately as well as the associated change in use of organic fertilizer (as explained in Table A1). The findings demonstrate two ways in which reduction in inorganic fertilizers took place because of our interventions. The first was by reducing excessive inorganic fertilizer usage relative to appropriate quantity required by the soil-specific condition for crop growth. The second was by using greater quantity of organic fertilizers as the farmers learnt to substitute inorganic fertilizers with organic nutrient options such as farmyard manure.

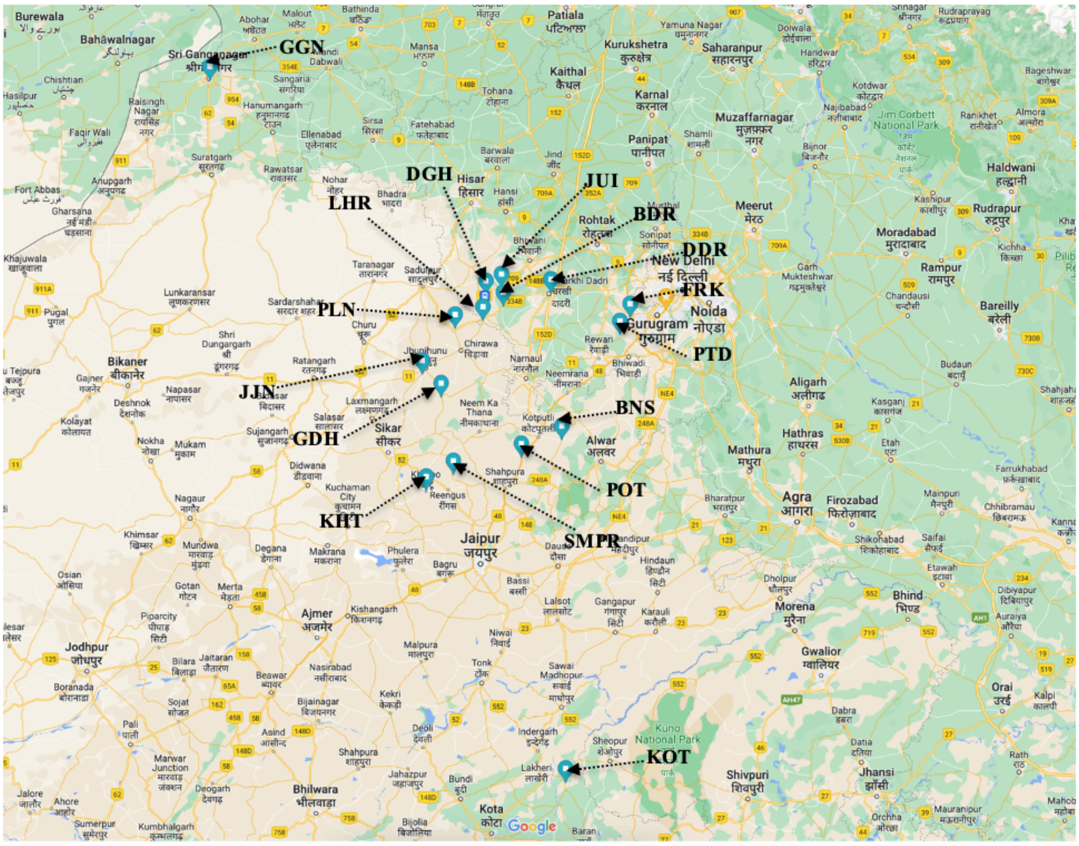

Figure A1a. Geographic location of the 16 centers in our sample

Center	Overall Sample		Base Program		Intervention A		Intervention B	
	Number of villages	Number of farmers	Number of villages	Number of farmers	Number of villages	Number of farmers	Number of villages	Number of farmers
BDR	10	156	4	88	3	23	3	45
BNS	36	188	12	59	12	55	12	74
DDR	30	224	10	73	10	92	10	59
DGH	19	127	7	45	6	58	6	24
FRK	25	170	9	64	8	57	8	49
GGN	39	81	13	20	13	26	13	35
GDH	31	206	11	69	10	78	10	59
JJN	19	173	7	71	6	42	6	60
JUI	27	212	9	34	10	69	8	109
KHT	32	330	12	128	10	101	10	101
KOT	21	88	7	44	7	34	7	10
LHR	23	256	9	102	7	119	7	35
POT	16	125	6	25	6	75	4	25
PTD	11	95	4	26	4	40	3	29
PLN	20	41	8	15	6	16	6	10
SMPR	26	133	10	51	9	41	7	41
Total 16 Centers	**362**	**2605**	**127**	**914**	**120**	**926**	**115**	**765**

Figure A1b. Distribution of the sample villages and farmers across center