SUSTAINABLE LAND USE FINANCE FOR SELF-RELIANCE IN GHANA

COST-BENEFIT ANALYSIS FINAL BRIEF

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CONTENTS

EXHIBITS

ACRONYM LIST

ADSCR	Annual debt service coverage ratio
AEZ	Agro-ecological zone
BAU	Business-as-usual
CAPI	Computer-assisted personal interview
CARD	Climate Adaptation in Rural Development
CBA	Cost-benefit analysis
CCAFS	Climate Change, Agriculture and Food Security
CGIAR	Consultative Group for International Agricultural Research
CIAT	International Center for Tropical Agriculture
CPI	Consumer price index
CR	Crop rotation
EPA	Environmental Protection Agency
ESG	Environmental, social, and governance
ETP	Enhanced tree planting
GAP	Good agricultural practices
GHG	Greenhouse gas
GHC	Ghanaian cedi
GSA	Global Shea Alliance
Ha	hectare
KII	Key informant interview
IFAD	International Fund for Agricultural Development
IMP	Improved systems
ISI-MIP	Inter-Sectoral Impact Model Intercomparison Project
N4J	Nature for Justice
NPK	Nitrogen, phosphorous, and potassium

NPV	Net present value
PICS	Purdue Improved Crop Storage
PV	Present value
RCP	Representative Concentration Pathway
SCC	Social cost of carbon
SHF	Smallholder farmer
SLUF	Sustainable Land Use Finance for Self-Reliance
USD	United States dollar
USAID	United States Agency for International Development

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EXECUTIVE SUMMARY

Agriculture is a mainstay of Ghana's economy and an important driver of its economic growth, poverty reduction, and food security (Ministry of Food and Agriculture [MoFA] 2019; Nyamekya et al. 2021). The sector contributes 20 percent to the country's gross domestic product (GDP) and employs a large share of households—up to three-quarters in some regions (GSS 2019; World Bank 2020). Smallholders are dominant; 90 percent of farmers cultivate fewer than two hectares (GSS 2019). However, the sector has low crop yields, which is one reason why one in eight Ghanaians are food insecure (WFP 2023). Limited gains in farm productivity, climatic threats, and barriers to gender equality in accessing farm inputs like fertilizer and labor are all key factors that will influence Ghana's development and food security prospects.

This brief, one of the Sustainable Land Use Finance for Self-Reliance (SLUF) consortium deliverables, reports the key insights from a cost-benefit analysis (CBA) Mathematica conducted to estimate the financial and economic returns of sustainable land-use practices promoted through the SLUF project. Adoption of sustainable land-use practices by farmers is likely to stall if economic returns, such as reduced GHGs and improved soil health, are not accompanied by financial returns such as increases in productivity and profitability (Pineiro et al. 2020). However, those financial returns do not reflect the totality of societal costs and benefits since climatic impacts of GHG-emitting activities are largely unpriced in the market. The lens of economic returns offers a more holistic means of assessing whether a practice should be encouraged because it accounts for non-monetary flows that are not captured in market transactions. By adopting this lens, the CBA helps address a research gap that exists around the economic and financial returns of adopting sustainable farming practices in sub-Saharan Africa.

This CBA sheds light on the returns to an agricultural technology package provided by three Ghanaian agribusinesses (investees), which were matched with impact investors and received funding to scale up their support activities to nearby smallholder farmers: Agrofredina, Clean Savana, and Idan Agro. The CBA specifically focuses on maize and soybean cultivation. All three investees provided out-grower clients with support for these two crops.

Our CBA combines insights on the GHG impacts of agriculture with socioeconomic data (for example, observed crop yields, input prices, and sales prices) and estimates of the social cost of carbon (SCC) to calculate i.) the net present value (NPV) of financial returns from the perspectives of smallholder farmers, investees, and investors, and ii.) society-wide economic returns from valuing the GHG impacts of adopting new technologies. In so doing, the study demonstrates the role that holistic accounting practices should play in guiding investment choices. Economic analyses, like the one conducted in this CBA, internalize unpriced environmental and social impacts that have real consequences for human welfare. Financial analysis methods which ignore those impacts can therefore lead to investment recommendations that underperform in social returns.

GEOGRAPHIC SCOPE AND RESEARCH CONTEXT

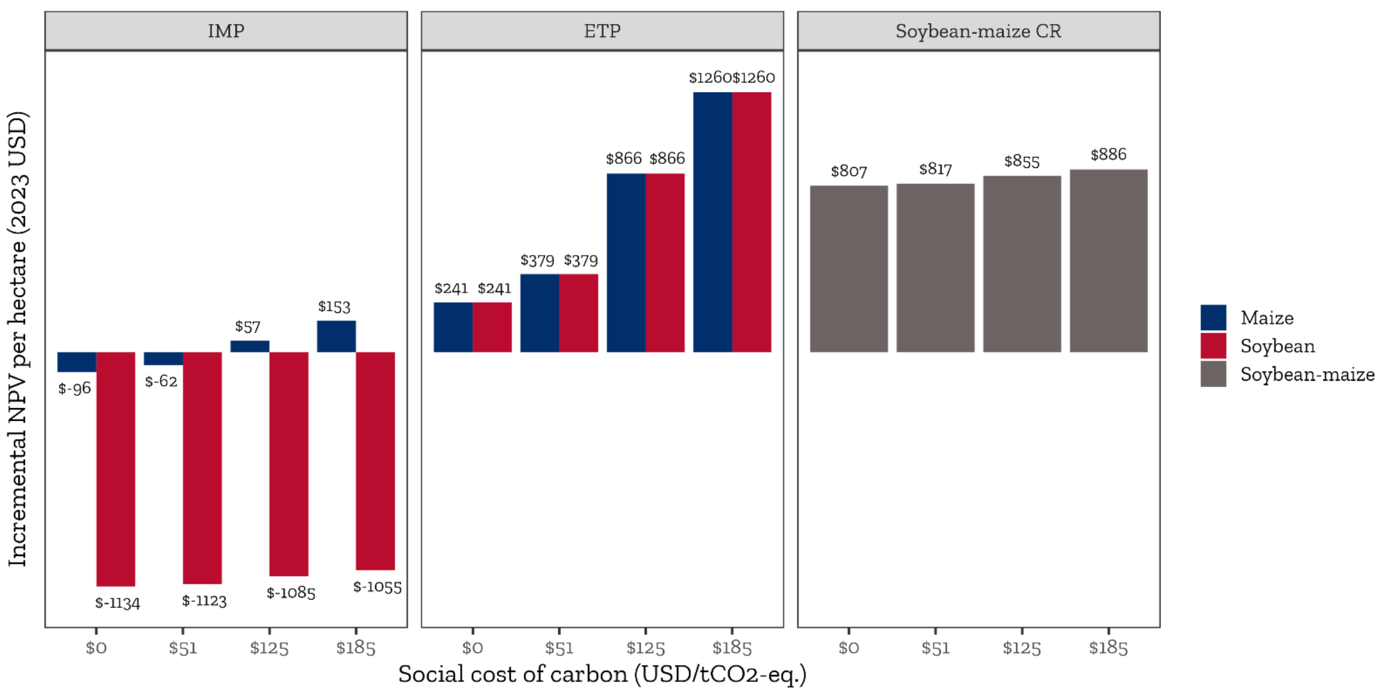
The study focuses on maize and soybean cultivation in the Northern and North East regions of Ghana, which respectively represented 21 and 9 percent of the cropped area in the Northern region and 20 and 12 percent in the North East region (MoFA 2022). At the time of data collection, the three investees collectively operated in communities in many of the districts in these two regions. Owing to the semi-arid climate and physical features, the agroecological zone in which both regions are located, known as the Savannah zone, is highly susceptible to ecological and climate changes. The regions are mainly covered by grassland and sparsely populated trees, and the zone is relatively warmer than the rainforest located further south. There is a single rainy season, roughly from April through October. Due to the scarcity of water and nutrients, the area is exceptionally fragile and prone to poverty (Callo-Concha et al. 2012).

The CBA results are based on survey results from 223 households, 107 forming the treatment group and 116 forming the comparison group. The treatment group households have worked with at least one of the investees and received an improved technology package (IMP) for maize and/or soybean, consisting of high-quality inputs, agricultural training, and support services like tractor ploughing. Comparison farmers have not engaged with investees or similar businesses and represent a business-as-usual (BAU) outcome, representing the status of treatment farmers in the absence of investee support. Under our "main scenario," we drew on primary and secondary data to assess the incremental financial and economic returns from adopting the technology packages provided by the investees. We also considered enhanced tree planting (ETP) and soybean-maize crop rotation (CR) as technology options. We then analyzed three additional scenarios in which we varied assumptions related to technology adoption rates, crop productivity, and climate risk. Under all scenarios, we estimated costs and benefits using primary data from farmer surveys and key informant interviews, estimates of GHG emissions from models of projected yields under climate change, carbon sequestration estimates from a model of tree growth dynamics, and secondary data from administrative sources. Results are reported as present value and net present value estimates for a 20-year horizon using a default discount rate of 12 percent.

KEY FINDINGS

- The incremental financial NPVs of IMP maize and soybean (relative to BAU) were negative ($-96/ha and -$1,134/ha), even though IMP farmers enjoyed a unit-price premium for selling their output to investees compared to other sales options (first two bars in the IMP panel of Exhibit ES.1). The key driver for these lower returns is due to IMP farmers self-reporting lower mean yields than BAU farmers for both maize and soybean. These findings indicate that IMP farmers would financially be better off adopting BAU practices. Because the financial NPVs do not consider unpriced environmental benefits or costs, as denoted by a $0 social cost of carbon, these results ignore any social benefits from mitigation efforts. Likewise, the financial returns exclude any social harms that would result from actions which increase GHG emissions.

Exhibit ES.1. Incremental per-hectare NPV (2023 USD)



Note: Present value = 2023-2024; discount rate = 12 percent; climate scenario = optimistic; carbon credit price = USD $30. Columns using an SCC of $0 denote the financial NPV.

CR = crop rotation; ETP = enhanced tree planting; IMP = improved technology package; NPV = net present value; SCC = social cost of carbon; USD = United States dollar.

- In contrast, net financial returns from implementing ETP and soybean-maize CR were large and positive. If farmers were able to access carbon credit markets and verify that their activities were emissions reducing, ETP adoption would provide farmers with larger carbon credit revenues ($197/ha) and the benefit of earnings from tree product sales ($137/ha). Net financial returns for implementing ETP amounted to $241/ha and accrued equally to maize and soybean plots. The biggest share of net incremental returns from soybean-maize CR ($807/ha) came from the bump in maize yield from the preceding soybean season.
- The financial benefits of Idan Agro and Clean Savana, two of the SLUF investees, are positive and primarily came from the principal and interest repayment of their technological packages. Other benefits included revenue from grain sales by both investees and agrochemical sales by Clean Savana. In addition, the financial analysis assessed the investors' (bankers') perspective and found that investees' annual cash flow was sufficient to comfortably service their loans.
- Because all three technology packages mitigate/sequester carbon, the incremental economic returns for all technology packages were higher than their respective financial returns. However, the monetized GHG emissions benefits were not always large enough to outweigh other associated costs. For example, over 20 years, the incremental per-hectare NPV of IMP maize cultivation was estimated as $-62, assuming a carbon price of $51; positive economic NPV values emerged only under higher assumed carbon prices (see Exhibit ES.1). The corresponding per-hectare economic NPV values of IMP soybean cultivation were consistently negative, ranging from $-1,123 to $-1,055, depending on the price of carbon. This suggests that, on average, these technologies delivered neither farmer livelihood nor global sustainability benefits over the longer term. In contrast, incremental per hectare economic NPVs of ETP and soybean-maize CR were large and positive, ranging from $379/ha for ETP to $817/ha for soybean-maize CR. This suggests the potential for "win-win" livelihood and sustainability impacts from widespread adoption of these technologies.

POLICY RECOMMENDATIONS

Whereas many evaluations of agricultural technologies focus exclusively on the financial results of technology adoption, and therefore the perspective of private benefits and private costs, our CBA considered a broader scope of societal benefits and societal costs that should be considered when determining whether new technologies are (1) truly sustainable and (2) should be scaled up. Accordingly, this brief also provides policy recommendations specific to the three technologies that are the focus of the main CBA, highlighting the importance of multi-sectoral programming to improve understanding of the implications and opportunities related to scaling promising agricultural technologies.

Investments by donors in developing or promoting new agricultural technologies should consider their financial implications for farmers. Through the collection of data on a comprehensive set of financial costs and benefits facing farmers who had adopted the focus technologies as well as those who had not, the analyses presented in this brief extended the focus of agronomic research beyond agricultural productivity outcomes. The reason for doing so is clear; an agricultural technology's failure to deliver financial benefits for adopting farmers has significant implications for scale-up over the longer term (for example, farmers' unwillingness to adopt the technology in the absence of subsidies to cover livelihood shortfalls, which in turn require additional donor financing). Such financial analyses can be carried out concurrently with research and development of new agronomic practices or cultivars, which often involve scientific field trials that can be expanded to gather information on associated costs and benefits.

Assessment of new technologies should also consider their multi-sectoral impacts. Through an assessment of the GHG mitigation/sequestration potential of the various technologies, this brief highlights the conditions under which improved agricultural technologies may or may not deliver global net benefits. This in turn has implications for key decisions relating to technology scale-up. For example, we demonstrated that economic returns associated with IMP maize cultivation are only positive when the price of carbon is assumed to be relatively high, whereas IMP soybean cultivation delivers neither livelihood nor climate benefits under any of the scenarios we considered. Such analyses help inform the ways in which limited resources should be allocated to promote wider dissemination of promising agricultural technologies.

Intra-household distribution of the burden associated with adopting the technology packages should be considered to inform equitable scale-up strategies. Our qualitative interviews with women in households that participated in surveys, for example, revealed that promoted agricultural technologies were more labor-intensive, requiring one to two additional weeks of general labor for planting and applying fertilizer. If this labor is disproportionately performed by women, it reduces the time they have available to participate in other productive activities. At the same time, the benefits associated with women's labor may accrue to the household as a whole or primarily to the male household head. Careful consideration of context-specific intra-household dynamics to inform scale-up strategies can help minimize the risk of unintended adverse effects on vulnerable or marginalized groups.

ASSUMPTIONS AND LIMITATIONS

The key assumptions for the CBA are as follows:

We developed five scenarios to estimate the costs and benefits of maize and soybean under improved systems and enhanced tree planting. The scenarios represent both management regimes that farmers are currently employing (for example, the BAU and IMP systems), as well as regimes that are not yet fully adhered to by farmers but could be with additional support from investees (for example, CR in a no-till/low-till system that retains soybean root structure in the soil). These precise components of the scenarios are based on the literature, findings from primary data collection, and interviews with the investees themselves. The different scenarios applied to both maize and soybean are:

A. **Business-as-usual (BAU).** The BAU scenario for maize and soybean cultivation assumes the use of conventional seed varieties and input decisions that a cultivator makes in the absence of services or support from an entity like one of the three investees. This scenario represents our best understanding of the counterfactual—the management paradigm that investee-supported farmers would face in the absence of the investee and therefore a natural baseline against which investee-supported farmers can be compared. BAU scenario parameters are sourced from primary data on farmers who grow maize or soybean and who do not receive support from any investee or similar agribusiness.

B. **Improved systems (IMP).** This scenario models the cost and benefit streams associated with maize and soybean growers who receive high-quality inputs and agricultural training on sustainable farming practices from the private sector, and more specifically from one of the SLUF-financed investees, under the assumption that comparable agribusinesses could provide the same services under a similar cost structure.

C. **Enhanced tree planting with improved systems (ETP + IMP).** In this scenario, out-growers couple improved practices (IMP) with planting tree saplings of some defined species on their land as a means of sequestering carbon.

D. **Improved systems and crop rotation (IMP + CR).** This scenario assumes that farmers adopt a crop rotation schedule of alternating seasons of maize and soybean cultivation. We assume an initial year of soybean cultivation and that the rotation schedule does not include any fallowing. This scenario introduces additional benefit streams in the CBA because of nitrogen fixation when under soybean cultivation. This increase in soil nitrogen reduces the amount of chemical fertilizer needed in the subsequent maize season, which has both economic impacts because of avoided GHG emissions and financial impacts.

E. **Enhanced tree planting with improved systems and crop rotation (ETP + IMP + CR).** This scenario is a combination of scenarios C and D.

- **Time period.** All scenarios consider a 20-year time horizon for 2023 through 2042.
- **Discount rate.** We apply the default 12 percent real discount rate advised by the United States Agency for International Development (USAID) for our financial and economic analyses. A standalone Excel workbook enables users to select alternate real rates of 0, 3, and 10 percent, all which decrease future discounting relative to our default.
- **Social cost of carbon.** We follow guidance from the US Interagency Working Group on the Social Cost of Greenhouse Gases and assign a default social cost of carbon value of $51/tCO_2$-equivalent when monetizing positive and negative emissions flows. We consider higher values of $125 and $185 in line with recent research indicating more significant economic damages from climate change in our sensitivity analysis.
- **Carbon credits.** In our financial analyses, we apply a $30/tCO_2$-equivalent value for carbon credits, based on current market conditions in California's Cap-and-Trade program, when modeling a potential revenue source for farmers who can demonstrate verified emissions reductions.
- **Costs.** Assumptions related to input and output costs (for example, cost of pesticide, machinery rental, fertilizer) come from farmer surveys carried out with selected farmers across the Northern and North East regions of Ghana. The main environmental costs arise from GHG emissions associated with fertilizer application and other on-farm management practices.
- **Benefits.** The main financial benefits for farmers arise from changes in crop yields (reflected in monetary terms), in earnings from sales of livestock feed/fodder generated from harvests, and from revenues stemming from sales of carbon credits associated with verified emissions reductions. For investees, the benefits primarily come from the principal and interest repayment of their technology packages as well as to some extent from the sale of inputs (such as agricultural chemicals).
- **Financial and economic analyses.** The financial analyses reflect the perspective of households in the Northern and North East regions of Ghana, in that they are principally informed by insights from farmer surveys. All available data on costs and benefits were converted to United States dollars (USD) using prevailing exchange rates. The economic analysis accounts for the costs (benefits) associated with the emissions (sequestration) of GHGs, but the financial analysis excluded this environmental component. However, the financial analysis does include potential revenues of farmers from the sale of carbon credits due to verified emissions reductions.

There are several limitations associated with our analysis. We note the key limitations below:

- **Longer-term changes.** If the investee-supported technology packages involve learning by doing, then adopters might require multiple years to fully achieve potential yield gains. In such a scenario, revisiting households that have adopted improved cultivation practices in future years might reveal higher yields for maize and soybean. Similarly, the relatively short period covered by this study means that it does not investigate the resilience of the focus technologies to climate change, which would have required more years of data covering a range of realized weather conditions (including both positive and negative extreme values).
- **Representativeness.** Our data collection focused on farmers supported by the investees and comparable farmers who had not received any investee support. Such farmers are likely not representative of the set of farmers in the Northern and North East regions of Ghana, and our results may not extend easily to farmers with significantly different profiles or to farmers in other regions with differing socioeconomic and agroecological conditions. Similarly, the investees whom this study focused on may not be representative of the typical agricultural firm in Ghana. In addition, this study focused on maize and soybean. Its results may not generalize to other crops, given the distinct agricultural practices associated with other crops with different agronomic characteristics.

- **Potential for additional sustainability benefits.** Adoption of the technology package may have financial and/or economic effects that were not included in the scope of this CBA, such as on nutrition and food security, water quantity and quality, and biodiversity. Scaling up adoption to other regions in Ghana could introduce additional benefit channels that were less relevant in the study's geographic context.
- **Limitations of projected impacts of climate change on yields.** The modeled projections of the future impacts of climate change on yields that this study uses assume that the future climate evolves according to the relatively pessimistic Representative Concentration Pathway (RCP) 8.5 emissions scenario. We partly account for this concern by summarizing model results under different risk settings. Nevertheless, these model results may not accurately reflect future climate trajectories and therefore the most likely forecast effects on crop yields.

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INTRODUCTION

Agriculture is a mainstay of Ghana's economy and an important driver of its economic growth, poverty reduction, and food security (MoFA 2019; Nyamekya et al. 2021). The sector contributes 20 percent to the country's gross domestic product (GDP) and employs a large share of households—up to three-quarters in some regions (GSS 2019; World Bank 2020). Smallholders are dominant; 90 percent of farmers cultivate less than 2 hectares (GSS 2019). However, the sector has low crop yields, which are one reason why one out of eight Ghanaians are food insecure (WFP 2023). Limited gains in farm productivity, climatic threats, and barriers to gender equality in accessing farm inputs are all key factors that will influence Ghana's development and food security prospects.

Various inefficiencies in the country's food systems have kept poverty and food insecurity rates high (OPHI 2020). Despite steadily increasing aggregate output levels in recent years—in part from fertilizer subsidy programs and deforestation-led cropland expansion—the yield gap for key crops remains high at 40 to 60 percent relative to yields that could be attained by improving extension and using recommended technologies (Akudugu et al. 2013; CIF 2022; MoFA 2019). Traditional farming methods and limited use of mechanization further characterize Ghanaian agriculture (IFPRI 2018). Ghana also ranks below average in cross-country comparisons of access to agricultural inputs and supply chain infrastructure (EIU 2022).

Agricultural production in Ghana faces substantial weather risk. Less than 0.5 percent of all agricultural land is irrigated (World Bank 2020), so rainfall timing and quantity are key determinants of crop yields. This weather sensitivity affects food security and incomes, particularly among poor and marginalized groups (Choudhary and D'Alesandro 2015). At the same time, climate change forecasts through 2050 for the country foreshadow decreased rainfall, rising temperatures, and more extreme weather events. Those trends suggest disruptions in the growing season, a shrinking base of cultivable land, and overall declines in crop yields (Chemura et al. 2020; Choudhary and D'Alesandro 2015; Connolly-Boutin and Smit 2015; WHO 2015).

Gender gaps are another important factor influencing the country's food system. While more than 50 percent of employed rural women are active in agriculture, they face systemic barriers in their access to productive assets, labor, and extension services (CGIAR 2021; FAO 2012). Across the continent, female land ownership is low, and agency over shared land is often limited (Doss et al. 2018). In Ghana, women enjoy less access to technology and financial services, are less likely to belong to agricultural groups, and spend more of their time performing unpaid labor than men (UNDP 2012, 2019; Yokyin 2020). Together, these barriers result in lower agricultural productivity and greater vulnerability to the effects of climate change. For example, women with insecure tenure are less likely to leave land fallow to restore soil fertility, while those with more secure land are more likely to adopt sustainable land-use practices such as planting and maintaining trees (Goldstein and Udry 2005; Quisumbing et al. 1999; UNDP 2019b).

Sustainable land-use practices can help mitigate the effects of climate change, increase yields, and create more gender-equitable resource-sharing. Although their effectiveness varies across locations, common practices that have produced benefits to farmers and the environment include crop rotation, cover cropping, and organic manure application (Acevedo-Siaca and Goldsmith 2020; Issahuku and Abdulai 2020; Pretty and Hine 2001). Sustainable land-use practices can help reduce greenhouse gas (GHG) emissions, of which agriculture is an important source, and sequester atmospheric carbon (Branca 2013). Studies find that such practices may also reduce risk in crop production and increase yields and revenues (Issahaku 2019; OECD 2021).

With support from USAID, the Sustainable Land Use Finance for Self-Reliance (SLUF) consortium designed a 30-month project with the ultimate goal of catalyzing USD $5 million in new private investment commitments to sustainable agriculture and natural resource management in Ghana. Those investments are intended to reduce GHG emissions, protect water and biodiversity resources, and strengthen agricultural value chains. The Alliance of Bioversity International and CIAT leads the consortium in partnership with the Consultative Group for International Agricultural

Research (CGIAR) Research Program on Climate Change, Agriculture and Food Security (CCAFS), Global Shea Alliance (GSA), Mathematica, and Nature for Justice (N4J).

This brief, one of the SLUF deliverables, reports the key insights from a cost-benefit analysis (CBA) Mathematica conducted to estimate the financial and economic returns of sustainable land-use practices promoted through the SLUF project. Adoption of sustainable land-use practices by farmers is likely to stall if economic returns, such as improved biodiversity and reduced GHGs, are not accompanied by financial returns such as increases in productivity and profitability (Pineiro et al. 2020). However, those financial returns do not fully reflect the societal costs and benefits. Adopting the lens of economic returns offers a more holistic means of assessing whether a practice should be encouraged, because it accounts for non-monetary flows that are not priced in the market. By adopting this lens, the CBA helps address a key research gap in the economic and financial returns of adopting sustainable farming practices in sub-Saharan Africa.

RESEARCH CONTEXT: SLUF-SUPPORTED AGRICULTURAL INVESTMENTS

The CBA examines the returns to an agricultural technology package provided by three Ghanaian agribusinesses: Agrofredina, Clean Savana, and Idan Agro. Through the USAID Ghana SLUF project, these businesses were matched with impact investors and received funding to scale up their support activities to nearby smallholder farmers (SHFs). The three businesses (investees) were selected through a rigorous review process that vetted candidate companies' ability to achieve the impact investors' portfolio environmental, social, and governance (ESG) objectives.

Although the packages the investees offered varied slightly, common elements include supplying farmers with high-quality inputs like seed and fertilizer, offering mechanized agricultural services such as ploughing, and providing tree saplings for farmers to plant on private or community land. Exhibit summarizes the key services the investees provided and their geographic extent.

Exhibit 1. Overview of SLUF-supported investees

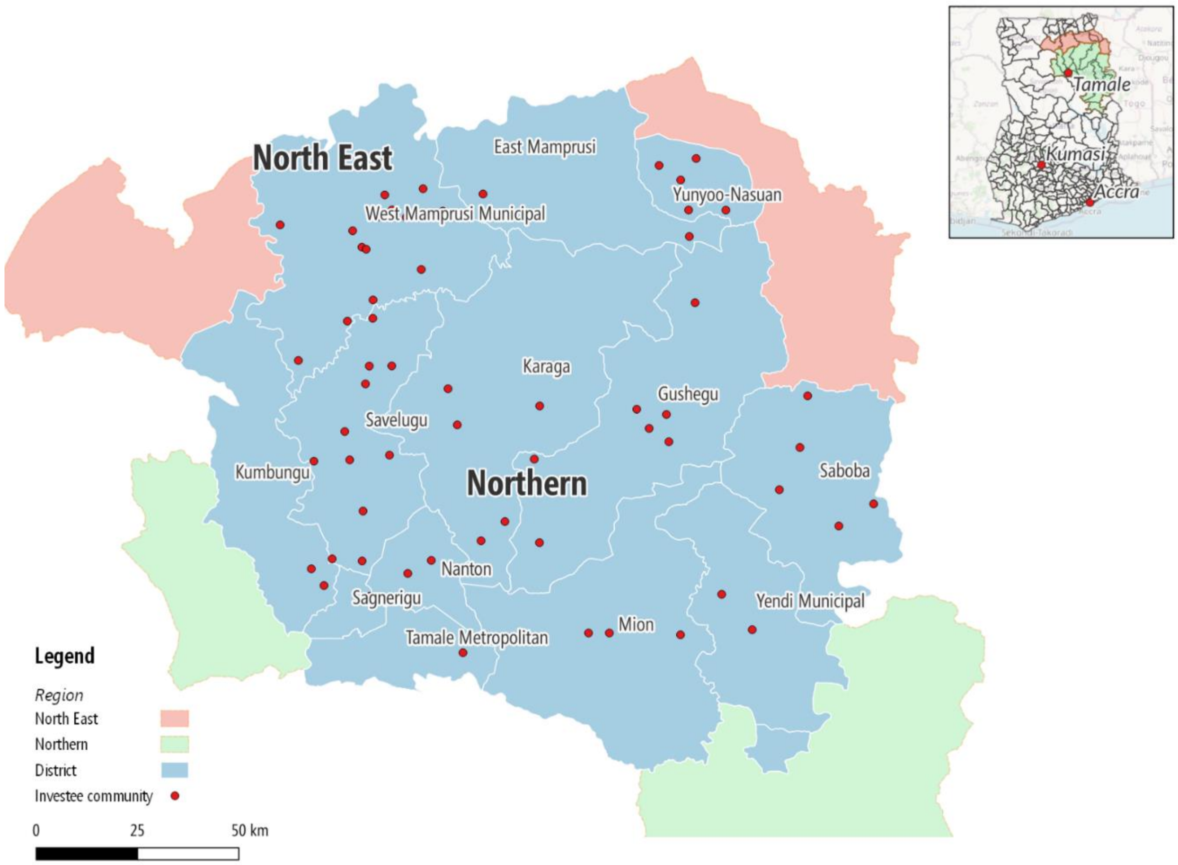
	Agrofredina	Clean Savana	Idan Agro
Services offered	• Input access (seed, fertilizer) • Ploughing with tractor • Provision of tree saplings • Off-taking	• Input access (seed, fertilizer) • Ploughing with tractor • Provision of tree saplings (mango)	• Input access (seed, fertilizer) • Drone-based pesticide/herbicide spraying • Ploughing with tractor • Provision of tree saplings (mango) • Off-taking
Number of SHFs served	2,000	780 (out-growers)	850 (out-growers)
Acres served	Approx. 10,000	1,000	2,500
Crops supported	Maize, soybean, shea, cashew, and rice	Maize, soybean, and rice	Maize, soybean, and rice
Regions served	Northern (5 districts)	Northern (3 districts)	Northern (3 districts) North East (2 districts)

SHF = smallholder farmers.

Although some of the investees also operate in-grower systems (through which farmers supply labor on land the investee owns or leases in exchange for wages or in-kind compensation), we focused on out-grower participants. Out-growers receive inputs from the investees on credit and implement components of the technology package on their own plots. Investee staff may provide training and recommendations to out-growers on specific practices, but the farmers determine which management practices to apply on their plots.

At the time of our data collection, the three investees collectively operated in communities in many of the districts in the Northern and North East regions, as shown in Exhibit 2. Investee communities are displayed as red points and any district in which at least one investee is active is shown in blue. Owing to the semi-arid climate and physical features, the agroecological zone in which both regions are located, known as the Savannah zone, is deemed highly susceptible to ecological and climate changes (Boafa et al. 2016). The regions are mainly covered by grassland and sparsely populated trees, and the zone is relatively warmer than the rainforest located further south. There is a single rainy season, roughly from April through October, which averages 600–1,500 mm/year. Due to the scarcity of water and nutrients, the region is exceptionally fragile and therefore prone to poverty (Callo-Concha et al. 2012).

Exhibit 2. Locations of communities with active investee operations in Northern and North East regions



Note: Results shown are based on client lists provided by the investees and may not comprehensively represent all areas where investees operate.

The CBA focuses on maize and soybean cultivation, which respectively represented 21 and 9 percent of the cropped area in the Northern region and 20 and 12 percent in the North East region (MoFA 2022).[1] All three investees provide clients with support for cultivating these two crops. Given the region's rainy season, the sowing window for maize and soybean usually spans June and August and harvests occur by December. Post-harvest activities may continue through March of the following year.

[1] MoFA (2022) provides total cropped area values only for major crops.

SCOPE AND METHODS FOR COST-BENEFIT ANALYSIS

The CBA focuses on translating private sector investments into improved agricultural systems with the potential to (1) increase yields through the use of high-quality inputs and (2) reduce on-farm GHG emissions. In addition, the CBA models enhanced tree planting, as all three investees distribute trees to promote agroforestry. Although the body of evidence is thin, past studies have explored the impact of a variety of agronomic practices on crop productivity and GHG emissions in Ghana. We present a brief overview of key relevant findings below:

- **Conventional agricultural practices** are not sustainable as they increase dependence on agrochemicals for crop production; degrade water, soil, air, and biodiversity; and contribute to GHG emissions (Adomako and Ampadu 2015).
- **Fertilizer use** patterns vary according to type (such as relative shares of inorganic versus organic fertilizers) as well as quantity. Fertilizer use contributes to GHG emissions and more specifically produces nitrous oxide (a potent GHG) and leads to nitrogen leaching (which contaminates groundwater sources) (Good and Beatty 2011).
- **Residue management,** the practice of removing or retaining crop materials on the field, in combination with reduced fertilizer application is a cost-effective approach for Ghanaian smallholder farmers that could reduce GHG emissions while increasing income compared to continuous maize systems. However, general guidance on the recommended share of total plant residue to return to the soil does not exist, since study results were site-specific (Estrada et al. 2008).
- **Crop rotation,** either with another crop or by leaving the land fallow, has proven effective to sequester carbon while increasing economic returns (Kermah et al. 2017). Although other crop-rotation systems are practiced, farmers typically work with a maize-soybean system.
- **Cover crops** in rotation with maize, such as calopo, can improve yields depending on the cover crop residue management practices (Fosu et al. 2004).

DESCRIPTION OF TECHNOLOGY PACKAGES

We considered five technology packages to estimate the costs and benefits of maize and soybean under improved systems and enhanced tree planting. The technology packages represent both management regimes that farmers are currently employing (for example, the business-as-usual and improved systems), as well as regimes that farmers do not yet fully follow but could follow with additional support from investees (for example, crop rotation in a no-till/low-till system that retains soybean root structure in the soil). These specific components are based on the literature, findings from primary data collection, and interviews with the investees. The different technology packages applied to both maize and soybean are:

A. **Business-as-usual (BAU).** The BAU technology package for maize and soybean cultivation assumes the use of conventional seed varieties and input decisions that a cultivator makes in the absence of services or support from an entity like one of the three investees. This scenario represents our best understanding of the counterfactual—the management paradigm that investee-supported farmers would face in the absence of the investee and therefore a natural baseline against which to compare investee-supported farmers. BAU parameters come from primary data on farmers who grow maize or soybean and do not receive support from any investee or similar agribusiness.

B. **Improved systems (IMP).** This technology package models the cost and benefit streams associated with maize and soybean growers who receive high-quality inputs and agricultural training on sustainable farming practices (among others, no-till agriculture, agroforestry, and improved post-harvest management) from the private sector, and more specifically from one of the SLUF-financed investees, under the assumption that comparable agribusinesses could provide the same services under a similar cost structure. We estimated the IMP scenario parameters from primary data on farmers growing maize or soybean and participating with one of the investees as an out-grower.

C. **Enhanced tree planting with improved systems (ETP + IMP).** In this technology package, out-growers couple improved systems (IMP) with planting tree saplings of some defined species on their land as a means of sequestering carbon. We based the parameter values for this technology package on primary data and desk research.

D. **Improved systems and crop rotation (IMP + CR).** This technology package assumes that farmers adopt a crop rotation schedule that alternates between maize and soybean cultivation. We assume an initial year of soybean cultivation and that the rotation schedule does not include any fallowing. This technology package introduces additional benefit streams in the CBA because of nitrogen fixation when under soybean cultivation. The increase in soil nitrogen reduces the amount of chemical fertilizer needed in the subsequent maize season, which has both financial and economic impacts because of avoided GHG emissions.

E. **Enhanced tree planting with improved systems and crop rotation (ETP + IMP + CR).** This technology package is a combination of C and D.

The key parameters considered in the CBA are labor costs, input and associated costs, fertilizer application rates, on-farm GHG emissions, and revenue, as shown in Exhibit 3. Since the scenarios encompass different practices, their parameters vary. In the BAU and IMP scenarios, the analysis includes a common set of parameters, but with distinct values. BAU farmers may or may not have expenses related to procuring the essential inputs in the IMP package. The ETP + IMP scenario adds parameters pertaining to farmers' tree planting behavior and the growth dynamics of the chosen tree species to model their cumulative carbon sequestration. The IMP + CR scenario adds effects from introducing a soybean-maize rotation, as described above. Lastly, the ETP + IMP + CR scenario contains the set of all possible parameters. As specified in the "Crops" column, a parameter may only apply to the maize instance of each scenario. For example, although we observed farmers applying urea to their maize plots, our survey results showed no soybean cultivators applying urea as a fertilizer.

Exhibit 3. Key parameters included in CBA, by technology package

			Technology package				
			A	B	C	D	E
Parameter	Unit	Crops	BAU	IMP	ETP + IMP	IMP + CR	ETP + IMP + CR
Crop labor costs							
Household labor	GHC/ha	Both	✓	✓	✓	✓	✓
Hired labor	GHC/ha	Both	✓	✓	✓	✓	✓
NPK fertilizer	GHC/ha	Both	✓	✓	✓	✓	✓
Urea fertilizer	GHC/ha	Maize	✓	✓	✓	✓	✓
Seed	GHC/ha	Both	✓	✓	✓	✓	✓
Herbicide	GHC/ha	Both	✓	✓	✓	✓	✓
Pesticide	GHC/ha	Both	✓	✓	✓	✓	✓
Machinery/equipment/animals	GHC/ha	Both	✓	✓	✓	✓	✓
Plot rental	GHC/ha	Both	✓	✓	✓	✓	✓
Irrigation	GHC/ha	Both	✓	✓	✓	✓	✓
Transportation	GHC/ha	Both	✓	✓	✓	✓	✓
Storage	GHC/ha	Both	✓	✓	✓	✓	✓
Crop residue management	GHC/ha	Both	✓	✓	✓	✓	✓
Crop drying and bags	GHC/ha	Both	✓	✓	✓	✓	✓

			Technology package				
			A	B	C	D	E
Parameter	Unit	Crops	BAU	IMP	ETP + IMP	IMP + CR	ETP + IMP + CR
Crop fertilizer usage and GHG emissions							
NPK quantity	kg/ha	Both	✓	✓	✓	✓	✓
Urea quantity	kg/ha	Maize	✓	✓	✓	✓	✓
GHG emissions from on-farm practices	tCO_2-eq/ha	Both	✓	✓	✓	✓	✓
Value of crop yield							
Crop yield	kg/ha	Both	✓	✓	✓	✓	✓
Crop price	GHC/ha	Both	✓	✓	✓	✓	✓
Value of crop yield	GHC/ha	Both	✓	✓	✓	✓	✓
Value of sold fodder	GHC/ha	Both	✓	✓	✓	✓	✓
Trees							
Number of trees planted	Total trees/ha	n.a.			✓		✓
Tree survival rate	Percentage	n.a.			✓		✓
Tree maintenance labor cost	GHC/ha/year	n.a.			✓		✓
Increase in crop yield	Percentage	Both			✓		✓
Value of harvested shea tree products	USD/ha/year	N/A			✓		✓
Carbon sequestration from trees	tCO_2-eq/ha	N/A			✓		✓
Soybean-maize crop rotation							
Decrease in nitrogen use in subsequent maize cultivation	kg N/ha	Maize				✓	✓
Decrease in NPK fertilizer use in subsequent maize cultivation	kg/ha	Maize				✓	✓
Increase in yield of subsequent maize cultivation	t/ha	Maize				✓	✓
GHG effects of decrease in fertilizer use in subsequent improved maize cultivation	tCO_2-eq/ha	Maize				✓	✓

BAU = business-as-usual; ETP = enhanced tree planting; GHG = greenhouse gas; GHC = Ghanaian cedi; ha = hectare; IMP = improved systems; n.a. = not applicable; NPK = nitrogen, phosphorous, and potassium; USD = United States dollar.

DATA SOURCES

The CBA analysis is based on the primary and secondary data sources summarized in Exhibit 4 and further discussed below.

Exhibit 4. Overview of data sources used in CBA

Data	Source	Key parameters
Household survey	CIAT/Mathematica	Labor costs, input and associated costs, fertilizer usage, crop yields and crop revenues, other earnings
Head woman key informant interview	CIAT/Mathematica	Qualitative responses on intra-household division of labor and control over assets
Crop model results for future yields under climate change	CARD	Projected crop yield estimates
On-farm GHG emissions	Cool Farm Tool	GHG emissions from fertilizer application and crop

Data	Source	Key parameters
		residues
Calculator for GHG sequestration by planted trees	CIAT	GHGs sequestered by year
Crop-specific planted area	MoFA (2022)	District-level maize and soybean planted areas (ha) for 2021

CARD = Climate Adaptation in Rural Development; CIAT = International Center for Tropical Agriculture; GHG = greenhouse gas; ha = hectare; MoFA = Ministry of Food and Agriculture.

PRIMARY DATA

Multi-module household surveys. Most of our parameter values are derived from responses to a computer-assisted personal interviewing (CAPI) household survey that a CIAT-led survey team fielded in February 2023. The data collection instrument was designed to collect data on cost and benefit streams farmers face including labor, inputs, and earnings from crop yields. The survey instrument (see Appendix A) included modules on (1) household and farm characteristics, (2) crop inputs, (3) agricultural labor, (4) the value of harvested crop, and (5) agroforestry. We provided selection criteria for which plots were eligible for the plot-level portions of the survey which differed between BAU and IMP farmers. For BAU farmers, the plot had to be between 2 and 14 acres with either maize, rice, or soybean as the primary crop. For IMP farmers, the plot had to be between 2 and 14 acres, with either maize, rice, or soybean as the primary crop, and be cultivated with inputs from one of the investees. If multiple plots satisfied these criteria, enumerators used a random number selector to pick one. When possible, enumerators performed a perimeter walk around one of the household's plots collecting GPS readings in order to obtain high-accuracy plot size measurements. Additionally, questions were included to capture the gender-differentiated impacts of sustainable farming practices. The survey's recall period was the 2021 season, which at the time of data collection was the most recently completed agricultural season.[2]

The survey was administered to 246 households cultivating maize, soybean, and/or rice in the North East and Northern regions. Of this sample, only 19 provided information on rice cultivation. Given the small number of rice observations, we dropped rice from the CBA scope. After dropping households reporting intercropped plots and those with outlier plot sizes, our final analysis sample consists of 223 households, divided into 107 from treatment areas and who actively participated with at least one of the investees ("treatment households") and 116 from comparison areas and who had no involvement with any of the investees or similar companies ("comparison households"). This sample consisted of 113 households cultivating maize (38 treatment and 75 comparison) and 110 households cultivating soybean (69 treatment and 41 comparison).

Survey selection differed for treatment and comparison households. Each of the three investees provided us with recent client lists of participating out-grower households, which we combined to form a sampling frame of potential treatment respondents who resided in 48 villages across 12 districts (Exhibit 2). These lists included a client's name, sex, age, crops grown, plot size, and village although data for some clients were incomplete. To avoid the possibility of inadvertently measuring spillover effects—since in investee communities there are households who are not clients but are still likely to access some information about best practices disseminated by investees that is unavailable to a true comparison household—we selected comparison households only from nearby communities where the three investees do not operate.

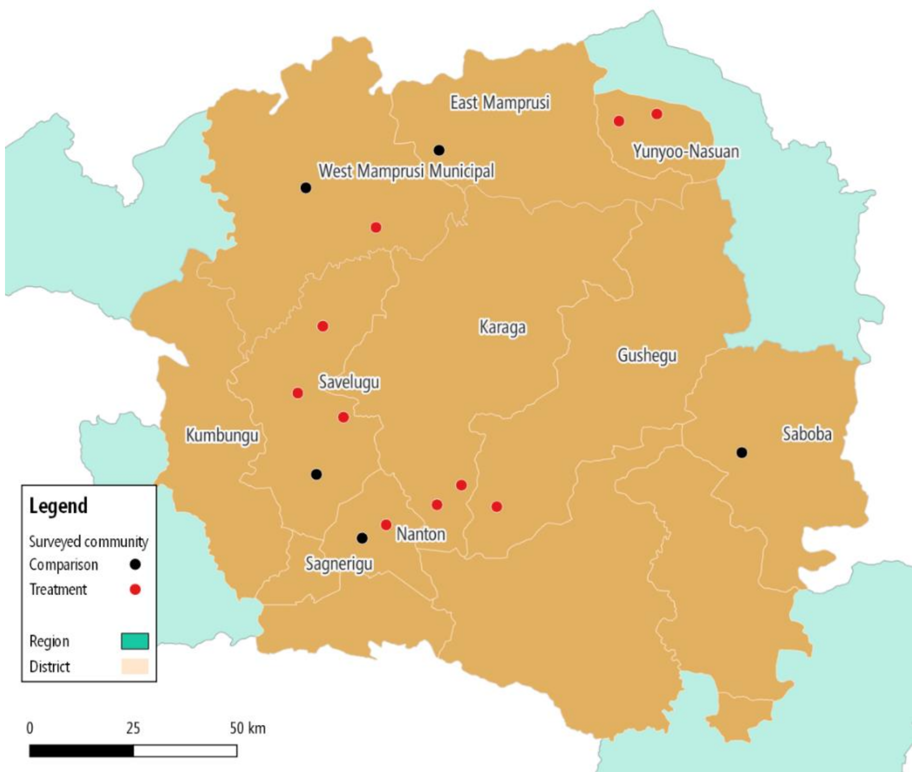
We identified these candidate comparison communities by mapping all investee communities in QGIS 3.28.1 (QGIS.org 2023) and using Google Maps and Open Street Map to select 17 nearby villages with similar characteristics, such as

[2] Although rainy season crops are harvested in November and December, sales are not completed until February/March in the following year. Since some respondents would not have completed selling their 2022 output prior to the survey, we selected 2021 as the recall year to ensure consistent responses across all respondents.

proximity to primary roads, geographic size, and approximate number of households.[3] Comparison villages were between 3.7 and 18.3 (mean of 10.2) kilometers (as the crow flies) from the nearest of the 48 treatment villages. Given their proximity to the treatment communities, coupled with similar agroecological conditions, we assumed comparison households in these locations grew a comparable mix of crops as the investees' clients. Survey reports validated this hypothesis.

We adopted stratified random sampling to select treatment and comparison villages and households. We randomly selected 11 treatment communities where investees were active and five comparison communities from the 17 described above, as shown in Exhibit 5.[4] Within each community, households were randomly selected and female clients, based on information provided in investee lists, were oversampled to ensure sufficient women's representation in our analysis. Enumerators were provided with all information available to the research team to locate selected households. In treatment communities, this included the name, age, sex, and village of residence, but not GPS coordinates of a plot or a household. For comparison communities, we provided GPS coordinates of selected buildings in the village for enumerators to visit. If the coordinates did not correspond to a household growing maize, rice, or soy, then the enumerator would survey a neighboring household growing one of those crops.

Exhibit 5. Communities where household survey was administered



[3] For all candidate comparison villages, we constructed a 1.5-kilometer radius spatial buffer centered at a village's geo-located point to establish a catchment area from which comparison households in a village might be selected. This step aimed to reduce enumerators' travel time in geographically dispersed villages. We used the Open Buildings Google Colab tool (https://colab.research.google.com/github/google-research/google-research/blob/master/building_detection/open_buildings_download_region_polygons.ipynb) to process Google's Open Buildings data set (https://sites.research.google/open-buildings/) and identify built structures within each village's buffer. After applying a 1-meter snap tolerance to connect immediately adjacent polygons, we dissolved the data set to display distinct structures that were more likely to represent household boundaries. By visually examining satellite imagery against the buildings data set, we selected only buildings with a footprint between 50 m^2 and 750 m^2 to discard information on buildings that were too small (for example, barns) or too large (for example, warehouses and schools) to plausibly be houses.

[4] Additional manual adjustments affecting a small number of treatment communities were required based on the survey team's initial scoping visit with community leaders. For example, despite being included in an investee client list, some treatment villages were in fact no longer engaged with an investee and needed to be substituted by another community.

Note: Districts shown in brown contain at least one community in which investees are active. In one of the survey treatment communities, all four respondents reported not using the investee's agricultural inputs package. These observations were dropped from the treatment sample and left us with 10 surveyed treatment communities.

Appendix D.1 provides summary statistics for treatment and comparison respondents. On several important dimensions, there are no statistically meaningful differences between the two groups, such as in household size, whether the household cultivates maize or cultivates rice, the number of household plots, GPS-measured plot size, or the use of mechanical tilling. Comparison farmers resided in villages that received only 17 mm more of rainfall during the 2021 rainy season than treatment farmers using rainfall estimates from Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) (Funk et al. 2015). This amounts to a negligible difference of 1.7 percent. All surveyed respondents were based in tropical, lowland, sub-humid agro-ecological zones (AEZ). Whereas 56 percent of treatment farmers were in AEZs with moderate soil/terrain limitations (AEZ-04), 100 percent of comparison farmers were in this AEZ class (Fischer et al. 2021, Table 10-2). Some key differences between the groups include women representing a larger proportion of treatment respondents (48 percent compared to 23 percent), treatment households being more likely to cultivate soybeans (87 percent compared to 58 percent), and treatment households as being less likely to apply any chemical fertilizers (27 percent compared to 52 percent).

Key informant interviews with women decision makers. In addition to the structured survey, the team also conducted semi-structured key informant interviews (KIIs) with 20 women from households that completed the household survey. The KIIs were designed to solicit women's perceptions on the effect that adopting investee-promoted improved agriculture has on gender disparities in the household by comparing results from women in treatment households with those from women in comparison households. Interview sections included questions on agricultural practices the household adopted, the gendered division of agricultural labor, the primary decision maker for key agricultural management decisions, issues of agency over income from crop sales, and any gendered differences in the care of trees and income derived from their products. Female enumerators led all interviews, supported by an assistant notetaker, and conducted them in the interviewee's preferred language (which was Dagbani in most cases). Enumerators noted whether an adult male was present during the conversation, which could have influenced an interviewee's candor. The full interview guide is in Appendix B.

Interviewees were selected through a random stratified sample at the community level. We randomly selected six treatment communities where the household survey was conducted and investees are active with out-growers, and then randomly selected a total of 12 households from our household survey sample. Similarly, we selected two comparison communities. In those communities, enumerators interviewed eight households included in the household survey sample. In each visit, enumerators asked to speak to the woman most knowledgeable about the plots targeted in the household survey. The spouse of the household head was the respondent in all but four cases where the household head's mother was the interviewee.

Investee cost data. To understand investees' revenue and cost streams for carrying out their programs, we asked the three investees to provide exhaustive data on their recurring and non-recurring costs, and the number of clients they serve (see Appendix C). Based on data for 2021 shared by two investees, we calculated their costs and revenues for providing services on a per-hectare basis for each crop they support.[5] We do not average the investees' financial information, but rather present them as separate entities which can be interpreted as a range. Since we do not know how representative their cost structures are relative to other agribusinesses that could provide similar technology support services, we cannot speak to whether the reported investee financial analyses are at, below, or above averaged expected values achievable from all agribusinesses.

[5] We did not receive financial information from Agrofredina Enterprise who therefore does not appear in any subsequent financial analyses from the investee's perspective. We received two different sources of information from the two investees to calculate and verify the per-hectare costs of crop packages. The investees confirmed our interpretation of their data, and the costs were largely consistent across the sources.

SECONDARY DATA

We supplemented our primary data collection with three types of secondary data: (1) forecast impacts of climate change on crop yields through 2050, (2) estimates of on-farm GHG emissions, and (3) species-specific GHG sequestration estimates for planted trees.

Climate impacts on crop yields. We used the Climate Adaptation in Rural Development (CARD) tool developed by the International Fund for Agricultural Development (IFAD 2019) to incorporate the likely effects of climate change on future crop yields for the CBA's 20-year horizon. CARD estimates, available as an Excel workbook, are crop-specific yield predictions from an ensemble of crop-climate models. In each of the crop models that comprise the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) (Rosenzweig 2013), the future climate evolves according to Representative Concentration Pathway (RCP) 8.5 emissions scenario. CARD summarizes model ensemble results according to three risk settings: pessimistic, median, and optimistic. Results for the risk settings, respectively, come from aggregating the 10th percentile of yield projections, median projections, and the 90th percentile of yield projections. The CBA uses CARD results for Ghana's Northern region and all projections are reported as relative to a base year, which we defined as 2021. For example, a 3.3 percent relative decline in yields for 2032 (the median risk setting for maize as shown in Exhibit 6) means that yields in that year for the purposes of the CBA are 96.7 percent of the survey-obtained yield. Yield predictions under irrigated cultivation are not available for the Northern region and therefore do not factor into this analysis.

Exhibit 6. Illustrative effect of varying climate change risk settings on relative crop yields

	Pessimistic	Median	Optimistic
Yields in 2032 relative to 2021 yields (%)			
Maize	-8.3	-3.3	-0.2
Soybean	-14.5	-4.5	+1.8
Yields in 2042 relative to 2021 yields (%)			
Maize	-18.2	-7.1	+0.2
Soybean	-27.7	-10.8	+6.5

Note: Each risk setting assumes the continuation of unirrigated, rainfed cultivation for all future periods.

GHG emissions from on-farm practices. On-farm practices such as fertilizer application and crop residue management contribute to GHG emissions, which we incorporated into the CBA using estimates exported from the Cool Farm Tool (https://coolfarmtool.org/). The Cool Farm Tool is an online carbon calculator hosted by the Cool Farm Alliance, which includes AB InBEV, Bayer, Cargill, Kellogg's, and Nestle as members. Inputs into the calculator include harvested amount per hectare, farm-gate ready amount (to account for post-harvest losses), crop residue amount and management, and fertilizer application.

Tree biomass carbon calculator. CIAT developed a biomass calculator by adapting allometric equation estimates from the literature for tree species that are relevant to the study area, including shea, cassia, neem, mango, and rosewood. Cumulative biomass values are estimated for each year subsequent to planting over a user-defined duration based on wood density, age of maturity, and tree height at maturity as model inputs.

Crop-specific planted area. We aggregate our financial and economic analysis results to the district level, to understand the potential total returns if specific technologies are scaled more broadly. Our aggregate results are based on crop-specific planted area (Appendix Exhibit D.2) as reported in MoFA (2022).

FINANCIAL ANALYSIS

The financial analysis reflects the financial benefits and costs to farmers and investees valued at self-reported market prices. We estimated the annual cash flows for benefits (revenues) and costs (inputs, labor), as well as annualized net cash flows for a 20-year period (2023–2042). All monetary values were collected in 2021 Ghanaian cedis and converted to 2023 United States dollars.[6] An overview of the considered revenues and costs for both farmers and investees is in Exhibit 7.

Exhibit 7. Financial revenues and costs for farmers and investees

Entity	Revenues	Costs
Farmers	• Value of crop yields • Earnings from sale of livestock feed/fodder generated from harvest • Carbon credits from avoided GHG emissions • Carbon credits from tree carbon sequestration	• Household labor valued at prevailing wage labor rate • Hired labor • Inputs, including seeds, fertilizer, and pesticides • Machinery, equipment, and animal traction rental and/or ownership costs • Plot rental (if applicable) • Irrigation • Transportation for acquiring inputs and selling harvest/feed • Storage (for example, PICS bags) • Crop residue management
Investees	• Principal repayment • Interest repayment • Other benefit streams (for example, sales of grains)	• Inputs, including seeds, fertilizer, and pesticides • Overhead (for example, office and warehouse lease, utilities, computer costs, taxes, and permits)

GHG = greenhouse gas; PICS = Purdue Improved Crop Storage.

Benefits such as the value of the crop yield and earnings from sales of livestock feed and fodder generated from harvests are expected to vary by year. We assume that real farmer costs are constant over time and that investees' non-recurring overhead costs are incurred in year 1 and again one decade later (2023 and 2033). We distributed investees' non-recurring and recurring overhead costs proportionally across crops according to their total hectarage in an investee's portfolio when estimating per hectare costs for each crop. For example, Idan Agro supports out-grower holdings of 689 hectares, of which 365 hectares are under maize cultivation. Consequently, we apportioned 53 percent (365/689) of their fixed and recurring costs to supporting maize cultivators, on top of any maize-specific costs the investee has disclosed.

ECONOMIC ANALYSIS

The financial analysis outlined above sheds light on a comprehensive set of monetary costs and benefits associated with maize and soybean cultivation in the focus regions in Ghana. However, not all costs and benefits associated with agricultural cultivation are reflected in monetary terms. For example, the practice of crop residue burning is a major source of air pollution in many parts of the world (for example, Cusworth et al. 2018). As the costs stemming from crop residue burning (such as negative health effects) are typically borne by others, individual farmers do not account for them when deciding to engage in the practice (Jack et al. 2022). Other agricultural practices can deliver non-monetary benefits. No-till farming, for instance, can reduce soil erosion (Seitz et al. 2020). Farmers may similarly fail to account for these environmental benefits when planning their planting and cultivation activities.

[6] We relied on consumer price index (CPI) Coicop Annexes from the Ghana Statistical Service and GHS—USD exchange rate data for 2023 from the Bank of Ghana to estimate the conversion rate of 6.35 GHS (2021) to 1 USD (2023).

The economic analysis is thus more comprehensive than the financial analysis as it monetizes and considers additional costs and benefits to the environment or society. In particular, the CBA extends the financial analysis described above by accounting for the costs and benefits associated with GHG emissions and sequestration, respectively. Specifically, it considers changes in GHG-related damages associated with farmers' agricultural practices in Ghana. Given this global perspective, which accounts for all benefits and costs associated with GHG sequestration and emissions, the economic analysis does not also separately consider potential revenue that farmers can generate through the sale of carbon credits. All other benefit and cost parameters in the economic analysis are identical to those of the financial analysis.

We note that the economic analysis does not consider the full suite of costs and benefits that could accrue when adopting sustainable agricultural practices. Benefit streams that are outside the scope of this analysis include any health, food security, or dietetic benefits from changes in caloric availability or unit costs of foods; water purification or filtration benefits from tree planting; effects on local ecosystems or public health because of changes in nitrogen-leaching dynamics from fertilizer application; contributions to avoided deforestation; and any earnings that might be associated with planted trees other than the carbon sequestration and harvested shea tree product revenues incorporated in our analysis. These CBA system boundary choices were made through consultations with the impact investors financing the investees as well as the SLUF consortium and correspondingly reflect the key learning objectives for the CBA.

ASSUMPTIONS

Across all technology packages, we adopted a 20-year time horizon over which we estimate crop yields, associated costs and benefits, and GHG emissions/sequestration values. All calculations were conducted in an Excel workbook that draws upon parameter values and assumptions described below.

COST ASSUMPTIONS

We used results from the household survey data to provide parameter values for maize and soybean cultivation costs under BAU and IMP systems. **Household and hired labor accounted for the largest share of costs and are higher among farmers cultivating maize and soybean under IMP** (Exhibit 8). Increased per-hectare labor demands were concentrated among men and women older than age 25, with smaller differences observed for younger laborers corresponding to their proportionally smaller labor contributions. In both maize and soybean systems, regardless of scenario, men supplied substantially more labor hours. Males above age 25 living in the household worked the most hours, followed by females above age 25 and then males between ages 15 and 25. The labor contributions of minors under age 15 were small.

Exhibit 8. Crop labor cost assumptions for financial and economic analyses (2021 GHC)

Category	Parameter	Unit	Maize (BAU)	Maize (IMP)	Soybean (BAU)	Soybean (IMP)
Household labor hours	Males older than 25	Total hours/ha	37	54	52	73
	Males ages 15–25		12	13	21	15
	Males younger than 15		3	3	2	6
	Females older than 25		23	28	28	35
	Females ages 15–25		7	5	8	5
	Females younger than 15		1	3	1	1
Household labor costs	Males older than 25	GHC/ha	239	347	337	471
	Males ages 15–25		51	54	87	65
	Males younger than 15		10	11	8	22
	Females older than 25		83	105	103	129
	Females ages 15–25		20	16	24	16
	Females younger than 15		3	8	2	3
Hired labor hours	Males older than 25	Total hours/ha	15	17	11	34
	Males ages 15–25		4	1	3	2
	Males younger than 15		0.47	0.16	0.37	0
	Females older than 25		6	17	6	5
	Females ages 15–25		0.44	0.18	0.18	0.15
	Females younger than 15		0.48	0.16	0.37	0
Hired labor costs	Males older than 25	GHC/ha	95	107	74	219
	Males ages 15–25		15	5	11	7
	Males younger than 15		2	1	1	0
	Females older than 25		21	63	21	17
	Females ages 15–25		1	1	1	0.46
	Females younger than 15		1	0.42	1	0

Note: All parameter values are calculated from the household survey. Costs are computed using plot size-weighted means by crop type, separately for BAU and IMP farmer households. We calculate household labor costs using the market wage rate observed for hired laborers.

BAU = business-as-usual; GHC = Ghanaian cedi; ha = hectare; IMP = improved systems.

Other key costs include crop inputs costs (such as seeds, fertilizer, and herbicide/pesticide), as well as costs related to storing and transporting cultivated harvest or fodder and crop residue management (Exhibit 9).

Exhibit 9. Other crop cost assumptions for financial and economic analyses

Category	Parameter	Maize (BAU)	Maize (IMP)	Soybean (BAU)	Soybean (IMP)
Key inputs	Seed cost	111	176	189	153
	Herbicide cost	85	68	77	60
	Pesticide cost	23	42	26	17
	Fertilizer cost	511	319	16	3
	Machinery, equipment, and animal traction costs	334	229	229	250
	Plot rental cost	11	12	4	15
	Irrigation cost	0	0	0	0
Other costs	Transport for acquiring inputs and selling harvest/fodder	66	33	72	46
	Transport for selling harvest/fodder	38	33	59	39
	Storage	7	12	25	13
	Crop residue management	7	4	24	11
	Other harvesting costs (crop drying and bags)	87	59	83	48

Note: All parameter values are calculated from the household survey and are in units of GHC/ha. Costs are computed using plot size-weighted means by crop type, separately for BAU and IMP households.

BAU = business-as-usual; GHC = Ghanaian cedi; ha = hectare; IMP = improved systems.

BENEFIT ASSUMPTIONS

The financial analysis for the BAU and IMP packages considered farmer benefits associated with maize and soybean yields and fodder, as well as potential carbon credit revenues from avoided GHG emissions (Exhibit 10). To estimate benefits to investees, the analysis incorporated principal repayment, interest payments, and revenue from selling grains. The economic analysis further considered the value of GHG emissions directly attributable to maize and soybean cultivation. Following guidance from the US Interagency Working Group on Social Cost of Greenhouse Gases (IWG 2021) to monetize the total cost of emitting a unit ton of CO_2-equivalent on society, we applied a social cost of carbon (SCC) equal to USD $51. We used alternate SCC values of $125 (Carleton et al. 2021) and $185 (Rennert et al. 2022) in our sensitivity analysis. The currently accepted IWG value is anticipated to be revised upwards in line with research finding costlier impacts of climate change in multiple domains such as health (morbidity and mortality), employment, agriculture, and economic growth. Furthermore, the US Environmental Protection Agency (EPA), which has sought public comment on how the social cost of GHGs should be calculated, may lower its SCC discount rate, which would increase the total value of future climate-induced costs (Rennert and Prest 2022).

Exhibit 10. Crop benefit assumptions for financial and economic analyses

Parameter	Unit	Maize (BAU)	Maize (IMP)	Soybean (BAU)	Soybean (IMP)
Crop yield	kg/ha	1,775	1,289	1,228	824
Crop price	GHC/kg	1.84	2.35	3.26	3.84
Earnings from crop fodder sales	GHC/ha	0	0	0	0
Avoided GHG emissions from improved cultivation	GHC/ha	n.a.	-0.22	N/A	-0.07
Carbon credit price	USD/tCO_2-eq	n.a.	$30	N/A	$30

Note: Values for crop yield, price, and earnings from fodder sales are calculated from the household survey. Crop yield values are computed using plot size-weighted means by crop type, separately for BAU and IMP households. The crop price for IMP households is the average off-taking price offered by investees. The crop price for BAU households is the average crop price for non-investee buyer options, including roadside, local market, main market, and private trader. We used the Cool Farm Tool calculate GHG emissions (Cool Farm Tool 2023) and then computed avoided GHG emissions from IMP by taking the IMP-BAU difference by crop type. We use a current carbon credit price (CARB 2023) to value the potential plausible credit revenue a farmer might receive for verified emissions reductions.

BAU = business-as-usual; GHC = Ghanaian cedi; GHG = greenhouse gas; ha = hectare; IMP = improved systems; n.a. = not applicable.

GHG EMISSIONS ASSUMPTIONS

We estimated per-hectare totals of CO_2-equivalent for maize and soybean based on agronomic parameter values derived from our household survey alongside ancillary values from secondary sources.[7] As we show in Exhibit 11, the key difference between the BAU and IMP technology packages for these parameters is the fertilizer amount, which in turn has implications for farmers' total costs and GHG emissions.

Exhibit 11. Ancillary parameter values used in on-farm GHG emissions calculations

Parameter	Value	Source
Residue to product ratio		
Maize (stalks, husks, and cobs)	2.08	Kemausuor et al. (2014)
Soybean (straw and pods)	3.5	Kemausuor et al. (2014)
Post-harvest losses		
Maize	30%	Opit et al. (2014)
Soybean	15.6%	Sugri et al. (2021)
Fertilizer characteristics		
NPK	15% N / 15% P_2O_5 / 15% K_2O Broadcast application Manufactured in Africa	Assumption
Urea	46% N Broadcast application Manufactured in Africa	Assumption

[7] We excluded emissions from direct energy use, field operations, or transportation from our calculations. Preliminary analysis using plausible values for each of these components showed that their total amounted to approximately 1 percent of total on-farm GHG emissions.

Parameter	Value	Source
Other characteristics		
Residue management	100% left distributed on field, or incorporated, or mulched	Assumption
Soil	Clay 1.72% ≤ soil organic matter ≤ 5.16% 2% soil organic carbon Poor drainage 5.5 ≤ pH ≤ 7.3	Assumption
Fertilizer quantity		
Maize	BAU: 196 kg/ha NPK, 56 kg/ha urea IMP: 113 kg/ha NPK, 45 kg/ha urea	Household survey
Soybean	BAU: 8 kg/ha NPK IMP: 1 kg/ha NPK	Household survey
Plot area irrigated		
Maize	0%	Household survey
Soybean	0%	Household survey
Annual GHG emissions from on-farm practices		
Maize	BAU: 1.495 tCO_2-eq IMP: 1.280 tCO_2-eq	Cool Farm Tool (2023)
Soybean	BAU: 0.999 tCO_2-eq IMP: 0.931 tCO_2-eq	Cool Farm Tool (2023)

Note: The Cool Farm Tool (2023) estimates of annual GHG emissions are based on yields values (Exhibit 10) combined with the parameter values shown in this table.

BAU = business-as-usual; GHG = greenhouse gas; ha = hectare; IMP = improved systems; NPK = nitrogen, phosphorous, and potassium.

TREE-PLANTING ASSUMPTIONS

Our assumptions related to the costs and climate impacts of enhanced tree planting come from primary and secondary data sources. We relied on household survey data to estimate the number of trees planted per hectare, tree survival rates, and labor costs associated with tree maintenance. We used the CIAT-developed carbon calculator to estimate carbon stock across years (above-ground and below-ground carbon) from cassia and shea trees (Exhibit 12). For the economic analysis, we valued the carbon sequestered from trees using the same alternate SCC values used to monetize GHG emissions from maize and soybean cultivation. We supplemented these parameters with a literature review on tree survival rates and benefits from tree products, including household earnings from shea collection. We do not assume that ETP directly provides positive yield effects for any maize or soybean with which shea trees are co-planted. This is a more favorable assumption than warranted in Ogwok et al. (2019) who observed yield reductions for maize and soybean planted with shea trees in a Ugandan field trial.

Exhibit 12. Key parameters and assumptions for enhanced tree planting

<table>
<tr><th>Parameter</th><th>Unit</th><th colspan="20">Value</th><th>Source</th></tr>
<tr><td>Number of trees planted</td><td>Total trees/ha</td><td colspan="20">10</td><td>Household survey</td></tr>
<tr><td>Tree survival rate</td><td>Percentage</td><td colspan="20">80%</td><td>Informed by household survey; Twumasi (2023)</td></tr>
<tr><td>Tree maintenance labor cost</td><td>GHC/ha/year</td><td colspan="20">79.32</td><td>Household survey</td></tr>
<tr><td>Increase in maize/soybean crop yields</td><td>Percentage</td><td colspan="20">0%</td><td>Study team assumption</td></tr>
<tr><td>Value of harvested shea tree products</td><td>USD/ha/year</td><td colspan="20">$64</td><td>Informed by Ingram et al. (2015); Lovett and Philipps (2018)</td></tr>
<tr><td rowspan="3">Carbon sequestration from trees</td><td rowspan="3">tCO_2-eq/ha/year</td><td colspan="20">Year</td><td rowspan="3">CIAT carbon stock calculator</td></tr>
<tr><td>2023</td><td>2024</td><td>2025</td><td>2026</td><td>2027</td><td>2028</td><td>2029</td><td>2030</td><td>2031</td><td>2032</td><td>2033</td><td>2034</td><td>2035</td><td>2036</td><td>2037</td><td>2038</td><td>2039</td><td>2040</td><td>2041</td><td>2042</td></tr>
<tr><td>0</td><td>0.004</td><td>0.01</td><td>0.02</td><td>0.04</td><td>0.08</td><td>0.1</td><td>0.3</td><td>0.5</td><td>0.9</td><td>1.5</td><td>2.3</td><td>3.1</td><td>3.8</td><td>4.3</td><td>4.4</td><td>4.3</td><td>3.9</td><td>3.4</td><td>2.8</td></tr>
</table>

CIAT = International Center for Tropical Agriculture; GHC = Ghanaian cedi; GHG = greenhouse gas; ha = hectare; USD = United States dollar.

SOYBEAN-MAIZE CROP ROTATION ASSUMPTIONS

Our assumptions related to the impacts associated with crop rotation (technology packages including CR) come primarily from a scan of secondary literature on the effects of soybean-maize crop rotation on subsequent-season maize cultivation in sub-Saharan Africa, and particularly Ghana and West Africa, where available. Key parameters related to these impacts include (1) the beneficial effect of CR on maize yields and (2) the reduction in NPK fertilizer use for maize production that results from soybean cultivation fixing soil nitrogen. We used the Cool Farm Tool (2023) to estimate the impact of reduced NPK fertilizer use on GHG emissions under all technology packages that include CR (Exhibit 13).

Exhibit 13. Key parameters and assumptions for soybean-maize crop rotation

Parameter	Unit	Value	Source
Change in nitrogen requirements for maize cultivation following season of soybean cultivation	kg N/ha	-25	Sanginga et al. (2002)
Change in NPK fertilizer use in subsequent maize cultivation	kg/ha	-125	Adzawla et al. (2021); AfricaFertilizer (2021)
Change in yield of subsequent maize cultivation	t/ha	+0.5	Franke et al. (2018); Kermah et al. (2019)
Change in GHG emissions intensity in subsequent maize cultivation season because of reduced fertilizer use	tCO_2-eq/ha	-0.145	Cool Farm Tool (2023)

GHG = greenhouse gas; ha = hectare; NPK = nitrogen, phosphorous, and potassium.

SCENARIO ASSUMPTIONS

In this brief, we present results for a main scenario and three alternative scenarios that generate additional insights to inform potential scale-up of improved agricultural technologies (Exhibit 14). To facilitate comparability of costs and benefits over this period, all scenarios used a real discount rate of 12 percent. We checked the sensitivity of our results to this parameter by also carrying out financial and economic analyses using alternative real discount rates of 0, 3, and 10 percent. These lower rates increase the present value of costs and benefits incurred in the somewhat distant future because they "discount" future value streams less than under the default rate. For the main scenario, we used the crop yield values computed from the household survey by crop type and BAU and IMP households. We also assumed an "optimistic" climate risk setting for modeling the effects of climate change on crop yields, and an adoption rate of 60 percent when considering the aggregate returns achievable by scaling up a technology package to entire districts in which the investees are active. The alternative scenarios examine the sensitivity of the main scenario's assumptions by varying either the adoption rate (alternative scenario 1, in which 100 percent of land currently cropped with maize or soybean adopts IMP practices), the crop yield of IMP households, (alternative scenario 2, in which there is no yield gap between BAU and IMP), or the climate risk setting (alternative scenario 3, in which climate change has stronger negative effects on crop yields).

Exhibit 14. Brief scenario assumptions

Assumption	Main scenario	Alternative scenario 1	Alternative scenario 2	Alternative scenario 3
Discount rate	12%	12%	12%	12%
Maize yield	BAU: 1,775 kg/ha IMP: 1,289 kg/ha	BAU: 1,775 kg/ha IMP: 1,289 kg/ha	BAU: 1,775 kg/ha IMP: 1,775 kg/ha	BAU: 1,775 kg/ha IMP: 1,289 kg/ha
Soybean yield	BAU: 1,228 kg/ha IMP: 824 kg/ha	BAU: 1,228 kg/ha IMP: 824 kg/ha	BAU: 1,228 kg/ha IMP: 1,228 kg/ha	BAU: 1,228 kg/ha IMP: 824 kg/ha
Climate risk setting	Optimistic	Optimistic	Optimistic	Median
Adoption rate	60%	100%	60%	60%

Note: Crop yield values are calculated from the household survey and computed using plot size-weighted means by crop type, separately for BAU and IMP households. The scenarios use the risk settings (optimistic, median, pessimistic) within the IFAD CARD tool to model the likely effects of climate change on future yields.

BAU = business-as-usual; CARD = Climate Adaptation in Rural Development; ha = hectare; IFAD = International Fund for Agricultural Development; IMP = improved systems.

RESULTS OF THE MAIN SCENARIO

KEY FINDINGS FROM THE MAIN SCENARIO

- Adoption of enhanced tree planting and soybean-maize crop rotation had a positive financial net present value (NPV) for farmers, but improved cultivation did not.
- Because all three technologies mitigate/sequester carbon, the incremental economic NPVs for all technologies were higher than their respective financial NPVs. However, the monetized GHG emissions benefits were not always large enough to outweigh other associated costs.
- Intra-regional variation in returns helps shed light on areas with positive financial and economic returns, which could be targeted initially for scale-up to deliver "win-win" livelihood and climate benefits.

FINANCIAL ANALYSIS

We use the BAU technology package as the baseline for estimating the incremental (marginal) costs and benefits of all other practices: adoption of the investee technology package, engaging in soybean-maize crop rotation, or planting trees on an actively cultivated plot. This approach of examining the incremental results allows us to exclude costs and benefits faced by farmers that are unrelated to farming practices and decisions associated with maize and soybean cultivation, since these would accrue under all scenarios. Under the BAU, we assume that maize and soybean are cultivated using conventional agronomic practices and that farmers make their management decisions independent of any investee or similar agribusiness. We also aggregate the results of our financial analysis and present district-level values based on the area under maize and soybean production using data from the Ministry of Food and Agriculture (MoFA 2022).

Exhibit 15 (Panel A) shows the present value (PV) of incremental financial costs and the PV of incremental financial benefits per-hectare over the 20-year period associated with IMP maize and soybean, ETP, and soybean-maize CR for farmers. It also shows the incremental per-hectare financial NPVs for the three technologies, which is the sum of the benefits PV value and -1 multiplied by the costs PV since costs are expressed as positive values. Exhibit 15 (Panel B) shows the present value of incremental financial costs and benefits for the investees, Idan Agro and Clean Savana. Key costs include costs of providing out-growers with inputs, debt servicing including repayments to impact investors, and other recurring and non-recurring costs.[8,9] The per-hectare values for each technology are additive by crop type; costs from enhanced tree planting, for example, can be added to the costs of improved maize cultivation. Positive values denote increases in costs and benefits relative to the BAU case, and negative values denote the opposite. More granular benefit and cost stream values are reported in Appendix Exhibit D.3.

[8] The data request template filled out by investees on their costs and revenues is in Appendix C.
[9] To arrive at costs per hectare for each investee, we divided costs by the total out-grower hectares served by the investee. We calculated the total number of hectares by multiplying the number of out-growers working with the investee by the size of the average technology package (in hectares).

Exhibit 15. Incremental per-hectare financial results (2023 USD)

Panel A: Farmers				
Technology	**Crop**	**Costs PV**	**Benefits PV**	**NPV**
IMP	Maize	-$137	-$233	-$96
	Soybean	$153	-$980	-$1,134
ETP	Maize	$93	$334	$241
	Soybean	$93	$334	$241
Soybean-maize CR	Both	$0	$807	$807
Panel B: Investees				
Investee	**Crop**	**Costs PV**	**Benefits PV**	**NPV**
Idan Agro	Maize, soybean, and rice	$22,799	$29,507	$6,708
Clean Savana	Soybean	$1,255	$2,241	$986

Note: Present value = 2023-2024; discount rate = 12 percent; climate scenario = optimistic; carbon credit price = USD $30. Since investees do not support the BAU technology package and hence incur no costs under that technology, their incremental values are equivalent to actual costs.

BAU = business-as-usual; CR = crop rotation; ETP = enhanced tree planting; IMP = improved systems; NPV = net present value; PV = present value; USD = United States dollar.

Compared to BAU maize, IMP maize is less expensive, while IMP soybean is at the margin costlier than the BAU soybean package. Although labor costs under IMP maize are about a third higher than for BAU maize, the costs of several key crop inputs including fertilizer, herbicide, machinery/equipment, and transport costs are lower.[10] Under IMP soybean cultivation, some crop input costs (such as fertilizer, seed, and herbicide/pesticide costs) are also lower than for BAU soybean, however, labor costs are 40 percent higher.

Compared to the BAU scenario, financial benefits are lower under IMP maize and soybean cultivation. Despite IMP farmers having access to higher sale prices for maize and soybean, since investees' off-take price exceeds the market price available for BAU farmers, their average yields are lower than BAU farmers. As a result, the incremental value of maize and soybean yields under IMP is negative. The largest component of the positive cash flows from adopting IMP comes from carbon credits, which results from lower fertilizer rates under IMP.

Carbon sequestration from ETP provides farmers with additional carbon credits and the benefit of earnings from tree product sales, while the biggest share of incremental returns from soybean-maize CR comes from the bump in maize yield assumed from the preceding soybean season. Annual carbon sequestration from trees starts at 0.004 tCO_2-eq/ha in 2024 and reaches 2.8 tCO_2-eq/ha in 2042. Benefits from shea tree products begin in 2032, ten years after tree planting. For soybean-maize CR, in each subsequent maize cultivation, yields increase by 0.5 tons/ha. Incremental returns also come from fertilizer cost-savings and carbon credits resulting from lower fertilizer use in each subsequent maize season. Reductions in fertilizer application result in 0.142 tCO_2-eq/ha of avoided GHG emissions during each maize season in rotation. See Exhibit D.3 for a detailed breakdown of the key benefits components for farmers and investees.

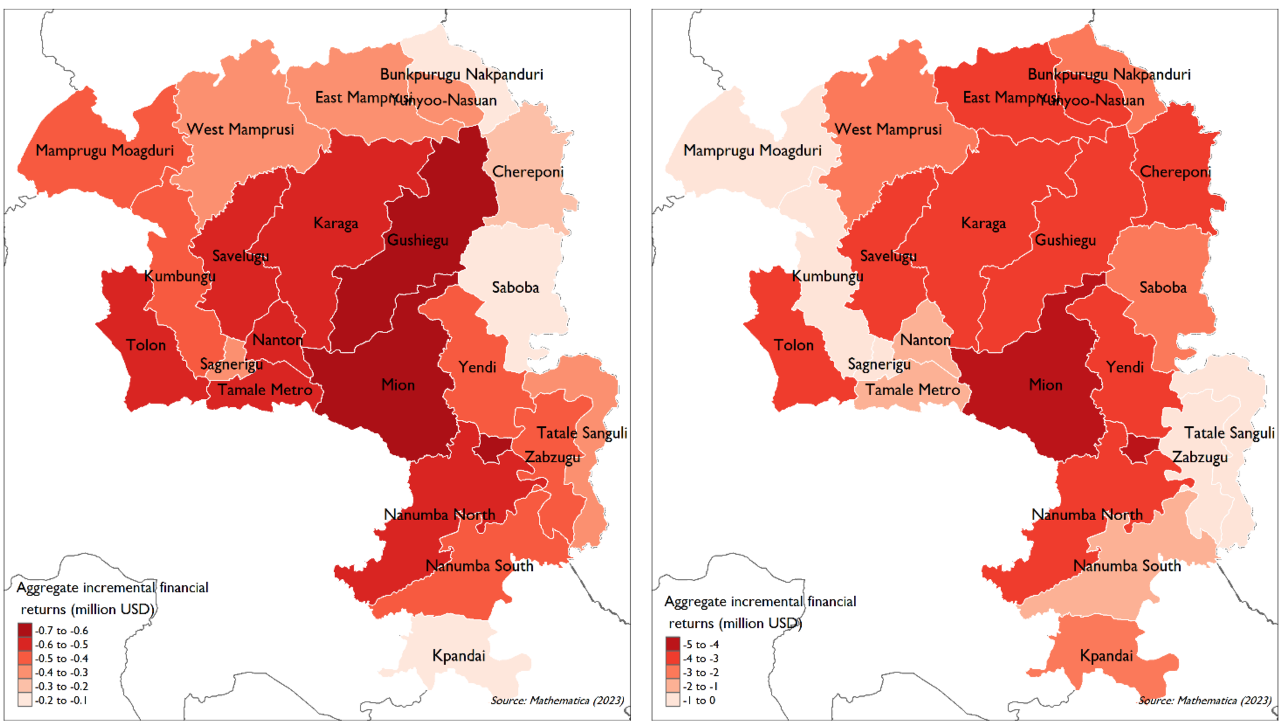
Adoption of ETP and soybean-maize CR had a positive financial NPV in the main scenario for farmers, but IMP cultivation did not. The incremental financial NPV for adoption of enhanced tree planting and soybean-maize crop rotation was $241 and $807, respectively, assuming a 12 percent discount rate. In contrast, the corresponding NPV for adoption of IMP cultivation ranged from −$96 per hectare for maize to −$1,123 per hectare for soybean. For investees, the incremental financial NPVs associated with their respective technology packages were positive, ranging from $986 for Clean Savana to $6,708 for Idan Agro.

[10] The breakdown of financial costs per hectare by technology is available in the Excel workbook.

Since the incremental financial NPVs for IMP maize and soybean are negative, we conducted a break-even analysis to determine the average yields needed for farmers to be indifferent between BAU and IMP technology packages, holding all other factors constant. **We estimated that if maize yields under IMP were 1,324 kg/ha (a 3 percent increase above observed IMP yields), and IMP soybean yields were 1,073 kg/ha (a 30.2 percent increase above observed IMP yields), then the incremental NPV for either would be $0.** Average yield values in excess of those thresholds would deliver positive financial benefits to farmers and would make them attractive technology packages independent of any economic gains IMP adoption would confer.

There is substantial intra-regional variation in the aggregate financial returns associated with scaling the three technologies across the Northern and North East regions. Exhibits 16, 17, and 18 respectively present incremental financial NPVs for farmers for the Northern and North East regions for IMP cultivation, ETP, and soybean-maize CR, aggregated up to the district level based on the total acreage currently planted with either crop. Incremental financial returns associated with IMP are consistently negative, regardless of crop, suggesting that farmers do not gain financially from engaging in the practice. Financial returns associated with ETP alongside maize cultivation, for example, are positive and concentrated in the districts of Mion and Gushiegu; positive incremental financial returns associated with soybean-maize CR are similarly concentrated in Mion where total returns are in excess of $8 million. In contrast, financial returns associated with ETP combined with soybean cultivation are positive and relatively evenly distributed across the two regions. Positive returns indicate that farmers in these areas should readily adopt the relevant technologies as they have the potential to deliver livelihood benefits.

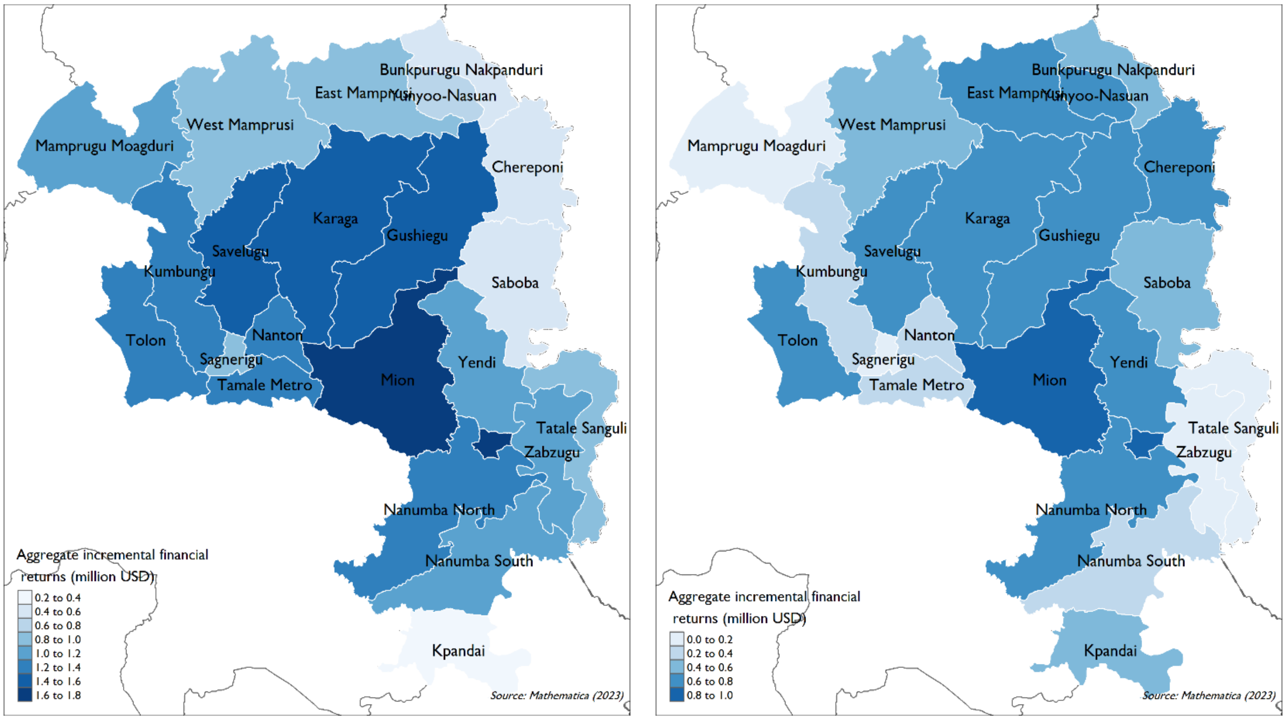
Exhibit 16. Aggregate incremental financial returns (NPVs) for farmers applying IMP cultivation of maize (left) and soybean (right), by district



Note: Present value = 2023-2024; discount rate = 12 percent; climate scenario = optimistic; adoption rate = 60 percent. The analysis uses the "optimistic" risk setting within the IFAD CARD tool to model the likely effects of climate change on future yields.

CARD = Climate Adaptation in Rural Development; IFAD = International Fund for Agricultural Development; IMP = improved systems; NPV = net present value; USD = United States dollar.

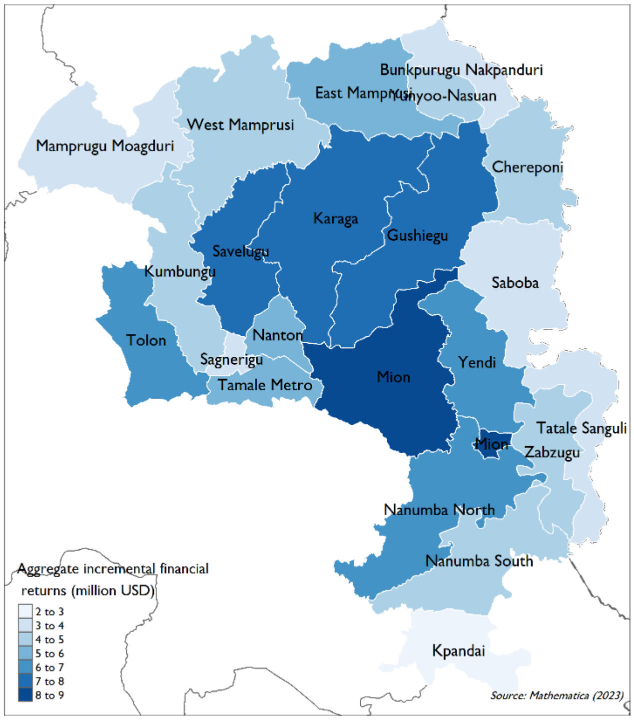
Exhibit 17. Aggregate incremental financial returns (NPVs) for farmers applying ETP with maize (left) and soybean (right), by district



Note: Present value = 2023-2024; discount rate = 12 percent; climate scenario = optimistic; adoption rate = 60 percent. The analysis uses the "optimistic" risk setting within the IFAD CARD tool to model the likely effects of climate change on future yields.

CARD = Climate Adaptation in Rural Development; ETP = enhanced tree planting; IFAD = International Fund for Agricultural Development; NPV = net present value; USD = United States dollar.

Exhibit 18. Aggregate incremental financial returns (NPVs) for farmers applying soybean-maize CR, by district



Note: Present value = 2023-2024; discount rate = 12 percent; climate scenario = optimistic; adoption rate = 60 percent. The analysis uses the "optimistic" risk setting within the IFAD CARD tool to model the likely effects of climate change on future yields.

CARD = Climate Adaptation in Rural Development; CR = crop rotation; IFAD = International Fund for Agricultural Development; NPV = net present value; USD = United States dollar.

Despite offering comparable services in their out-grower technology packages, the two investees report substantially different costs per hectare. The financial benefits of Idan Agro and Clean Savana are positive and primarily come from the principal and interest repayment of their technology packages. They also include revenue from grain sales by both investees and agrochemical sales by Clean Savana.

The financial analysis also assessed the investors' (bankers') perspective and found that investees' annual cash flow is sufficient to comfortably service their loans. To inform the investors' perspectives in the CBA, we first removed annual loan principal and interest payments. We then calculated the annual debt service coverage ratio (ADSCR) which is the ratio of the annual net cash flow to the annual debt repayment (Exhibit 19). An ADSCR of 1.2 to 1.5 is often considered a benchmark for investible projects. We assumed a fixed annual loan repayment schedule and that non-recurring overhead costs are incurred in the first year and again one decade later. In a year with non-recurring overhead costs (year A), the ADSCR for Idan Agro is 3.2. In years without these costs it is 4.2 (year B). Since the ADSCR in years A and B are above the 1.2 or higher required by investors as a worthwhile investment, it signifies that Idan Agro will have sufficient cash flow each year to cover the annual loan repayment.[11] We do not account for any anticipated volatility in annual crop yields under climate change that might impact the ADSCR since this volatility will affect investees' costs *and* revenues which are likely to cancel each other out.

[11] We cannot estimate an ADSCR for Clean Savana as we did not receive information on its loan repayments.

Exhibit 19. Investee annual debt service coverage ratio (2023 USD)

Idan Agro	Year A	Year B
Net cash flow (without loan repayment)	$394,214	$517,884
Annual repayment (principal and interest)	$121,583	$121,583
Annual debt service coverage ratio (ADSCR)	3.2	4.3

Note: 2021 cash flow information provided by Idan Agro. We assume that non-recurring overhead costs are incurred in the first year and again one decade later. Year A illustrates the ADSCR during a year with non-recurring costs. Year B shows the ADSCR for years without non-recurring costs.

USD = United States dollar.

ECONOMIC ANALYSIS

The economic analysis extends the financial analysis by considering costs and benefits associated with GHG emissions and sequestration, respectively. Exhibit 20 (Panel A) shows the present value of incremental economic costs and benefits per hectare over the 20-year period associated with the three technology packages for farmers. It also shows the incremental per-hectare economic NPVs for the three technologies. Exhibit 20 (Panel B) shows the present value of incremental economic costs and benefits for the investees. Because the economic analysis considers the GHG mitigation/sequestration associated with the technologies as a global benefit, all costs are unchanged. In addition, investees' returns are unaffected by GHG mitigation/sequestration, and are thus also unchanged.

Exhibit 20. Incremental per-hectare economic results (2023 USD)

Panel A: Farmers				
Technology	**Crop**	**Costs PV**	**Benefits PV**	**NPV**
IMP	Maize	-$137	-$199	-$62
	Soybean	$153	-$970	-$1,123
ETP	Maize	$93	$472	$379
	Soybean	$93	$472	$379
Soybean-maize CR	Both	$0	$817	$817
Panel B: Investees				
Investee	**Crop**	**Costs PV**	**Benefits PV**	**NPV**
Idan Agro	Maize, soybean, and rice	$22,799	$29,507	$6,708
Clean Savana	Soybean	$1,255	$2,241	$986

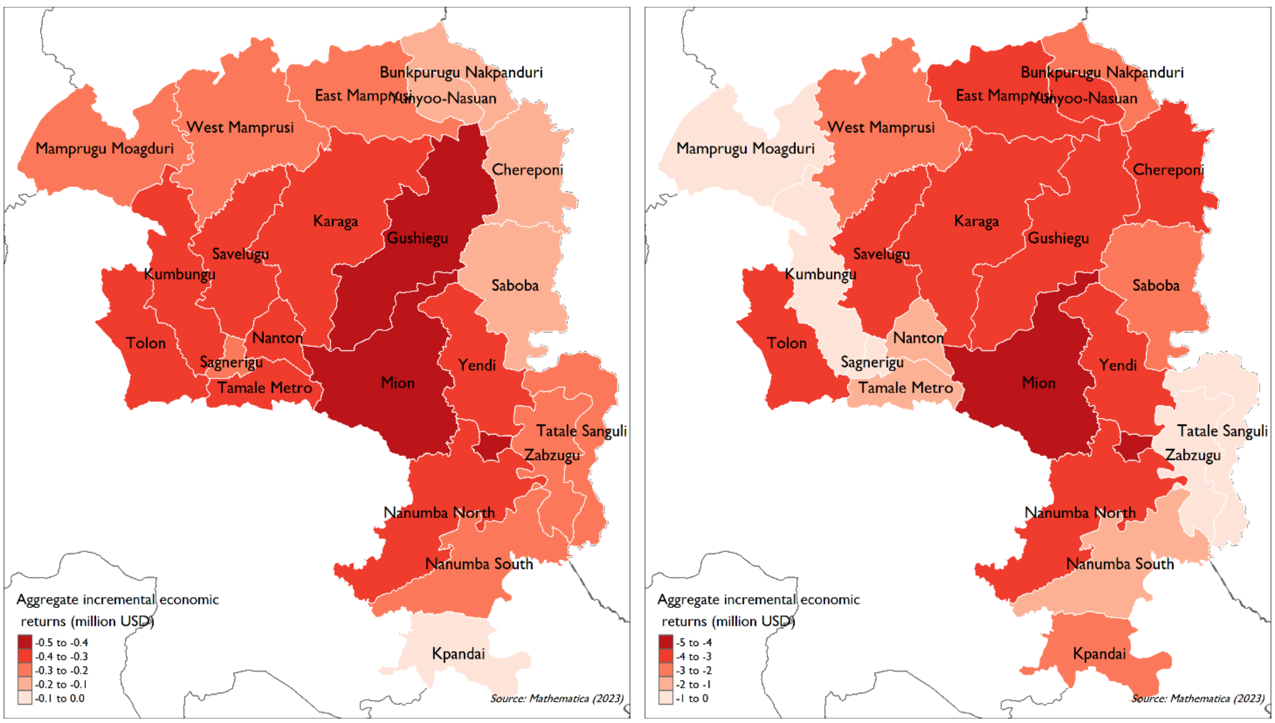
Note: Present value = 2023-2024; discount rate = 12 percent; climate scenario = optimistic; social cost of carbon = USD $51. The analysis uses the "optimistic" risk setting within the IFAD CARD tool to model the likely effects of climate change on future yields. Since investees do not support the BAU technology package and hence incur no costs under that technology, their incremental values are equivalent to actual costs.

BAU = business-as-usual; CARD = Climate Adaptation in Rural Development; CR = crop rotation; ETP = enhanced tree planting; IFAD = International Fund for Agricultural Development; IMP = improved systems; NPV = net present value; PV = present value; USD = United States dollar.

Because all three technologies mitigate/sequester carbon, the incremental economic NPVs for all technologies were higher than their respective financial NPVs. However, the monetized GHG emissions benefits were not always large enough to outweigh other associated costs. For example, over 20 years, the incremental per-hectare NPV of IMP maize cultivation was –$62, assuming a carbon price of $51; positive economic NPV values emerged only under higher assumed carbon prices (Appendix Exhibit D.3). The corresponding economic NPV values of IMP soybean cultivation were consistently negative, ranging from –$1,123 to –$1,055, depending on the price of carbon. This suggests that, on average, these technologies are delivering neither farmer livelihood nor global sustainability benefits over the longer term. In contrast, incremental per-hectare economic NPVs of ETP and soybean-maize CR are large and positive, ranging from $379 per hectare for ETP to $817 per hectare for soybean-maize CR. This suggests the potential for "win-win" livelihood and sustainability impacts from widespread adoption of these technologies.

Farmer-level economic returns associated with the three technologies also demonstrate intra-regional variation. Exhibits 21, 22, and 23 present the intra-regional variation in incremental economic NPVs for the Northern and North East regions for IMP, ETP, and soybean-maize CR, respectively, for the main scenarios. Given the GHG sequestration potential of each of these technologies, aggregate incremental economic returns under the main scenario are higher than the corresponding incremental financial returns. Areas in which both levels are positive (such as the district of Mion for soybean-maize CR) could be targeted initially for scale-up of the respective technologies in order to deliver "win-win" financial and climate benefits. Conversely, implementation in areas where neither financial nor economic returns are positive (as in the case IMP cultivation) should be downscaled as these activities are delivering neither livelihood nor sustainability gains. We report aggregate results at the region level in Appendix Exhibit D.5.

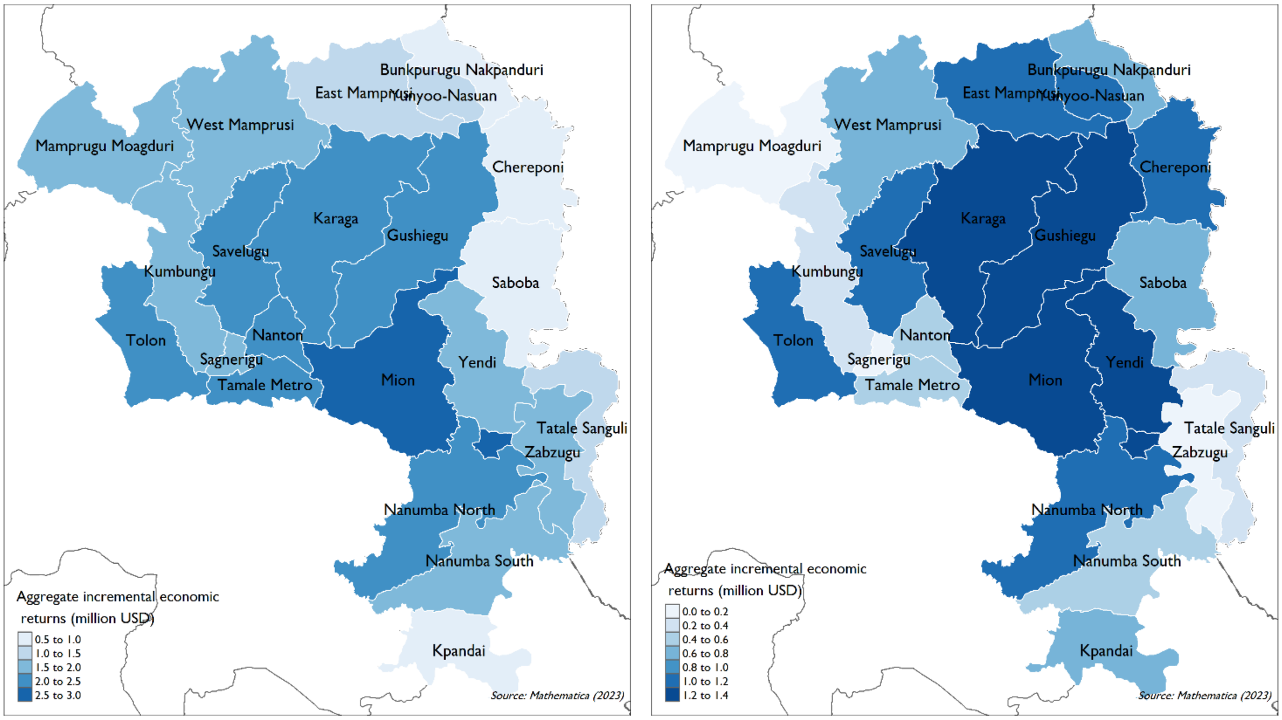
Exhibit 21. Aggregate incremental economic returns (NPVs) for farmers applying IMP cultivation of maize (left) and soybean (right), by district



Note: Present value = 2023-2024; discount rate = 12 percent; climate scenario = optimistic; social cost of carbon = USD $51; adoption rate = 60 percent. The analysis uses the "optimistic" risk setting within the IFAD CARD tool to model the likely effects of climate change on future yields.

CARD = Climate Adaptation in Rural Development; IFAD = International Fund for Agricultural Development; IMP = improved systems; NPV = net present value; USD = United States dollar.

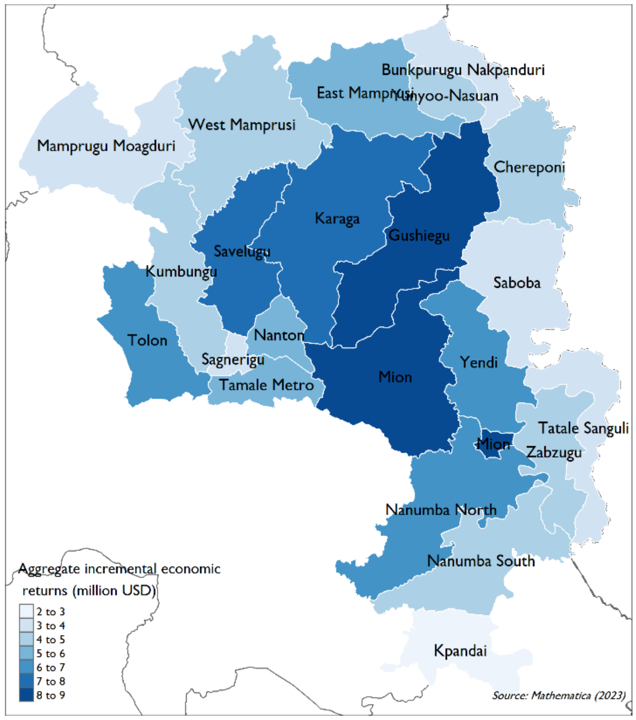
Exhibit 22. Aggregate incremental economic returns (NPVs) for farmers applying ETP with maize (left) and soybean (right), by district



Note: Present value = 2023-2024; discount rate = 12 percent; climate scenario = optimistic; social cost of carbon = USD $51; adoption rate = 60 percent. The analysis uses the "optimistic" risk setting within the IFAD CARD tool to model the likely effects of climate change on future yields.

CARD = Climate Adaptation in Rural Development; ETP = enhanced tree planting; IFAD = International Fund for Agricultural Development; NPV = net present value; USD = United States dollar.

Exhibit 23. Aggregate incremental economic returns (NPVs) for farmers applying soybean-maize CR, by district



Note: Present value = 2023-2024; discount rate = 12 percent; climate scenario = optimistic; social cost of carbon = USD $51; adoption rate = 60 percent. The analysis uses the "optimistic" risk setting within the IFAD CARD tool to model the likely effects of climate change on future yields.

CARD = Climate Adaptation in Rural Development; CR = crop rotation; IFAD = International Fund for Agricultural Development; NPV = net present value; USD = United States dollar.

LIMITATIONS

The main limitations of this analysis are as follows:

1. If the investee-supported technology packages involve learning by doing, then adopters might require multiple years to fully achieve potential yield gains. In such a scenario, revisiting households that have adopted improved cultivation practices in future years might reveal higher yields for maize and soy. Similarly, the relatively short period covered by this study means that it does not investigate the resilience of the focus technologies to climate change, which would have required more years of data covering a range of realized weather conditions.
2. Our primary data collection strategy involved sampling farmers targeted by the investees and comparable farmers who had not received any investee support. Such farmers are likely not representative of the set of farmers in the Northern and North East regions of Ghana. Similarly, the investees whom this study focused on may not be representative of the typical agricultural firm in Ghana.
3. The CARD tool, which this study uses to model the projected impact of climate change on agricultural yields, assumes that the future climate evolves according to the RCP 8.5 emissions scenario. This is a high-emissions climate scenario that implicitly assumes the absence of concerted mitigation efforts driven by climate policy. As a result, it may be considered too pessimistic, and may not accurately reflect future climate trajectories.
4. Our primary data collection focuses exclusively on the Northern and North East regions of Ghana. The productivity effects of adopting the various technology packages are likely to differ by agroecological conditions and therefore may vary significantly from the results obtained in this CBA.

RESULTS FROM ALTERNATIVE SCENARIOS

KEY FINDINGS FROM THE MAIN SCENARIO

- Adoption of enhanced tree planting and soybean-maize crop rotation had a positive financial net present value (NPV) for farmers, but improved cultivation did not.
- Because all three technologies mitigate/sequester carbon, the incremental economic NPVs for all technologies were higher than their respective financial NPVs. However, the monetized GHG emissions benefits were not always large enough to outweigh other associated costs.
- Intra-regional variation in returns helps shed light on areas with positive financial and economic returns, which could be targeted initially for scale-up to deliver "win-win" livelihood and climate benefits.

The main scenario evaluates financial and economic returns associated with moving from conventional agricultural technologies and practices assumed to be cultivated in the BAU case to the adoption of the agricultural technology package offered by the investees. In this scenario, underlying agricultural practices (such as tillage, planting methods, and fertilizer usage) are assumed to be the same as in the BAU case, although their specific levels vary between BAU and IMP farmers. Specifically, for the investee-promoted agricultural technologies as well as BAU cultivation, we assume that farmers till their plots, plant their crops in rows, and apply synthetic fertilizer.

Subsequent scenarios adjust these and other parameters to assess how the financial and economic returns associated with adoption of sustainable agricultural technologies change. In this section, we present the results from three alternative scenarios that generate additional insights to inform potential scale-up of improved agricultural technologies. Specifically:

1. **Alternative scenario 1** assumes that the adoption rate of each technology is 100 percent to shed light on how perfect adoption of promoted technologies would modify the costs and benefits associated with adoption when considered in aggregate, at district or region level.
2. **Alternative scenario 2** assumes that there are no differences in crop yields between targeted farmers who have adopted the agricultural technologies and comparison farmers who have not to partly account for baseline differences in observed yields levels between the two groups.
3. **Alternative scenario 3** uses the "median" risk setting to summarize the CARD model results relating to the projected impacts of future climate change on agricultural yields in Ghana, which results in lower maize and soybean yields than under the "optimistic" setting used in our main scenario.

These scenarios serve as sensitivity analyses for the main scenario results, allowing us to gauge the extent to which the main findings are driven by assumptions relating to the adoption rate, baseline differences in farmer skills (as proxied by yields), and projected impacts of climate change on agricultural performance. Note that because the returns and costs for investees do not depend on farmer-level yields, the incremental per-hectare NPVs for investees under each of the alternative scenarios are identical to those under the main scenario. For this reason, this section presents incremental per-hectare NPV values for farmers, and incremental regional values for both farmers and investees.

RESULTS OF ALTERNATIVE SCENARIO 1 (FULL ADOPTION)

Alternative scenario 1 assumes that the adoption rate of each technology is 100 percent to shed light on how full adoption of promoted technologies would modify the costs and benefits associated with adoption. The incremental per-hectare NPVs for farmers are identical to those under the main scenario because full adoption does not affect per-hectare returns—we assume that a technology package is either adopted or not adopted on an individual plot, and that adoption-level differences arise when considering a collection of plots. Exhibit 24 presents results from using those per-hectare NPVs to estimate region-wide returns associated with the three technologies. IMP maize cultivation delivers positive returns at the regional level only for SCC values above some value between $51 and $125. Regardless of SCC value, IMP soybean cultivation delivers negative financial and economic returns. The financial and economic NPVs associated with ETP are positive and large, reaching a combined $205 million for both regions under an SCC of $185. Soybean-maize CR is less responsive to rising SCC values since the incremental reductions in GHG emissions are smaller than the sequestration levels in ETP.

Exhibit 24. Incremental regional NPV under alternative scenario 1 (2023 USD)

					Economic NPV		
Actor	Technology package	Crop	Region	Financial NPV (millions)	$51 carbon price (millions)	$125 carbon price (millions)	$185 carbon price (millions)
Farmer	IMP	Maize	Northern	-$12.5	-$8.1	$7.4	$20.0
			North East	-$3.1	-$2.0	$1.9	$5.0
		Soybean	Northern	-$61.2	-$60.7	-$58.6	-$57.0
			North East	-$23.2	-$23.0	-$22.2	-$21.6
	ETP	Maize	Northern	$31.5	$49.5	$113.1	$164.7
			North East	$7.9	$12.4	$28.4	$41.3
		Soybean	Northern	$13.0	$20.5	$46.8	$68.1
			North East	$4.9	$7.8	$17.7	$25.8
	Soybean-maize CR	Both	Northern	$149.0	$150.9	$157.9	$163.6
			North East	$42.9	$43.5	$45.5	$47.1
Investee: Idan Agro	IMP	Maize, soybean, and rice	Northern	$1,238.8	$1,238.8	$1,238.8	$1,238.8
			North East	$356.9	$356.9	$356.9	$356.9
Investee: Clean Savana	IMP	Soybean	Northern	$53.3	$53.3	$53.3	$53.3
			North East	$20.2	$20.2	$20.2	$20.2

Note: Present value = 2023-2024; discount rate = 12 percent; climate scenario = optimistic; carbon credit price = USD $30; adoption rate = 100 percent. Since investees do not support the BAU technology package and hence incur no costs under that technology, their incremental values are equivalent to actual costs.

BAU = business-as-usual; CR = crop rotation; ETP = enhanced tree planting; IMP = improved systems; NPV = net present value; USD = United States dollar.

RESULTS OF ALTERNATIVE SCENARIO 2 (NO BASELINE YIELD DIFFERENCE)

As noted in Exhibit 10, our primary data showed that farmers that had adopted investee-promoted IMP cultivation practices had lower yields than comparable farmers who had not. These baseline yield differences could be stemming from a variety of factors, including differences in skill levels between targeted and comparison farmers. To offset those inter-group baseline differences, under alternative scenario 2 we assume that crop yields between BAU and IMP farmers are identical.

Exhibits 25 and 26 show the incremental per-hectare costs, benefits and NPVs from the financial and economic analyses, respectively, for farmers under alternative scenario 2. If there were no baseline differences in yields, IMP maize and soybean cultivation would have large, positive financial as well as economic benefits for farmers, on the scale of $1,250 per hectare. This indicates that the lower yields observed for targeted farmers are a key driver of low or negative IMP returns under the main scenario. Because the returns associated with ETP and soybean-maize CR are not directly governed by farmers' yields, the incremental NPVs for these technologies under alternative scenario 2 equal those from the main scenario.

Exhibit 25. Incremental per-hectare financial results under alternative scenario 2 (2023 USD)

Panel A: Farmers				
Technology	**Crop**	**Costs PV**	**Benefits PV**	**NPV**
IMP	Maize	-$137	$1,112	$1,249
	Soybean	$153	$856	$702
ETP	Maize	$93	$334	$241
	Soybean	$93	$334	$241
Soybean-maize CR	Both	$0	$807	$807
Panel B: Investees				
Investee	**Crop**	**Costs PV**	**Benefits PV**	**NPV**
Idan Agro	Maize, soybean, and rice	$22,799	$29,507	$6,708
Clean Savana	Soybean	$1,255	$2,241	$986

Note: Present value = 2023-2024; discount rate = 12 percent; climate scenario = optimistic; carbon credit price = USD $30. Since investees do not support the BAU technology package and hence incur no costs under that technology, their incremental values are equivalent to actual costs.

BAU = business-as-usual; CR = crop rotation; ETP = enhanced tree planting; IMP = improved systems; NPV = net present value; PV = present value; USD = United States dollar.

Exhibit 26. Incremental per-hectare economic results under alternative scenario 2 (2023 USD)

Panel A: Farmers				
Technology	**Crop**	**Costs PV**	**Benefits PV**	**NPV**
IMP	Maize	-$137	$1,145	$1,283
	Soybean	$153	$866	$713
ETP	Maize	$93	$472	$379
	Soybean	$93	$472	$379
Soybean-maize CR	Both	$0	$817	$817
Panel B: Investees				
Investee	**Crop**	**Costs PV**	**Benefits PV**	**NPV**
Idan Agro	Maize, soybean, and rice	$22,799	$29,507	$6,708
Clean Savana	Soybean	$1,255	$2,241	$986

Note: Present value = 2023-2024; discount rate = 12 percent; climate scenario = optimistic; social cost of carbon = USD $51. The analysis uses the "optimistic" risk setting within the IFAD CARD tool to model the likely effects of climate change on future yields. Since investees do not support the BAU technology package and hence incur no costs under that technology, their incremental values are equivalent to actual costs.

BAU = business-as-usual; CARD = Climate Adaptation in Rural Development; CR = crop rotation; ETP = enhanced tree planting; IFAD = International Fund for Agricultural Development; IMP = improved systems; NPV = net present value; PV = present value; USD = United States dollar.

RESULTS OF ALTERNATIVE SCENARIO 3 ("MEDIAN" CLIMATE RISK SETTING)

As noted in the Data Sources subsection, CARD summarizes climate-crop model ensemble results according to three risk settings: pessimistic, median, and optimistic, which respectively reflect the 10th percentile, median, and 90th percentile values from the distribution of all climate-crop model output. The main scenario employs the optimistic risk setting. To assess the extent to which relatively more pessimistic future climate projections might change results, we select the median risk setting in our alternative scenario 3. As shown in Exhibits 27 and 28—which display incremental per-hectare costs, benefits and NPVs from the financial and economic analyses from alternative scenario 3—median climate risk only marginally improves NPVs for IMP cultivation relative to the main scenario. Since the median risk setting assumes lower crop yields in all years, the improved incremental NPV arises from a shrinking difference in yield *levels* between IMP and BAU. For example, the maize yield difference in year 1 is 486 kg/ha (Exhibit 10). Since climate impacts through CARD acts as a percentage penalty on yields, the difference in subsequent years will be smaller than 486 kg/ha which would translate to an improved relative position for IMP technologies. However, the overall pattern—whereby incremental per-hectare financial NPVs for both IMP maize and soybean cultivation are negative, and incremental per-hectare economic NPVs are negative except for maize at higher assumed carbon prices—is unchanged. In addition, because returns from ETP and soybean-maize CR do not directly depend directly on farmers' yields, the incremental per hectare NPVs for these technologies under alternative scenario 3 are identical to those under the main scenario.

Exhibit 27. Incremental per-hectare financial results under alternative scenario 3 (2023 USD)

Panel A: Farmers				
Technology	**Crop**	**Costs PV**	**Benefits PV**	**NPV**
IMP	Maize	-$137	-$226	-$89
	Soybean	$153	-$943	-$1,096
ETP	Maize	$93	$334	$241
	Soybean	$93	$334	$241
Soybean-maize CR	Both	$0	$807	$807
Panel B: Investees				
Investee	**Crop**	**Costs PV**	**Benefits PV**	**NPV**
Idan Agro	Maize, soybean, and rice	$22,799	$29,507	$6,708
Clean Savana	Soybean	$1,255	$2,241	$986

Note: Present value = 2023-2024; discount rate = 12 percent; climate scenario = median; carbon credit price = USD $30. Since investees do not support the BAU technology package and hence incur no costs under that technology, their incremental values are equivalent to actual costs.

BAU = business-as-usual; CR = crop rotation; ETP = enhanced tree planting; IMP = improved systems; NPV = net present value; PV = present value; USD = United States dollar.

Exhibit 28. Incremental per-hectare economic results under alternative scenario 3 (2023 USD)

Panel A: Farmers				
Technology	**Crop**	**Costs PV**	**Benefits PV**	**NPV**
IMP	Maize	-$137	-$193	-$55
	Soybean	$153	-$932	-$1,086
ETP	Maize	$93	$472	$379
	Soybean	$93	$472	$379
Soybean-maize CR	Both	$0	$817	$817
Panel B: Investees				
Investee	**Crop**	**Costs PV**	**Benefits PV**	**NPV**
Idan Agro	Maize, soybean, and rice	$22,799	$29,507	$6,708
Clean Savana	Soybean	$1,255	$2,241	$986

Note: Present value = 2023-2024; discount rate = 12 percent; climate scenario = median; social cost of carbon = USD $51. The analysis uses the "median" risk setting within the IFAD CARD tool to model the likely effects of climate change on future yields. Since investees do not support the BAU technology package and hence incur no costs under that technology, their incremental values are equivalent to actual costs.

BAU = business-as-usual; CARD = Climate Adaptation in Rural Development; CR = crop rotation; ETP = enhanced tree planting; IFAD = International Fund for Agricultural Development; IMP = improved systems; NPV = net present value; PV = present value; USD = United States dollar.

CROSS-SCENARIO COMPARISON

Farmers should find it financially beneficial to adopt ETP and soybean-maize CR. The financial NPVs for these technologies are relatively large and positive under all scenarios. Under the main scenario, for example, the NPVs of the stream of financial returns are $241 and $807 per hectare for ETP and soybean-maize CR, respectively. For ETP, these gains result from the value of tree products as well as revenue from carbon credits for the carbon sequestered by trees. For soybean-maize CR, gains result primarily from the value of the increase in maize yield due to adoption of the practice, and partly due to fertilizer cost savings and carbon credits.

Positive economic returns associated with ETP and soybean-maize CR mean that promotion of these technologies has the potential to deliver "win-win" outcomes. In addition to financial gains for farmers, the adoption of ETP and soybean-maize CR also mitigates/sequesters GHG emissions. This in turns reduces global damages associated with climate change. For this reason, the economic NPVs associated with adoption of the two technologies are consistently larger than their corresponding financial returns across all scenarios.

Returns from improved cultivation are greatly dependent on yields. Due to lower reported yields among farmers who had adopted investee-promoted improved cultivation practices relative to comparison farmers who had not, financial returns associated with IMP maize and soybean cultivation were lower under the main scenario than under the BAU scenario. In particular, higher investee-guaranteed prices (relative to market rates) were not sufficient to outweigh the negative implications of lower yields. Additionally, due to the relatively limited GHG emissions mitigation/sequestration associated with adoption of these practices, corresponding economic returns were also negative. There were only two instances where this was not case: (1) when carbon prices were assumed to be relatively high (IMP maize cultivation only); and (2) when no yield differential between comparison and targeted farmers was assumed to exist (IMP cultivation of both crops). This suggests that if IMP cultivation practices do not result in higher yields for adopting farmers, they will deliver neither livelihood nor sustainability gains over the longer term.

INTRA-HOUSEHOLD DISTRIBUTION OF COST AND BENEFITS

To better understand the intra-household gender implications of adopting practices promoted by the investees, we conducted 20 KIIs (12 treatment, eight BAU) with women in households that participated in the survey. Those implications cannot always effectively be discerned through survey responses. Therefore, we analyzed transcripts to determine if there are important and gender-differentiated consequences of the recommended practices that, although not priced or included in NPV estimates, are important in holistically considering impacts from a given intervention.

Land is owned by the household or in the name of the male household head. Only one respondent, a mother of the household head, indicated that she herself owned land. These findings are in line with trends in northern Ghana where cultural and administrative barriers to female landownership persist. Even when women do formally own land, decisions are customarily made by a male household member (IFPRI 2020). Most women did cultivate crops, frequently groundnut and/or soybean, on a piece of land (averaging one to two acres in size) allocated to them by the household head.

Women across treatment and comparison households are unevenly applying recommended agricultural practices. Crop rotation is reportedly practiced by all treatment household respondents and all but one comparison respondent while the use of a tractor for land preparation is preferred over zero/reduced tillage. Other improved practices promoted by the investees, such as planting in rows, sowing seeds in a hole, and applying fertilizer in a hole next to the plant have mixed adoption rates—roughly similar numbers of adopters and non-adopters—across both treatment and comparison households. Women who practice CR state that it increases soil fertility and subsequently improves yields. Interviewees adopting these practices self-reported higher yields, ease of harvesting, and reduced pests as benefits.

The recommended agricultural practices are more labor intensive than traditional practices and can cut into time women have available for other income-generating activities at certain times of year. Respondents from treatment and comparison groups alike mentioned that these practices required one to two additional weeks of general labor for planting and applying fertilizer. Women are heavily involved in this cultivation phase and reportedly conduct around 40 percent of the labor. Accordingly, one interview respondent stated that "planting in rows [...] is labor intensive [because] it increases the amount of work you do, and the time spent on it." These practices thus further increase the demand for women's labor during the early stages of the agricultural season and take away time to, for example, harvest shea or work as a seamstress. Some respondents mentioned that this time investment was compensated at a later stage in the season as crops planted in rows are faster to harvest. While planting and precise fertilizer placement are viewed as increasing women's labor burden for those activities, one respondent stated that "crop rotation is helping [her] by reducing the time [she] spends on farming activities," which allows her "to roast groundnut for sale."

Men typically exercise decision-making power over which crops are grown and what inputs are bought for the household's agricultural land. The man typically also decides, sometimes after consulting with their spouse(s), how much of the harvest is sold and how sales income is spent, keeping the interests of the household in mind. One respondent described the reason in terms of norms. "We have a meeting as a family and decide on what we should cultivate but it is the man that will decide on the final crops […]. This is because they are our husbands, and we cannot be above them in decision making." Another respondent explained that male decision making is common because the husband is the most knowledgeable of agriculture in the household: "[the male household head] has the final say in the crops to grow for a particular year and [what] inputs will be applied since he is the one to support […] the farm."

For crops on land assigned to women, or for plots on which they did most of the agricultural labor, women are more likely to report that their view is heard or considered by the household head. This is a noteworthy change and suggests that at minimum the interviewed women—those with more labor responsibilities—are also somewhat more empowered than women working on plots that are not their own. A few respondents noted that they had the final say when taking into account household consumption and other necessities in the decision making. However, that they still need "to inform him about the spending" likely signals a lack of full autonomy.

Access to credit inputs and collaboration with investees can trigger a shift in the role of a crop in the household, from subsistence to income generation, potentially leading to a transfer of responsibility from women to men. Almost all interviewed treatment households grew at least maize, soybean, and groundnut, while comparison households generally cultivated maize and soybean as the main crops. Through the interviews, it became apparent that women were responsible for soybean in comparison households and groundnut in treated households. This shift in women's responsibilities from soybean to groundnut cultivation, as a result of collaborating with the investees, could benefit the family's crop diversification, food security, and resilience to shocks. However, the interviews indicated that responsibility corresponds with empowerment. Hence, this shift could also mean that women in treated households were losing decision-making power as the crop towards which their responsibility shifted likely represents a smaller share of the household's total crop production. In addition, groundnuts are typically mainly grown for home consumption while soybean is often considered a cash crop. Women could thus also see their influence over how the household's sales income is spent reduced. These findings emphasize the importance of considering gender roles and crop diversification in designing sustainable livelihood interventions.

CONCLUSIONS AND POLICY RECOMMENDATIONS

This brief drew on primary and secondary data to estimate the financial and economic returns to adopting an improved agricultural technology package promoted by Ghanaian agribusinesses as part of the USAID-funded SLUF project. We focused on an improved technology package developed for maize and soybean cultivation in Ghana's Northern and North East regions.

We found that adopters received smaller financial returns than BAU farmers applying traditional agricultural practices and who were not engaged with receiving support from a private company. Average maize and soybean yields were lower on IMP plots than on BAU plots—even though IMP farmers had access to a higher sales price for their harvested output since investees offered their clients a premium off-take price compared to other sales options available to cultivators. The carbon mitigation/sequestration benefits associated with adopting the technology package were not large enough to offset the negative financial returns facing farmers. In contrast, adoption of ETP and soybean-maize CR delivered both livelihood and climate benefits.

Whereas many evaluations of agricultural technologies focus exclusively on the financial results of technology adoption, and therefore the perspective of private benefits and private costs, our CBA considered a broader scope of societal benefits and societal costs that should be considered when determining whether new technologies are (1) truly sustainable and (2) should be scaled up. Accordingly, this brief also provides policy recommendations specific to the three technologies that are the focus of the main cost-benefit analyses, highlighting the importance of multi-sectoral programming to improve understanding of the implications and opportunities related to scaling promising agricultural technologies.

Investments by donors in developing or promoting new agricultural technologies should consider their financial implications for farmers. The cost-benefit analyses presented in this brief hinged on collecting data on a comprehensive set of financial costs and benefits facing farmers who had adopted the focus technologies as well as those who had not. In so doing, these analyses extended the focus of agronomic research beyond simply agricultural productivity outcomes. The reason for doing so is clear: an agricultural technology's failure to deliver financial benefits for adopting farmers has significant implications for scale-up over the longer term (for example, farmers' unwillingness to adopt the technology in the absence of subsidies to cover livelihood shortfalls, which is turn requires additional donor financing). Such financial analyses can be carried out concurrently with research and development of new agronomic practices or cultivars, which often involve scientific field trials that can be expanded to gather information on associated costs and benefits.

Assessment of new technologies should also consider their multi-sectoral impacts. A key component of the cost-benefit analyses presented in this brief was the focus on assessing the multi-sectoral impact of the focus technologies. Specifically, through an assessment of the GHG mitigation/sequestration potential of the various technologies, we highlighted the conditions under which they may or may not deliver global net benefits. This in turn has implications for key decisions relating to technology scale-up. For example, we demonstrated that economic returns associated with IMP maize cultivation are only positive when the price of carbon is assumed to be relatively high—above \$51/tCO_2-eq. Given recent advances in the policy and research dialogue surrounding the social cost of carbon (for example, EPA 2022), these higher carbon prices may be the appropriate benchmarks to consider for future analyses. This suggests that a strategy for scaling-up improved maize cultivation should aim to account for the "wedge" between negative financial returns and positive economic returns (for example, through carbon financing). In contrast, improved soybean cultivation delivers neither livelihood nor climate benefits under any of the scenarios we considered, suggesting that additional resources may be better allocated to other promising agricultural technologies.

Landscape-level analysis is important for shedding light on geographical variations in returns and informing scale-up strategies. The cost-benefit analyses presented in this brief shed light on returns at the district level. These results incorporate the influence of variation in adoption rates across administrative units, thereby shedding light on where initial scale-up efforts may be most impactful. For example, district-level results indicate that incremental financial returns associated with ETP as well as soybean-maize CR are among the highest in Mion (Exhibits 17 and 18). This suggests that widespread dissemination of these technologies will be relatively easy to achieve, given the livelihood gains that they present to adopting farmers. Initial success associated with scale-up in this district could gain stakeholder buy-in and generate key lessons for expanding in other areas where the potential for returns is lower.

Intra-household distribution of the burden associated with adopting the technology packages should be considered to inform equitable scale-up strategies. Our qualitative interviews with women in households that participated in surveys revealed that promoted agricultural technologies were more labor-intensive, requiring one to two additional weeks of general labor for planting and applying fertilizer. If this labor is disproportionately performed by women, it reduces the time they have available to participate in other productive activities. At the same time, the benefits associated with women's labor may accrue to the household as a whole or primarily to the male household head. Careful consideration of context-specific intra-household dynamics is merited to inform scale-up strategies that might minimize or avoid unintended adverse effects on vulnerable and/or marginalized groups.

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APPENDIX A: FARMER SURVEY – SUSTAINABLE LAND-USE FOR SELF-RELIANCE

OVERVIEW OF MODULES

	Module	Start. time	End time	Est. time	Content
A	Consent & Screening			3 min	Intro
B	Household Characteristics			5 min	Household roster (age, gender, educ)
C	Plot Selection & Characteristics			5 min	Size, crops, plot selection, rent
D	Plot Inputs			8 min	Land preparation, seed, fertilizer, chemicals, bags, irrigation
E	Agricultural Labor			5 min	Collated for males, females, and children
F	Crop Usage: Main Crop			5 min	Harvested, lost, sold, consumed
G	Crop Usage: 2nd Crop			5 min	Harvested, lost, sold, consumed
H	Trees			3 min	Species, planted, maintenance
I	Gender			4 min	Differential impacts
J	Finish & Plot Dimensions			2 min	Thank you and GPS plot measurement
K	Final Section			N/A	Completed by the enumerator
	Total Time			**45 min**	

REFERENCES IN THE SURVEY

Reference	Description
%selected_plot%	The plot selected to collect input, labor and yield information on. The variable %selected_plot% is identified in question C12
%crop%	The main %crop% grown on the selected plot. Identified in question C4.
%second_crop%	The second %crop% grown on the selected plot. Identified in question C6.

SCREENING AND CONSENT

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
start_time	Start time	*date* *current timestamp (date & time)*			
interviewer_name	Interviewer full name	*text*			
treatment	Enumerator: Are you interviewing a treatment or control farmer?	*single-select*	Treatment 1 Control 0		
farmer	Enumerator: Please select the treatment farmer name. [List should show the farmer location (village, ward) and phone number to confirm their identify]	*List*		Treatment == 1	
Confirmation Decision-Maker					
intro_dm	If you find the selected household attempt to seek out a competent respondent. A competent respondent must be at least 18 years of age or older and must have knowledge of the household and its agricultural activities. After identifying the prospective respondent, please ask the following screening questions before obtaining their consent to take part in the study.	*static text*			
A1	Are you the person or one of persons who make farming decisions and is most knowledgeable regarding the crops that this household cultivated between May 2021 and December 2021?	*single-select*	Yes 1 No 0		
A2	Can I speak to the person making those decisions to ask questions about the crops you grow and the inputs that were used? Instructions: If "Yes", collect consent to conduct survey from main decision-maker.	*single-select*	Yes 1 No 0	A1 = 0	
A3	Why not?	*single-select*	Person is unavailable 1 [Reschedule] Person refused 2 [Terminate]	A2 = 0 [End of survey]	

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
			Other (specify) 96		
A4	Enumerator: What is the gender of the respondent?	*single-select*	Female 1 Male 0 Non-binary 3 I prefer not to say 98		
Consent					
Consent	Hello. My name is [xxxx] and I am working with the International Center for Tropical Agriculture (CIAT). We are conducting a study supported by the United States Agency for International Development (USAID) that is being carried out by Mathematica, a US-based research firm. We are gathering information from 250 farmers in your area to improve our understanding of the costs and benefits of sustainable land use agricultural practices in Ghana. The findings and recommendations flowing from this study might benefit you directly by providing insights into the costs and benefits of adopting different agricultural practices. If you agree to participate in this interview, we will ask you several questions about your household and your farm's agricultural activities. The questions are organized in modules and each module starts with a brief introduction of the topic. One of the modules contains questions for the wife or partner of the (male) household head, and we would also like to confirm the size of one the household's plots using a GPS-based tool or satellite imagery. The survey is expected to take about 45 minutes to complete. Any information you provide will be kept strictly confidential by the parties conducting this study. However, due to the make-up of the population under study, the combined answers to the survey's questions may make an individual person identifiable. The researchers will make every effort to protect your confidentiality. If you are uncomfortable answering any of the demographic questions, you may leave them blank. After the interview has been conducted, your responses will be stored in a secure location. Collected personal information, such as your name, location, and phone number will be stored in a separate dataset during the analysis to protect your privacy. In addition, the study results will be presented in a report and will not include any personal information which could be used to identify you or members of your household directly. Your participation in this study is voluntary and there are no risks or negative consequences associated with participation. If you choose to participate, you have the option not to answer a	*static text*			

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
	question, or stop the interview at any time and for any reason without consequences. You also have the alternative to not participate, and there will be no consequences for nonparticipation. Your participation is very important to our study and is part of a larger effort we are making to provide relevant information to help understand and improve agricultural practices in Ghana. However, there are no immediate benefits from participating in this interview and your responses may not affect any current, planned, or future delivery of services related to this project or any other project or program. If you have any questions regarding the research project, you may contact the main researcher Tiffany Talsma by email at t.talsma@cgiar.org. If you would like to speak with someone other than the primary investigator regarding questions or concerns, or if you would like to discuss your rights as a research participant, you may contact our local contact Samuel Seddoh at CSIR Campus, No.6 Agostino Neto Road, Airport Residential Area, Cantonments, Accra, phone number: +233540111160. Do you have any questions about the survey or what I have said? [INTERVIEWER ADDRESS RESPONDENT'S QUESTIONS.]				
A5	Do you agree to participate in this interview?	*single-select*	Yes 1 [Go A7] No 0		
A6	Could you please share why you felt unable to consent to this survey?	*text*		A5==0 [End of survey]	
Screening					
A7	Did your household grow any of the following **crops** from May to December 2021?	*multi-select*	Maize 1 Soybean 2 Rice 3 None of the above 0 [Terminate Survey]		
A8	What services/goods has your household received from Idan Agro/ Clean Savana or AgroFredina or Clean Savana between January 2021 and December 2021?	*text*	Crop Input 1 Mechanical Services 2 Other (Specify)	treatment == 1	

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
			96		
A9	Enumerator: Did the respondent's household take out a package of agricultural inputs, such as hybrid seed and synthetic fertilizer, from Idan Agro or Clean Savana? Instructions: Confirm that the enumerator received inputs from one of the investees	*single-select*	Yes 1 No 0 [Terminate survey] Don't know 99	treatment == 1 & A7.ContainsAny(1,2,3)	
A10	Are you currently engaged with any other private sector company offering inputs or services on credit?	*single-select*	Yes 1 [Terminate survey] No 0	treatment == 1 & A7.ContainsAny(1,2,3) & A9==1	
A11	Did you use the inputs you received from Idan Agro/Clean Savana on land you own or rent (out-grower), or land that is owned by a private sector company such as Idan Agro/Clean Savana (in-grower)? Instructions: The survey should be terminated for farmers who are in-growers and farm on private sector owned land. In-grower schemes are a profit-sharing model where farmers are offered training, production facilities, and land to grow crops.	*single-select*	In-grower 1 [Terminate survey] Out-grower 2 Both 3	treatment == 1 & A9 == 1	
A12	For which of the following crops did your household receive inputs from Idan Agro/Clean Savana?	*multi-select*	Maize 1 Soybean 2 Rice 3 Other (specify) 96 [Terminate survey if only "Other Specify", continue if one of the crops was selected]	treatment == 1 & A9 == 1	

HOUSEHOLD CHARACTERISTICS

Question number	Question text	Answer type	Response options	Enabling condition	Constraint

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
Static text	To start, I would like to ask you a few questions about you, your household and your farm.	*static text*			
B1a	What is your first name?	*text*			
B1b	What is your family name?	*text*			
B2	How many household members, including yourself, consistently live in your household? Explain: A household is a group of people who have usually slept in the same dwelling and share their meals together. Example of households are: • A household consisting of a man and his wife/wives and children, father/mother, nephew, and other relatives • A household consisting of a woman and her children • A household consisting of a single person • A household consisting of a couple or several couples with or without children	*numeric*			
roster_ intro	Could you provide me the age for everyone in the household and the relationship to the household head, and highest level of educational attainment for adults in the household starting with yourself?	*Static text*			
B3a	[For each household member] Name Instructions: A nickname for each household member is enough, you do not need to record full legal names.				
B3b	[For each household member] Age Instructions: For infants that are not a year old, record 0.	*numeric*			B4<=100 (Age cannot be above 100.)
B4	[For each household member] Gender	*single-select*	Male 0 Female 1 Non-binary 2 I prefer not to say -98	B3 > 15	

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
B5	[For each household member] Relationship to the household head	*single-select*	Household head 1 Spouse/partner of head 2 Child/adopted child 3 Grandchild 4 Niece/nephew 5 Mother/father 5 Sister/brother 6 Son/daughter-in-law 7 Grandfather/mother 8 Father/mother-in-law 9 Other relative 10 Servant 11 Lodger 12 Other non-relative 13	B3 > 15	
B6	[For each household member] Education		None 0 Kindergarten 1 Primary 2 JSS/JHS 3 Middle 4 SSS/SHS 5 Secondary 6 Voc/Tech/Comm	B3 > 15	

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
			7 Teacher, Agric/ Nursing Training 8 Polytechnic 9 University (bachelor) 10 University (post graduate) 11 Professional 12 Don't know -99		
B7	Thank you for answering those questions on the members of your household. What is your marital status/what is marital status of the household head?	*single select*	Single (never married) 1 Married w/ one spouse 2 Married w/ multiple spouses 3 Living with partner 4 Divorced 5 Separated 6 Widowed 7 I prefer not to say -98		

PLOT SELECTION & CHARACTERISTICS

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
Intro_c	Thank you for answering those questions I would now like to ask you about the land you				

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
	cultivated between May and December 2021.That is, not the crops you cultivated this year, in 2022, but the year before, in 2021. Let's first clarify a few terms. A **parcel** is a piece of land exploited by one or more persons as a single farming unit. A parcel may be bounded by natural boundaries and may comprise one or more plots. The natural boundary of a parcel may be a road, a waterway or a field belonging to another farm. A **plot** is defined a continuous piece of land on which a unique crop or a mixture of crops is grown, under a uniform, consistent crop management system. A plot can be a part of a parcel or cover the entire parcel.				
C.1 Plot Selection (2021 Season)					
C1	How many plots did you or anyone in your household use for growing maize, soybean, or rice from May to December 2021?	*numeric*			
C2a	Please list for me the names of all the plots that you or anyone in your household used for growing maize, soybean or rice from May to December 2021? [repeat for each plot]	*text*			
C2b	Please describe where the plot is located relative to your dwelling [repeat for each plot]	*text*			
C3a	What is the size of the plot? <u>Select Unit.</u> [repeat for each plot]	*single-select*	Square Pole 1 Acre 2 Hectare 3 Other (specify) - 96		
C3b	What is the size of the plot? <u>Select Quantity.</u> [repeat for each plot]	*numeric*		C3b>100 & C3b< 0.1 (The plot size seems too small/large.)	
C4	What was the main crop cultivated on this plot from May to December 2021? %crop% = Response	*single-select*	Maize 1 Soybean 2		

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
	[repeat for each plot]		Rice 3 Other (specify) - 96		
C5	Did you grow any other crops from May to December 2021 (apart from %crop%) on this plot? [repeat for each plot]	*single-select*	Yes 1 No 0		
C6	What other crop(s) did you plant on this plot from May to December 2021? [repeat for each plot]	*multi-select*	Cowpea 1 Pigeon pea 2 Mucuna (velvet bean) 3 Dolicos 4 Stylosanthes 5 Fonio 6 Beans 7 Cassava 8 Groundnut/Peanut 9 Guinea corn 10 Hibiscus 11 Maize 12 Millet 13 Potatoes/Sweet Potatoes 14 Rice 15 Sorghum 16 Tigernut 17 Wheat 18 Yam 19 Soybean 20	C5==1	

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
			Other (specify) - 96		
C7	Was the %crop% grown from May to December 2021 on this plot a purestand or inter-cropped with another crop? If purestand, please consider whether the two crops are actually separated into two separate plots.If yes, go back to question C1. [repeat for each plot]	*single-select*	Inter-cropping 1 Purestand 2	C5 == 1	
C7b	What share of the plot was intercropped? Instructions: And intercrop pattern of 1:1 (one row of crop A followed by one row of crop B) translates to 50%. An intercrop pattern of 1:2 translates to 33%. And intercrop pattern of 1:3 translates to 25%.	*numeric*	[Numeric] Don't know -99	C7 == 1	E5>=0 & E5<=100
C8	Did you use inputs or services from Idan Agro/Clean Savana/Agrofredina on this plot from May to December 2021? [Repeat for each plot]	*multi-select*	Yes, Idan Agro 1 Yes, Clean Savana 2 Yes, Agrofredina 3 No 0	treatment == 1 & C4.ContainsAny (1, 2,3)	
C9	What inputs and or services from Idan Agro/Clean Savana/Agrofredina did you use on this plot from May to December 2021? [Repeat for each plot]	*multi-select*	Seed 1 Fertilizer 2 Plowing/Tilling 3 Other mechanized services 4 Other (specify) 96	treatment == 1 & C8 ContainsAny (1, 2,3)	
C.2 Selected Plot – Detailed Plot Information					
static text	Interviewer: If more than one plot, use the selection tool to randomly select one of the listed plots.	*static text*			

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
	Selection Criteria – Control (BAU) Farmers • (C3) Plot size 2-14 acres • (C4) Main crop: maize, rice, or soybean Selection Method – Treatment (Investee) Farmers • (C3) Plot size 2-14 acres • (C4) Main crop: maize, rice, or soybean • (C8) Used input from investees (Idan Agro/Clean Savana/Agrofredina) • (A10) Farmer is an out-grower not an in-grower • (C5) Monocropped plot preferred				
C10	Interviewer: Enter the name of the randomly selected plot.	*text*			
static text	For the questions that follow we will focus on %selected_plot%. When answering these questions, please only think of the costs and inputs used on this single plot. If inputs were shared across several plots, please estimate the cost of the inputs and what share was used on the selected plot. I: Crop input questions will focus on one randomly selected plot.	*static text*			
Rent					
C11	Interviewer: Enter the main crop grown on the selected plot?	*single-select*	Maize 1 Soybean 2 Rice 3		
C12	Did you **rent** this plot from May to December 2021? Instructions: In-kind payments include part of the harvest and labor.	*multi-select*	Yes, paid in cash 1 Yes, paid in kind 2 No 0		
C13	How much did you pay, in cash, for renting this plot from May to December 2021? (GH₵)?	*numeric*	[Numeric] Don't know 99	C12 contains(1)	
C14	What period did this cash payment cover? I: Read options.	*multi-select*	One year 1 6 months 2	C12 contains(1)	

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
			Rainy season 3 Dry season 4 Other (specify) 96		
C15	What is the value of any payments in-kind you have made for renting this plot from May to December 2021? (GH₵)?	*numeric*	[Numeric] Don't know 99	C12 contains(2)	
C16	What period did this in-kind payment cover?	*single-select*	One year 1 6 months 2 Agricultural season (Roughly May until December) 3 Other (specify) - 96	C12 contains(2)	
C17	Who owns the plot?	*single-select*	The household (as collective) 1 The household head 2 Family of the household head 3 The spouse/one of the spouses of the household head 4 Family of the spouse 5 Other (specify) - 96	C12 contains(0)	

PLOT INPUTS (2021 SEASON)

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
static text	Next, I would like to ask you about the inputs and methods related to %crop% production on %selected_plot% from May to December 2021. The same year for which you just answered questions on ownership and rent. I would like to remind you to please make sure to only think of %selected_plot% when answering these questions. When I refer to the 2021 season, I am speaking of the season for which you sowed around May 2021 and harvested around December 2021.				
Land Preparation					
D1	How did you prepare the land for planting on %selected_plot%? Instructions: Prompt responses.	*single-select*	No-tillage 1 Ridge till (ridges) 2 Reduced or minimum tillage 3 Traditional tillage 4 Other (specify) -96		
Land Preparation - Animal					
D2	Did you or any member of your household use any **animals** to till the land for %crop% production on %selected_plot% for the 2021 season?	*single-select*	Yes 1 No 0		
D3	How many days did your household use animals <u>owned</u> by the household for preparing the land on %selected_plot% for the 2021 season? Instructions: Enter "0" if no animals owned by the household were used on the plot.	*numeric*	[Numeric] Don't know -99	D2 == 1	
D4	How much was spent on feeding the animals <u>owned</u> by this household used for preparing the land on %selected_plot% for the 2021 season (GH₵)? Instructions: If the animals were exclusively fed through open grazing the cost is "0" unless the respondent paid a fee in which case the fee should be included. If feed was not purchased but gifted or otherwise obtained, ask the farmer to estimate the cash value of feed given to the animals.	*numeric*	[Numeric] Don't know -99	D3 > 0	

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
D5	How many days did your household use rented animals for animal traction in %crop% production on %selected_plot% for the 2021 season? Instructions: Enter "0" if none.	*numeric*	[Numeric] Don't know -99	D2 == 1	
D6	How much was spent in cash in total on renting these animals for preparing on %selected_plot% for the 2021 season (GH₵)? Instructions: Enter "0" if none.	*numeric*	[Numeric] Don't know -99	D5 > 0	
D7a	Did you give the owner of the animals a share of your %crop% harvest in return for their services?	*Single-select*	Yes 1 No 0	D5 > 0	
D7b	How many bags of the %crop%'s harvest did your share in return for their services? Capture the unit.	*Multi-select*	1 Kilogram 1 5kg bags 2 10kg bags 3 25kg bags 4 50kg bags 5 60kg bags 6 100kg bags 7 [Local unit] -96	D7a == 1	
D7c	*[Loop through each of the responses chose for D7ba]* How many bags of the %crop%'s harvest did your share in return for their services? Capture the quantity.	*numeric*		D7a == 1	
D7d	What is the value of (other) in-kind payment in total made to rent these animals for preparing this plot for the 2021 season (GH₵)? Instructions: Estimate the total value of in-kind payments excluding payments made as a share of the %crop% harvest.	*numeric*	[Numeric] Don't know -99	D5 > 0	

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
Land Preparation - Machinery					
D8	Did you or any member of your household use any **machinery** to till the land for %crop% production on on %selected_plot% in preparation for the 2021 season?	*single-select*	Yes 1 No 0		
D9a	Did you receive this service from Idan Agro/Clean Savana/Agro Fredina?	*single-select*	Yes 1 No 0	treatment == 1 & D8 == 1	
D9b	Did you receive this service from another organization or company?	*single-select*	Yes 1 No 0		
D10	Do you or another member of your household own the machinery used to till the land for %crop% production on on %selected_plot% for the 2021 season?	*single-select*	Yes 1 No 0	(D8 == 1 & D9 == 0) or (D8 == 1 & treatment == 0)	
D11	How much did you spend on fuel for the machinery you own to prepare the land on %selected_plot% (GH₵)?	*numeric*	[Numeric] Don't know -99	D10 == 1	
D12	How much was spent in cash in total on <u>renting</u> the machinery to prepare the land on %selected_plot% for the 2021 season (GH₵)? Instructions: Enter "0" if nothing.	*numeric*	[Numeric] Don't know -99	D8 == 1	
D13	What is the value of in-kind payment in total on <u>renting</u> the machinery to prepare the land on %selected_plot% for the 2021 season (GH₵)? Instructions: Enter "0" if nothing.	*numeric*	[Numeric] Don't know -99	D8 == 1	
D14	Did you till the entire plot?	*single-select*	Yes 1 No 0	D1 > 1	
D15	In centimeters, approximately how deep did you till the soil?	*numeric*	[Numeric] Don't know -99	D1 > 1	D15>TBD& D15<TBD (This number seems too small/large.
D16	How many days prior to planting did you till the soil?	*numeric*	[Numeric]	D1 > 1	

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
			Don't know -99		
D17	Have you tilled the plot at the start of every season in the last 5 years?	*single-select*	Yes 1 No 0	D1 > 1	
D18	Other than for the season from May to December 2021 when did you last till the soil on this plot?	*Single-select*	2020 1 2019 2 2018 3 2017 4 More than 4 years before 5 I do not remember -99	D17 == 0	
Cost of Inputs – Seeds [Repeat for Main Crop, Second Crop, and Third Crop]					
seed	Enumerator: Is the second/third crop a seed crop?	*single-select*	Yes 1 No 0		
D19a	What type of %main_crop/second_crop% seed was used on %selected_plot% for the season from %season_1/season_2%	*multi-select*	Open-pollinated Varieties 1 Hybrid Seed 2 Other (specify) -96	Seed = 1	
D20	Is it certified or recycled seed?	*multi-select*	Certified 1 Recycled 2 Both 3	Seed = 1	
D21	For how many seasons have you recycled the seed?	*Numeric*	[Numeric] Don't know -99	D20 contains(2 or 3)	
D22	Approximately how many kilograms of <u>recycled</u> %main_crop/second_crop% seeds were planted on %selected_plot% for the 2021 season (kg)?	*numeric*	[Numeric] Don't know -99	D20 contains(2 or 3)	

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
	I: Use the size of the seed bag to determine the total quantity used in kilograms.				
D23a	What do you estimate is the market price for the for the <u>recycled</u> % main_crop/second_crop% seed at the time of planting that was used on %selected_plot% for the 2021 season (GH₵)?	*numeric*	[Numeric] Don't know -99	D20 contains(2 or 3)	
D23b	How much <u>recycled</u> %crop% seed would one be able to buy for that amount at the time of planting?	*single-select*	1 Kilogram 1 5kg bags 2 10kg bags 3 25kg bags 4 50kg bags 5 60kg bags 6 100kg bags 7 [Local unit] -96	D23a is not "Don't know"	
D24	Approximately how many kilograms of <u>certified</u> % main_crop/second_crop% seeds were planted on %selected_plot% for the 2021 season (kg)? I: Use the size of the seed bag to determine the total quantity used in kilograms.	*numeric*	[Numeric] Don't know -99	D20 contains(2 or 3)	
D25a	What do you estimate is the market price for <u>certified</u> % main_crop/second_crop% seed that was used on %selected_plot% for the 2021 season (GH₵)?	*numeric*	[Numeric] Don't know -99	D20 contains(2 or 3)	
D25b	How much <u>certified</u> % main_crop/second_crop% seed would one be able to buy for that amount?	*single-select*	1 Kilogram 1 5kg bags 2 10kg bags 3 25kg bags 4 50kg bags 5 60kg bags 6 100kg bags 7 [Local unit] -96	D25a is not "Don't know"	
D25c	How much did you pay in total for the cuttings or stems used to grow %second_crop%?	*numeric*	[Numeric] Don't know -99	Seed = 0	

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
Cost of Inputs – Herbicide & Pesticide					
D26	What was the total quantity of herbicide used in %crop% production on %selected_plot% for the 2021 season? I: Use the size of the bottle/bag to determine the total quantity used.	*numeric*	[Numeric] Don't know -99		
D27	What is the unit of measure for this quantity?	*single-select*	Liters 1 Kilograms 2	D26 is not -99 & D27 >0	
D28	What was the typical price of herbicide used in %crop% production on %selected_plot% for the 2021 season (GH₵)?	*numeric*	[Numeric] Don't know -99	D26 is not -99 & D27 >0	
D29	What quantity of herbicide was purchased at the stated typical price for the 2021 season? I: Use the size of the herbicide bottle/bag to determine the quantity purchased at the stated typical price in liters/kilograms.	*numeric*	[Numeric] Don't know -99	D26 is not -99 & D27 >0	
D30	What is the unit of measure for the quantity of herbicide purchased at the stated typical price?	*single-select*	Liters 1 Kilograms 2 Other (specify) -96	D26 is not -99 & D27 >0	
D31	What was the total quantity of pesticide used in %crop% production on %selected_plot% for the 2021 season? I: Use the size of the bottle/bag to determine the total quantity used.	*numeric*	[Numeric] Don't know -99		
D32	What is the unit of measure for this quantity?	*single-select*	Liters 1 Kilograms 2	D31 is not -99 & D31 >0	
D33	What was the typical price of pesticide used in %crop% production on %selected_plot% for the 2021 season (GH₵)?	*numeric*	[Numeric] Don't know -99	D31 is not -99 & D31 >0	
D34	What quantity of pesticide was purchased at the stated typical price? I: Use the size of the pesticide bottle/bag to determine the quantity purchased at the stated typical price in liters/kilograms.	*numeric*	[Numeric] Don't know -99	D31 is not -99 & D31 >0	

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
D35	What is the unit of measure for the quantity of pesticide purchased at the stated typical price?	*single-select*	Liters 1 Kilograms 2 Other (specify) -96	D31 is not -99 & D31 >0	
Cost of Inputs - Fertilizer					
D36	Which type(s) of inorganic or organic fertilizer did your household use in %crop% production on %selected_plot% for the 2021 season? %fertilizer% = Response(s)	*multi-select*	NPK 1 UREA 2 Animal dung 3 Crop residue 4 Inoculant (e.g. rhizobium) 5 TSP (Triple super phosphates) 6 None 0 Other (specify) -96		
D37	At what times did you apply the %fertilizer%?	*multi-select*	Prior to seeding 1 At planting 2 After planting 3	D36 > 0	
D38	How many times after planting %crop% did you apply %fertilizer%?	*Numeric*	[numeric] Don't know -99	D37 Contains(3)	
D39	How did you apply the synthetic %fertilizer%?	*multi-select*	On the surface 1 Sub-surface 2 Other (specify) -96 Don't know -99	D36 == 1,2, or 6	

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
D40a	How much %fertilizer% was used on plot during %crop% production for the 2021 season? Select the unit.	*single-select*	1 Kilogram 1 5kg bags 2 10kg bags 3 25kg bags 4 50kg bags 5 60kg bags 6 100kg bags 7 Cart 8 [Local unit] -96		
D40b	How much %fertilizer% was used on plot during %crop% production for the 2021 season? Select the quantity. I: Use the size of the fertilizer bag to determine the total quantity used in kilograms.	*numeric*	[Numeric] Don't know -99	D36 > 0	
D41	What was the typical price of %fertilizer% for the 2021 season (GH₵)? (Fertilizer types: NPK, UREA)	*numeric*	[Numeric] Don't know -99	D36 > 0	
D42a	How much %fertilizer% were purchased at the stated typical price? *Select the unit.*	*single-select*	1 Kilogram 1 5kg bags 2 10kg bags 3 25kg bags 4 50kg bags 5 60kg bags 6 100kg bags 7 Cart 8 [Local unit] -96	D36>0	
D42b	How much %fertilizer% were purchased at the stated typical price? *Select the unit.*	*numeric*	[Numeric] Don't know -99		

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
Cost of Inputs – Drying, Bags & Storage					
D43a	How did you dry %crop% after harvesting?	*multi-select*	Dried in the field 1 Drying in the sun 2 Drying in the sun on a tarp 3 Drying in the house 4 Other (specify) -96		
D43b	What is the typical price of a drying tarp (GH₵)?	*numeric*	[Numeric] Don't know -99	D43a == 3	
D43c	How many drying tarps did you use?	*numeric*	[Numeric] Don't know -99	D43a == 3	
D43d	How many years can a typical tarp be used for?	*numeric*	[Numeric] Don't know -99	D43a == 3	
D44a	What type of bag did you typically use for harvesting %crop% on on %selected_plot% for the 2022 season?	*single-select*	50 kg bag 1 100 kg bag 2 Other (specify size in kg) -96 Did not use any bags 0		
D44b	What was the typical price of the empty type of bag you used in %crop% production on on %selected_plot% for the 2021 season (GH₵)?	*numeric*	[Numeric] Don't know -99	D44a > 0	
D44c	How many bags did you use?	*numeric*	[Numeric] Don't know -99	D44a > 0	

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
D45a	What is your main methods of storage for %crop%? I: Read out options. %storage%	*multi-select*	Unprotected pile 1 Heaped in house 2 Cobs tied to the roof 3 Bags in house 4 Hermetic bags (PICS, AgroZ, Elite), 5 Metallic silo 6 Plastic containers 7 Other (specify) -96		
D45b	[Loop through options selected in D45a if options 5, 6, or 7 are selected] What is the typical price of %storage%?	*numeric*	[Numeric] Don't know -99	D45a == 4, 5 or 6	
D45c	[Loop through options selected in D45a if options 5, 6, or 7 are selected] How many %storage% did you use?	*numeric*	[Numeric] Don't know -99	D45a == 4, 5 or 6	
D46	[Loop through options selected in D45a if options 5, 6, or 7 are selected] How many years can a typical %storage% be used for?	*numeric*	[Numeric] Don't know -99	D45a == 4, 5 or 6	
Cost of Inputs – Other					
D47	How much did your household pay for transportation to acquire all purchased inputs used in %crop% production on %selected_plot% for the 2021 season (GH₵)?	*numeric*	[Numeric] Don't know -99		
D48	How much was spent in managing crop residue from %crop% production on on %selected_plot% for the 2021 season (GH₵)? For example, for labor, materials or transportation?	*numeric*	[Numeric] Don't know -99		
D49	Besides land preparation, did you or any member of your household use any animals for traction in %crop% production on %selected_plot% for the 2021 season?	*single-select*	Yes 1 No 0		

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
D50	What did you use your animals for %crop% production on on %selected_plot%?		Planting 1 Weeding 2 Pesticide/herbicid e application 3 Harvesting 4 Other (specify) 98	D49 == 1	
D51	Besides land preparation, how many days did your household use animals owned for animal traction in %crop% production on this plot from May to December 2021?	*numeric*	[Numeric] Don't know -99	D49== 1	
D52	Besides land preparation, how many days did your household use rented animals for animal traction in %crop% production on this plot for the 2021 season? Instructions: Enter "0" if none.	*numeric*	[Numeric] Don't know -99	D49== 1	
D53	Besides land preparation, how much was spent in cash in total on renting these animals for %crop% production on %selected_plot% for the 2021 season? Instructions: Enter "0" if none. Include in-kind payments as well.	*numeric*	[Numeric] Don't know -99	D52>0	
D54	Besides land preparation, how much was spent on feeding the animals used for traction in %crop% production on %selected_plot% for the 2021 season (GH₵)?	*numeric*	[Numeric] Don't know -99	D49 == 1	
D55	Besides land preparation, did you or any member of your household use any machinery in %crop% production on %selected_plot% for the 2021 season?	*single-select*	Yes 1 No 0		
D56	What did you use machinery for in %crop% production on %selected plot% for the 2021 season?	*multi-select*	Planting 1 Weeding 2 Pesticide/herbicid e application 3 Harvesting 4 Threshing 5 Shelling 6 Other (specify) -	D55 == 1	

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
			98		
D57	Besides land preparation, how much in total did your household spend to rent machinery and other equipment for %crop% production on %selected plot% for the 2021 season (GH₵)? Instructions: Include in-kind payments	*numeric*	[Numeric] Don't know -99	D55 == 1	
D57b	Besides land preparation, how much did you spend on fuel for the machinery you rented for %crop% production on %selected_plot% for the 2021 season (GH₵)?	*numeric*	[Numeric] Don't know -99	D55 == 1	
Cost of Irrigation					
D58	Did you make use of an irrigation system on %selected_plot% for the 2021 season?	*single-select*	Yes 1 No 0		
D59	What is the source of irrigation water on %selected_plot%?	*multi-select*	Well 1 Borehole 2 Lake/Natural Pond 3 Created Pond 4 River/Stream 5 Other 6	D58 == 1	
D60	How much has your household paid for irrigation water used in %crop% production on %selected_plot% for the 2021 season (GH₵)?	*numeric*	[Numeric] Don't know -99		
D61	What systems of irrigation are on %selected_plot%?	*multi-select*	Diverted Stream 1 Bucket 2 Hand pump 3 Treadle pump 4 Motor pump 5 Gravity 6	D58 == 1	

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
			Shadoof 7 Open canals 8 Sprinkler 9 Other (specify) -98		
D62a	Approximately how much does it cost in fuel or electricity to irrigate %selected_plot% for the 2021 season (GH₵)?	*numeric*	[Numeric] Don't know -99	D61 == 5	
D62b	Approximately how much did you spend on non-fuel. non-electricity costs, such as water usage rights, to irrigate %selected_plot% for the 2021 season (GH₵)?	*numeric*	[Numeric] Don't know -99	D58 == 1	
D63	On average, how many hours per week did you spend on pumping water?	*numeric*	[Numeric] Don't know -99	D58 == 1	0>D63 & DC63<=168
D64	How many weeks did you irrigate the plot for the 2021 season?	*numeric*	[Numeric] Don't know -99	D58 == 1	
D65	Did you irrigate the plot yourself for the 2021 season or was it done by someone else?	*single-select*	Did it myself 1 Done by someone else 2	D58 == 1	

AGRICULTURAL LABOR (2021 SEASON)

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
intro_e	Next, I would like to ask you about the labor by male adults, female adults, and children involved in %crop% production in %selected_plot% from May to December 2021. As with the previous questions, please think of the 2021 season when answering the following questions.	*static text*			
E1	Did any members of your household support in the following activities for the production of %crop%?	*multi-select*	Land clearing and preparation 1 Planting/Fertilizing/Herbicide/Weeding 2		

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
			Harvesting 3 Threshing/Shelling /Bagging 4 Other activities 5 No activities 6		
E2	Did you hire any paid labor to work on this plot for the following activities for the production of %crop%?	*multi-select*	Land clearing and preparation 1 Planting/fertilizing/ Herbicide/Weeding 2 Harvesting 3 Threshing/Shelling /Bagging 4 Other activities 5 No activities 6		
E3	I will now ask two questions for each of these labor activities. For how many days did you and your household members work on **%activity%** on %selected_plot%?	*numeric*		E1 != 6	
E4	How many hours a day did you and your households typically work on **%activity%** on %selected_plot%?	*numeric*		E1 != 6	E4>0 & E4<=24
E4b	How many <u>members of your household</u> worked on %activity% for %crop% production on %selected_plot%?	*numeric*		E1 != 6	
E5	What share of the **%activity%** performed by members of the household was conducted by: 1) Male household members older than 25 2) Male household members between the ages of 15 and 25 3) Male household members younger than 15 4) Female household members older than 25 5) Female household members between the ages of 15 and 25	*numeric*		E1 != 6	E5>=0 & E5<=100

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
	6) Female household members younger than 15				
E6	How many persons did you or anyone else in the household hire to work on %activity% for %crop% production on this plot for the %year% season?	*numeric*		E2 != 6	
E7	For how many days did a typical hired person work on %activity% for %crop% production on this plot for the %year% season (days total)? (Activities: 1) land clearing and preparation; 2) planting/fertilizing; 3) spraying/weeding/bird scaring; 4) harvest/threshing/bagging; 5) miscellaneous)	*numeric*		E2 != 6	
E8	How many hours per day did a typical hired person work on %activity% for %crop% production on this plot for the %year% season (hours per day)?	*numeric*		E2 != 6	E8>0 & E8<=24
E9	What share of work doing the **%activity% performed by hired people from outside the household** was conducted by: 1) Male older than 25 2) Male between the ages of 15 and 25 3) Male younger than 15 4) Female older than 25 5) Female between the ages of 15 and 25 6) Female younger than 15 [%hired_person = categories selected]	*numeric*		E2 != 6	Sum of E9<100
E10	For each of the gender and categories, I will now ask the same question. Normally, how much did your household pay per day to the **%hired_person%** to work on %activity% for %crop% production on this plot for the 2022 season (GH₵)? I: Include any cash and GH₵ value of any in-kind payments.	*numeric*		E2 != 6	E10>0
Perceived Impact					
intro_pi	I will now read out some questions to you and I would like you to tell me to what extent different agricultural practices decrease or increase the work required from you. The answer options are "Decreases greatly", "Decreases slightly", "Stayed the same", "Increases slightly", "increases greatly", and "No Opinion".				

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
	When responding to the following statements, please only think of the labor you personally have to provide, not that of other household members. For example, if you are not involved with weeding the plot then changes in how the plot is weeded would not change the labor you provide; it would stay the same.				
E11	Do you think the adoption of "zero tillage" or "minimum tillage" decreases or increases the total time in days and hours required from you personally when preparing the land?	*single-select*	Decreases greatly1 Decreases slightly 2 Stayed the same 3 Increases slightly 4 Increases greatly 5 No Opinion -99		
E12	Do you think the adoption of "zero tillage" and "minimum tillage" by farmers in your community would decrease or increase the number of employment opportunities for you personally?	*single-select*	Decreases greatly1 Decreases slightly 2 Stayed the same 3 Increases slightly 4 Increases greatly 5 No Opinion -99		
E13	Do you think planting in rows, putting seeds in holes, and applying fertilizer in holes decreases or increases the total time in days and hours required for you personally to work at planting?	*single-select*	Decreases greatly1 Decreases slightly 2 Stayed the same 3 Increases slightly		

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
			4 Increases greatly 5 No Opinion -99		
E14	Do you think adopting the practice of planting in rows by farmers in your community decreases or increases the number of employment opportunities for you personally?	*single-select*	Decreases greatly1 Decreases slightly 2 Stayed the same 3 Increases slightly 4 Increases greatly 5 No Opinion -99		
E15	Do you think the adoption of herbicide decreases or increases the total time in days and hours required from you personally when preparing the land?	*single-select*	Decreases greatly1 Decreases slightly 2 Stayed the same 3 Increases slightly 4 Increases greatly 5 No Opinion -99		
E16	Do you think the adoption of herbicide by farmers in your community decreases or increases the number of employment opportunities for you personally?	*single-select*	Decreases greatly1 Decreases slightly 2 Stayed the same 3 Increases slightly		

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
			4 Increases greatly 5 No Opinion -99		
E17	Do you think post-harvest mechanization decreases or increases the total time in days and hours required from you personally when preparing the land?	*single-select*	Decreases greatly1 Decreases slightly 2 Stayed the same 3 Increases slightly 4 Increases greatly 5 No Opinion -99		
E18	Do you think post-harvest mechanization in your community decreases or increases the number of employment opportunities for you personally?	*single-select*	Decreases greatly1 Decreases slightly 2 Stayed the same 3 Increases slightly 4 Increases greatly 5 No Opinion -99		
E19	Do you think the adoption of new agricultural practices such as no/zero tillage and planting in rows, increases or decreases the time you personally have available for non-farm related income generating activities?	*single-select*	Decreases greatly1 Decreases slightly 2 Stayed the same 3		

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
			Increases slightly 4 Increases greatly 5 No Opinion -99		

CROP USAGE – MAIN CROP (2021 SEASON)

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
Static text	I'd now like to ask you about how you used the harvest from your crop(s) you cultivated between May and December 2021. Please only think of this season when answering the following questions.	*static text*			
F1a	How many kilograms of %crop% did you harvest from %selected_plot%? <u>Capture the unit.</u> (Crop options: maize, rice, soybeans)	*multi-select*	1 Kilogram 1 5kg bags 2 10kg bags 3 25kg bags 4 50kg bags 5 60kg bags 6 100kg bags 7 [Local unit] 7		
F1b	[Loop through each of the responses chose for F1a] How many kilograms of %crop% did you harvest from %selected_plot%? <u>Capture the quantity.</u> (Crop options: maize, rice, soybeans)	*numeric*			
F2a	How many kilograms of %crop% did you harvest altogether from your plots (kg)? <u>Capture the unit.</u> (Crop options: maize, rice, soybean)	*multi-select*	1 Kilogram 1 5kg bags 2 10kg bags 3		

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
			25kg bags 4 50kg bags 5 60kg bags 6 100kg bags 7 [Local unit] 7		
F2b	*[Loop through each of the responses chose for F1a]* How many kilograms of %crop% did you harvest altogether from your plots for the %year% season (kg)? Capture the quantity I: Use the size of the bag used for the harvested crop to determine the quantity harvested in kilograms. (Crop options: maize, rice, soybean)	*numeric*			
F3	Did your household use any of the harvested %crop% from the %year% season for …?	*multi-select*	Household Consumption 1 Sales 2 Livestock feed/fodder 3 Other (specify) -96		
F4	What percentage of the harvested %crop% did you reserve for household consumption?	*numeric*	[Number from 0-100]	F3.Contains(1)	F4>0 & F4<=100
F5a	What percentage of the harvested %crop% did you sell?	*numeric*	[Number from 0-100]	F3.Contains(2) Must be less than or equal to 100 or 1, depending on encoding.	F5a>0 & F5a<=100
F5b	Who/what were the main buyers/outlets for your %crop% sales?	*multi-select*	Roadside 1 Mobile market 2 Local Market 3 Private trader in local market 4	F3.Contains(2)	

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
			Local merchant 5 Main market 6 Private trade in main market 7 Businessperson 8 Farmgate 9 Agrofredina 10 Clean Savanah 11 Idan Agro 12 Other (specify) - 96		
F6a	[For each buyer/outlet] What was the typical price per kilogram of the %crop% you harvested for the 2021 season (GH₵)?	*numeric*		F3.Contains(2)	
F6b	[For each buyer/outlet] How many kilograms of %crop% were sold at the stated typical price? I: Use the size of the bag used for the sold crop to determine the quantity sold at the stated typical price in kilograms.	*numeric*		F4>0	
F7	What share of your total annual household income came from selling %crop% in 2021?	*numeric*		F3.Contains(2)	
F8	Who in the household takes the crop to the market to sell?	*multi-select*	Male household member 1 Female household member 2 Both 3	F3.Contains(2)	
F9	How much did your household pay for transportation, including tolls, to sell %crop%, feed and/or fodder generated from the %year% season (GH₵)?	*numeric*		F3.Contains(1) and F5a>0 OR F3 Contains(3)	
F10	How much did your household pay for the storage of %crop% and feed generated from it from the %year% season (GH₵)?	*numeric*		F3.ContainsAny(1,3)	

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
F11	What part(s) of the harvested %crop% were used as livestock feed/fodder?	*multi-select*	Leaves 1 Stalks 2 Other (specify) -96	F3.Contains(3)	
F12	What percentage of the harvested %crop% did you use for livestock feed/fodder?	*numeric*		F3.Contains(1)	F12>0 & F12<=100
F13	What percentage of the livestock feed/fodder generated from the harvested %crop% did you sell?	*numeric*		F3.Contains(1) Must be less than or equal to 100 or 1, depending on encoding.	F13>=0 & F13<=100
F14	What was the typical price of the cattle feed/fodder generated from the harvested %crop% (GH₵)?	*numeric*		F13>0	
F15	How many kilograms of cattle feed generated from the harvested %crop% were sold at the stated typical price? I: Use the size of the feed bag to determine the quantity sold at the stated typical price in kilograms.	*numeric*		F13>0	
F15b	How much did you receive in total for the livestock feed/fodder from the harvested %crop% that you sold? Instructions: Include the value of in-kind payments.	*numeric*		G13>0	
F16	Did you remove any %crop% residue from plots after the harvest from the 2021 season?	*single-select*	Yes 1 No 0		
F17	What percentage of %crop% residue did you remove from %selected_plot% after the harvest from the 2021 season?	*numeric*		F16==1	F17>0 & F17<=100
F18	For what did you use the %crop% residue?	*multi-select*	Livestock feed 1 Fuel 2 Other (specify) -	F16==1	

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
			96		

CROP USAGE – SECOND CROP (2021)

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
Static text	I'd now like to ask you about how you used the harvest from your second crop on the select plot for the 2021 season. Please only think of the 2nd crop, %second_crop%, grown on the selected plot between May and December 2021.				
G1a	How many kilograms of %second_crop% did you harvest from %selected_plot%? Capture the unit. (Crop options: maize, rice, soybeans)	*multi-select*	1 Kilogram 1 5kg bags 2 10kg bags 3 25kg bags 4 50kg bags 5 60kg bags 6 100kg bags [Local unit] 7		
G1b	[Loop through all options selected in G1a] How many kilograms of %second_crop% did you harvest from %selected_plot% the %year% season? Capture the quantity. (Crop options: maize, rice, soybeans)	*numeric*			
G2a	How many kilograms of %second_crop% did you harvest altogether from your plots from the %year% season (kg)? Capture the unit. (Crop options: maize, rice, soybean)	*single-select*	1 Kilogram 1 5kg bags 2 10kg bags 3 25kg bags 4 50kg bags 5 60kg bags 6 100kg bags 7 [Local unit] 7		

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
G2b	How many kilograms of %second_crop% did you harvest altogether from your plots (kg)? Capture the quantity. (Crop options: maize, rice, soybean)	*numeric*			
G3	Did your household use any of the harvested %second_crop% for …?	*multi-select*	Household Consumption 1 Sales 2 Cattle feed/fodder3 Other (specify) -96		
G4a	What percentage of the harvested %second_crop% did you reserve for household consumption?	*numeric*		G3.Contains(1)	G4a>0 & G4a<=100
G4b	What percentage of the harvested %second_crop% did you sell?	*numeric*		G3.Contains(2)	G4b>=0 & G4b<=100
G5	Who/what were the main buyers/outlets for your %second_crop% sales?	*multi-select*	Roadside 1 Mobile market 2 Local Market 3 Private trader in local market 4 Local merchant 5 Main market 6 Private trade in main market 7 Businessperson 8 Farmgate 9 Agrofredina 10 Clean Savanah 11 Idan Agro 12	G3.Contains(2)	

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
			Other (specify) - 96		
G6a	[For each buyer/outlet] What was the typical price of the %second_crop% you sold from the 2021 season (GH₵)? We will ask about the volume associated with this price in the next question	*numeric*		G3.Contains(2)	
G6b	[For each buyer/outlet] How many kilograms of %second_crop% were sold at the stated typical price? I: Use the size of the bag used for the sold crop to determine the quantity sold at the stated typical price in kilograms.	*numeric*		G4>0	
G7	What share of your total annual household income came from selling %second_crop% in 2021? Instructions: Enter 100 if 100% of household income came from selling crop. Enter 0 is none of the household income came from selling this crop.	*numeric*	[Number between 0 and 100]	G3.Contains(2)	
G8	Who in the household takes the crop to the market to sell?	*multi-select*	Male household member 1 Female household member 2 Both 3	G3.Contains(2)	
G9	How much did your household pay for transportation to sell %second_crop%, feed, and/or fodder generated from the %year% season (GH₵)?	*numeric*		G3.Contains(2) and G4> 0 OR G3.Contains(3)	
G10	How much did your household pay for the storage of %second_crop% and feed generated from the %year% season (GH₵)?	*numeric*		G3.Contains(1,3)	
G11	What part(s) of the harvested %second_crop% were used as cattle feed?	*multi-select*	Leaves 1 Stalks 2 Other (specify) - 96	G3.Contains(3)	
G12	What percentage of the harvested %second_crop % did you use for livestock feed/fodder?	*numeric*		G3.Contains(3)	G12>0 & G12<=100

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
G13	What percentage of the livestock feed/fodder generated from the harvested %second_crop% did you sell?	*numeric*		G3.Contains (3) Must be less than or equal to 100 or 1, depending on encoding.	G13>=0 & G13<=100
G14	What was the typical price of the livestock feed/fodder generated from the harvested %second_crop% (GH₵)?	*numeric*		G13>0	
G15	How many kilograms of livestock feed/fodder generated from the harvested %crop% were sold at the stated typical price? I: Use the size of the feed bag to determine the quantity sold at the stated typical price in kilograms.	*numeric*		G13>0	
G15b	How much did you receive in total for the livestock feed/fodder from the harvested %crop% that you sold? Instructions: Include the value of in-kind payments.	*numeric*		G13>0	
G16	Did you remove any %second_crop% residue from plots after the harvest from the %year% season?	*single-select*	Yes 1 No 0		
G17	What percentage of %second_crop% residue did you remove from %selected_plot% after the harvest from the %year% season?	*numeric*		G16==1	G17>0 & G17<=100
G18	For what did you use the %second_crop% residue?	*multi-select*	Livestock feed 1 Fuel 2 Other (specify) -96	G16==1	

TREES

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
Static text	I'd now like to ask you questions on the trees you planted between January and December 2022.				

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
H1	Did you receive any trees from Idan Agro/Clean Savana/Agrofredina between January and December of 2022?	*single-select*	Yes 1 No 0	treatment == 1	
H2	What tree species did you receive from Idan Agro/Clean Savana/Agrofredina between January and December 2022?	*multi-select*	Mango 1 Cassia 2 Shea Nut 3 Tamarind 4 Nim 5 Other Specie 1 (specify) -96 Other Specie 2 (specify) -97	H1 == 1	
H3	How many %species_planted% did you receive between January and December of 2022? [loop through all selected species]	*numeric*		H1 == 1	
H4	Did you plant any new trees between January and December of 2022?	*single-select*	Yes 1 No 0	[All]	
H5	What species of trees did you plant between January and December of 2022?	*multi-select*	Mango 1 Cassia 2 Shea Nut 3 Tamarind 4 Nim 5 Other Specie (Specify) (1) -96 Other Specie (Specify) (2) -97	H4 == 1	
H6a	How many %species_planted% did you plant between January and December of 2022? [loop through all selected tree species]	*numeric*		H4 == 1	

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
H6b	How many of %species_planted% trees you plant between January and December of 2022 were still alive a year later?	*numeric*		H4 == 1	
H7	Where did you plant the %species_planted% trees? [loop through all selected tree species]	*multi-select*	On a plot 1 On community land 2 Other (specify) - 96	H4 == 1	
H7b	How large is the area of land on which you planted %species_planted%? *Enter unit.*	*single-select*	Square Pole 1 Acre 2 Hectare 3 Other (specify) - 96	H4 == 1	
H7c	How large is the area of land on which you planted %species_planted%? *Enter quantity.*	*numeric*		H4 == 1	
H8	How many hours per month do you spend on maintaining, for example watering, pruning and/or fertilizing, the %species_planted% trees you planted between January and December of 2022? [loop through all selected tree species]	*numeric*		H4 == 1	H8>0 & H8<=720
H9	Who in the household is primarily responsible for maintaining the trees?	*single-select*	Male household member 1 Female household member 2 Shared by male and female household members 3	H4 == 1	

GENDER

Question number	Question text	Answer type	Response options	Enabling condition	Constraint

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
I1	Thank you for answering those questions, I would now like to speak to your wife/partner to ask a few questions while you step out. Is she available to answer a few questions?	*single-select*	Yes 1 No 2 Refused -97	[A6 == 0 & B7 == 2] or [A6 == 0 and B7 == 3] or [A6 == 0 and B7 == 4]	
I2	Enumerator: Please select who is still present while the questions in this section are being answered.	*single-select*	Just the wife 1 Wife and children 2 Wife and other adult family members 3 Other 4	I1 = 1 or B7c == 1	
Intro_i	Hello. My name is [xxxx] and I am working with the International Center for Tropical Agriculture (CIAT). We are conducting a study supported by the United States Agency for International Development (USAID) that is being carried out by Mathematica, a US-based research firm. We are gathering information from 250 farmers in your area to improve our understanding of the costs and benefits of sustainable land use agricultural practices in Ghana. The findings and recommendations flowing from this study might benefit you directly by providing insights into the costs and benefits of adopting different agricultural practices. If you agree to participate in this interview, we will ask you several questions about your household and your farm's agricultural activities. The questions are organized in modules and each module starts with a brief introduction of the topic. One of the modules contains questions for the wife or partner of the (male) household head, and we would also like to confirm the size of one the household's plots using a GPS-based tool or satellite imagery. The survey is expected to take about 45 minutes to complete. Any information you provide will be kept strictly confidential by the parties conducting this study. However, due to the make-up of the population under study, the combined answers to the survey's questions may make an individual person identifiable. The researchers will make every effort to protect your confidentiality. If you are uncomfortable answering any of the demographic questions, you may leave them blank. After the interview has been conducted, your responses will be stored in a secure location. Collected personal information, such as your name, location, and phone number will be stored in a separate dataset during the analysis to protect your privacy. In addition, the study results will			I1 == 1	

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
	be presented in a report and will not include any personal information which could be used to identify you or members of your household directly. Your participation in this study is voluntary and there are no risks or negative consequences associated with participation. If you choose to participate, you have the option not to answer a question, or stop the interview at any time and for any reason without consequences. You also have the alternative to not participate, and there will be no consequences for nonparticipation. Your participation is very important to our study and is part of a larger effort we are making to provide relevant information to help understand and improve agricultural practices in Ghana. However, there are no immediate benefits from participating in this interview and your responses may not affect any current, planned, or future delivery of services related to this project or any other project or program. If you have any questions regarding the research project, you may contact the main researcher Tiffany Talsma by email at t.talsma@cgiar.org. If you would like to speak with someone other than the primary investigator regarding questions or concerns, or if you would like to discuss your rights as a research participant, you may contact our local contact Samuel Seddoh at CSIR Campus, No.6 Agostino Neto Road, Airport Residential Area, Cantonments, Accra, phone number: +233540111160. Do you have any questions about the survey or what I have said? [INTERVIEWER ADDRESS RESPONDENT'S QUESTIONS.]				
I3a	Do you agree to participate in in this interview?	*single-select*	Yes 1 No 2	I1 == Yes	
I3	Are you 18 years or older?	*single-select*	Yes 1 No 2	I2a ==Yes	
ineligible	Thank you for your time but unfortunately you are ineligible to participate in this part of the survey.	*static-text*		I3 = No [Skip to next section]	
I4	How old are you?	*numeric*	[Numeric]	I3 = Yes	
Labor [I3 = Yes]					
intro_pi	I will now read out some questions to you and I would like you to tell me to what extent to the practice decreased or increased the work required from you.				

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
	The answer options are "Decreased greatly", "Decreased slightly", "Stayed the same", "Increased slightly", "increased greatly", "No Opinion", and "Not applicable". If your household did adopt the practice on any of your fields your work on, please answer "not applicable" When responding to the following statements, please only think of changes to your personal situation, not that of other household members. For example, if you are involved in planting and a change in how planting increases the time you need to sow a plot by a lot, then the answer for that particular question is "Increased greatly". Similarly, if the household's main form of weeding is by hand and the adoption of herbicide how now significantly decreased the number of hours you have to weed, then the answer for that particular question is "decreased greatly". However, you are not involved with weeding the plot then changes in how the plot is weeded would not change the labor you provide; it would stay the same. You would then answer "stayed the same" for that particular question.				
I5	Has the adoption of "zero tillage" or "minimum tillage" decreases or increases the total time in days and hours required from you when preparing the land?	*single-select*	Decreased greatly1 Decreased slightly 2 Stayed the same 3 Increased slightly 4 Increased greatly 5 No Opinion 99 Not Applicable 95		
I6	Has the adoption of "zero tillage" and "minimum tillage" by farmers in your community would decrease or increase the number of employment opportunities for you?	*single-select*	Decreased greatly1 Decreased slightly 2 Stayed the same 3 Increased slightly		

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
			4 Increased greatly 5 No Opinion 99 Not Applicable - 95		
I7	Has planting in rows, putting seeds in holes, and applying fertilizer in holes decreases or increases the total time in days and hours required for <u>you</u> to work at planting?	*single-select*	Decreased greatly1 Decreased slightly 2 Stayed the same 3 Increased slightly 4 Increased greatly 5 No Opinion -99 Not Applicable - 95		
I8	Has the adoption the practice of planting in rows by farmers in your community decreases or increases the number of employment opportunities for <u>you</u>?	*single-select*	Decreased greatly1 Decreased slightly 2 Stayed the same 3 Increased slightly 4 Increased greatly 5 No Opinion -99 Not Applicable - 95		

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
I9	Has the adoption of herbicide decreases or increases the total time in days and hours required from you when preparing the land?	*single-select*	Decreased greatly1 Decreased slightly 2 Stayed the same 3 Increased slightly 4 Increased greatly 5 No Opinion -99 Not Applicable -95		
I10	Has the adoption of herbicide by farmers in your community decreases or increases the number of employment opportunities for you?	*single-select*	Decreased greatly1 Decreased slightly 2 Stayed the same 3 Increased slightly 4 Increased greatly 5 No Opinion -99 Not Applicable -95		
I11	Has the adoption of new agricultural practices such as no/zero tillage and planting in rows, increases or decreases the time you have available for non-farm related income generating	*single-select*	Decreased greatly1		

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
	activities?		Decreased slightly 2 Stayed the same 3 Increased slightly 4 Increased greatly 5 No Opinion -99 Not Applicable -95		
Ownership/Decision Making [I3 = Yes]					
112	Compared to the previous season from May to December 2020, has taking out inputs with Idan Agro/Clean Savana/Agrofredina as a loan, increased or decreased your influence over what agricultural practices are used in your household's plots?	*single-select*	Decreased greatly1 Decreased slightly 2 Stayed the same 3 Increased slightly 4 Increased greatly 5 No Opinion -99 Not applicably -95	treatment == 1	
113	Compared to the previous season from May to December 2020, has taking out inputs with Idan Agro/Clean Savana/Agrofredina as a loan, increased or decreased your influence over how income from agricultural activities is spent?	*single-select*	Decreased greatly1 Decreased slightly 2 Stayed the same 3 Increased slightly	treatment == 1	

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
			4 Increased greatly 5 No Opinion -99 Not applicably -95		
I14	Compared to the previous season from May to December 2020, has taking out inputs with Idan Agro/Clean Savana/Agrofredina as a loan, increased or decreased your influence over how income from non-agricultural activities is spent?	*single-select*	Decreased greatly1 Decreased slightly 2 Stayed the same 3 Increased slightly 4 Increased greatly 5 No Opinion -99 Not applicably -95	treatment == 1	

CLOSE & FIELD DIMENSIONS

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
Landmark	Enumerator: Enter description of location relative to nearest landmark	*text*			
GPS	Enumerator: Capture GPS coordinates of interview location.	*gps*			
J1	Is there a telephone number at which we can reach your household in case we have any follow-up questions? Your telephone number will not be used for any other purposes or shared with anyone other than those working on this study?	*single-select*	Yes 1 No 0 Don't know -99 Refuse -98		

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
J2	What is this phone number?	*numeric (integer)*		J1==1	
J3	This concludes our survey, thank you very much for answering those questions. I would now like to measure the size of %plot% using my tablet. Would you be able to walk me to the field?	*single-select*	Yes 1 No 0		
Plot measurements					
J4	Enumerator: are you able to collect the perimeter outline of the plot?	*single-select*	Yes 1 No 0		
J5	Enumerator: Why not?	*single-select*	Too far away 1 Obstacle in the field 2 Other (specify) - 98		
J6	Enumerator: Capture GPS of plot	*GPS*	GPS		
end_time	End time	*date current timestamp (date & time)*			

FINAL SECTION

Note: This section is be completed by the enumerator after the survey has been completed.

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
K1	What are the main construction materials of outside walls?	*single-select*	Cement-bonded bricks/stones 1 Mud-bonded bricks/stones 2 Wood 3		

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
			Bamboo/leaves 3 Unbaked bricks 5 Other (specify) -98 N/A (no outside walls) -97		
K2	What is the main material used on the roof of this building?	*single-select*	Straw / thatch 1 Earth / mud 2 Wood / planks 3 Galvanized iron 4 Concrete / cement 5 Tiles / slate 6 Other (specify) -98 N/A (no roof) -97		
K3	What are the main construction materials used on the floor of this dwelling?	*single-select*	Soil 1 Wood 2 Tile 3 Cement 4 Cow dung 5 Other -98		
K4	What proportion of the questions do you feel the respondent had difficulty answering?	*single-select*	All 4 Most 3 Some 2 Few 1 None 0		

Question number	Question text	Answer type	Response options	Enabling condition	Constraint
K5	Were there any specific questions that made the respondent uncomfortable or embarrassed?	*single-select*	Yes 1 No 0		
K6	Please list the question number(s) which made the respondent uncomfortable or embarrassed:	*text*		K5 == 1	
K7	Do you have any comments on the interview? For example, did anything significant happen during the interview?	*text*			

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APPENDIX B: KEY INFORMANT INTERVIEW GUIDE

INTERVIEW START

The interviewer should ask to speak to a woman in the household who has the most knowledge of the plots for which data was collected through the HH survey (i.e. maize, soybean, rice). In many cases, this is the spouse of the male household head. However, it might also be a different family member with a role of authority.

Name of the participant	
Position of the respondent within the household (e.g., spouse of household head, household head, etc.)	
Investee Client ID (for investee clients only) (e.g., Clean Savanah, Idan Agro)	
District	
Village	
Date (dd/mm/yyyy) of the interview	
Time of interview start	
Time of interview end	
Adult male household member present during interview (Yes/No)	
Language of the interview	
Name of moderator/interviewer(s)	
Name of assistant	

INTRODUCTION AND CONSENT

The purpose of this section is to explain the objective of the study, to obtain her consent to take part in the interview and request her approval for an audio recording of the interview.

Thank you for taking the time to speak with us today. My name is [Name] and I work for [Data Collection Firm]. We are contracted by CIAT, the International Center for Tropical Agriculture, to conduct an evaluation of USAID's project entitled "Sustainable Land use Finance for Self-Reliance". As part of the project, we are conducting interviews with women in agricultural households to understand women's role in implementing agricultural practices and their agency over the income generated from their labor. For that reason, we would like to speak with you today to understand what agricultural practices your household implements, your role in their implementation, and how your household makes decisions regarding how agricultural income is spent.

I would like to emphasize that there are no right or wrong answers in this interview. Participation in this discussion is voluntary and you may skip any question you do not want to answer. You may also stop participating at any time. There is no risk and no direct advantage for participating in this study. None of your responses will be identified as yours in study reports or shared with anyone outside the study team.

If you have any questions regarding the research project, you may contact the main researcher XXXXXXXX by email at XXXXXX. If you would like to speak with someone other than the primary investigator regarding questions or concerns, or if you would like to discuss your rights as a research participant, you may contact our local contact XXXXX.

Before I begin with the interview, I would also like to get you permission to record our discussion. This is so that we accurately capture the thoughts and ideas you share. The recordings will only be heard by the researchers involved in this study and will be destroyed once the study and report writing are complete. **Do I have your permission to record the discussion?**

If yes, start voice recorder

Thank you very much. **Do you have any questions before we begin?**

Once questions have been answered, proceed with the guide below.

INTRODUCTION

4. **I'd like to start by getting to know you. Could you introduce yourself by providing your name, age, and position in the household?**
   - *If the interviewee looks particularly uncomfortable, ask about her day or the weather. Try to find something to connect with the respondent to "break the ice".*
5. **Thank you. I'd now like to talk about your household's farming activities. Can you briefly tell me about the crops your household grows and the role the women in your household have in cultivating them?**
   a. How many plots does your household have and what crops does your household grow?
   b. Does your household own any agricultural land? Is any of the land in your or your family's name?
   c. Are you or any other women in the households responsible for any of the plots or crops? If so, which crops and who own the land on which these crops are cultivated?

AGRICULTURAL PRACTICES

6. **Thank you. I would now like to learn more about the agricultural practices your household uses on your maize, or soya field(s). Does your household:**
   a. Use minimum or zero tillage?
   b. Plant in rows?
   c. Place seed and fertilizer in a hole?
   d. Rotate the crops on your field by growing a legume?

   If the respondent is not familiar with the above terms, please use the explanation below:

   - *Minimum or zero tillage:*
     - *Zero tillage is a minimum tillage practice in which the crop is sown directly into soil not tilled since the harvest of the previous crop*
     - *Minimum tillage farming is a system of planting crops unto untilled soil by opening a narrow slot, trench or band of sufficient width and depth to planting while leaving the rest of the field untouched.*
   - *Planting in row: Row planting involves sowing and growing seeds in a straight-line, and maintaining a certain distance between rows of plants, as opposed to broadcasting the seed over a field.*
   - *Placing seed and fertilizer in a hole: The practice of creating a hole in the soil in which the seed and/or fertilizer is placed. The seed and/or fertilizer in the hole are typically covered with soil.*
   - *Crop rotation: The practice of planting different crops, for example legumes, om the same plot across a sequence of growing seasons to improve soil health, optimize nutrients in the soil, and combat pest and weed pressure.*

7. **If adopted: Has the adoption of [practice above] changed how much or how little labor you and other female members of your household preform throughout the season? Have any of the practices changed when in the year work for female household members starts? Ends?**
   - **If increase or change in timing, has adoption of any of the above practices changed how much time there is available for other income generating activities?**

8. **Some people think practices such as minimum tillage, planting in rows, placing seed and fertilizer in soil and crop rotation increase the income from a plot over several seasons, other people think is not worth it. What do you think?**

9. **Have you have ever advocated for the adoption of any such practices on your household's plots? If yes, how was this received by other household members?**

LABOR

10. **Thank you. Could you tell me how agricultural labor is divided in your household across different activities? Examples of activities are 1) land clearing and preparation; 2) planting/fertilizing; 3) weeding/bird scaring; 4) harvesting; 5) post-harvest handling (drying, threshing, shelling).**
    a. Are all activities equally split between men and women or are some activities male or female dominated? What would you say the percentage split is?
        - *If the respondent is not familiar with percentages use counting objects. For example, pretend that the total amount of work is represented by 10 pebbles. How many of those pebbles are allocated to males and females.*
        - *If activities are not evenly split, please inquire why the respondent thinks this is the case.*

DECISION-MAKING

Thank you. I would now like to talk about decision-making within the household. Decision-making looks slightly different in every household and one method is not better or worse than another. For instance, who makes decisions can be based on what is customary in your household, what is normal in your community (social norms), who is most informed or best positioned to make the decision, or who own the assets, such as farmland, to which the decision pertains. The decision-making process can also change depending on the topic where one person makes decisions for some topics but not others.

11. **When thinking about decision-making around which crop or crops to grow and what inputs to use, who is normally involved in your household and what factors determine the final decision?**
    a. Is this different for crops for which you or other female household members do most of the agricultural labor or for which you are "responsible" within the household?
12. **When thinking about decision-making around how much of the harvest to sell, who is normally involved in your household and what considerations factor into the decision?**
    a. Is this different for crops for which you or other female household members do most of the agricultural labor or for which you are "responsible" within the household?

INCOME & AGENCY

13. **When thinking about decision-making around how the income from selling crops is used, who is normally involved in your household and how is the decision made?**
    a. Is this different for crops for which you or other female household members do most of the agricultural labor or for which you are "responsible" within the household?
14. **To what extent do you feel you can make your own personal decisions regarding how the income from selling crops from is spent?**
    a. Is this different for crops for which you or other female household members do most of the agricultural labor or for which you are "responsible" within the household?

TREES

Thank you for answering those questions. I would now like to ask you about trees.

1. **Does your household grow any trees? If yes, what species of tree do you grow?**
2. **Are the trees grown on your own land or on shared community land?**
3. *[If household grows trees]* **Who in the household is typically responsible for tree maintenance. For example, watering, pruning and/or fertilizing?**
4. *[If household grows trees]* **Do any of the trees produce fruits or nuts?**
    a. [For each species] If yes, how old are the trees that produce fruits or nuts?
    b. [For each species] If yes, at what age did the trees start producing fruits or nuts?
5. *[If household grows fruit trees]* **Who in the household is typically responsible for picking the fruits?**
6. *[If household grows fruit trees]* **Has the harvested fruit substituted produce that your household would previously purchase?**
7. *[If household grows fruit trees]* **Who decides whether the harvest from trees is sold?**
8. *[If household sell harvested fruit or nuts]* **Who decides what happens to the income from the sales?**

CLOSING

Those are all the questions that I have. Is there anything else you'd like to tell me about the topics we discussed today?

Thank you for your time and participation. It is greatly appreciated.

Turn off voice recorder.

Please note any additional information about the respondent, including any problems encountered, etc.

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APPENDIX C: INVESTEE DATA REQUEST

The following data request template was sent to the three investees to report back their recurring and non-recurring costs in order to be incorporated into the investee's view in the CBA.

Exhibit C.1. Investee data request template

Parameter		**2021 (Year 1)**			**2022 (Year 2)** *Optional*			**Description**	**Source (Document, Page Number)**
		In-grower	**Out-grower**	**Total**	In-grower	**Out-grower**	**Total**		
Clients	Req'd								
Maize Clients (#)	Yes								
Maize Average Package size (acres)	Yes								
Soybean Clients (#)	Yes								
Soybean Average Package size (acres)	Yes								
Rice Clients (#)	Yes								
Rice Average Package Size (acres)	Yes								
Other Clients (#)	Yes								
Investee-Level Costs		(GHC)	(GHC)	(GHC)	(GHC)	(GHC)	(GHC)		
Total Non-Recurring Costs									
Market Research								Cost of conducted market research or risk analysis (Including labor cost)	
Software and IT								E.g. One-off purchase of software, servers or other hardware	
Infrastructure								E.g. Cost of setting up operations such as tree nursery	
Furniture								E.g. Once-off purchases such as desks, chairs	
Office supplies								E.g. Once-off purchases such as computers	
Transportation								E.g. Purchase of cars, trucks or other means of transportation	
Farming								E.g. Purchase of tractors or	

Parameter		2021 (Year 1)			2022 (Year 2) *Optional*			Description	Source (Document, Page Number)
		In-grower	**Out-grower**	**Total**	In-grower	**Out-grower**	**Total**		
Equipment								plows to facilitate mechanized service offering	
Other recurring costs									
Total Non-Recurring Costs	Yes								
Total Recurring Costs (Annual)								Multiply monthly (x12), biweekly (x26), or weekly (x52) to obtain total annual costs	
Inputs - Maize Seed	Yes							Total cost of seed (unit price x total quantity) that was sold to farmers	
Inputs - Maize Fertilizer	Yes							Total cost of fertilizer (unit price x total quantity) that was sold to farmers	
Inputs - Maize Other (if any)	Yes							Total cost of other inputs that were sold to farmers	
Inputs - Soybean Seed	Yes							Total cost of seed (unit price x total quantity) that was sold to farmers	
Inputs - Soybean Fertilizer	Yes							Total cost of (unit price x total quantity) fertilizer that was sold to farmers	
Inputs - Soybean Other (if any)	Yes							Total cost of other inputs that were sold to farmers	
Inputs - Rice Seed	Yes							Total cost of (unit price x total quantity) seed that was sold to farmers	
Inputs - Rice Fertilizer	Yes							Total cost of (unit price x total quantity) fertilizer that was sold to farmers	
Inputs - Rice Other (if any)	Yes							Total cost of other inputs that were sold to farmers	
Office Supplies								E.g., Stationary, printer ink	
Office & Warehouse Lease								E.g., Cost of office or warehouse lease	
Utilities								E.g., Cost of electricity and gas	
Software and IT								E.g., Annual or monthly fees to use software	
Transportation								E.g., Cost of fuel for cars, trucks and farming equipment	
Farming Equipment								E.g., Fuel for the plouGHC, annual servicing, etc.	

Parameter		2021 (Year 1)			2022 (Year 2) *Optional*			Description	Source (Document, Page Number)
		In-grower	Out-grower	Total	In-grower	Out-grower	Total		
Services								external party	
Loan - Repayments								E.g., Total loan repayments (principal + interest) for received financial support	
Labor - Staff costs (incl. benefits)								E.g., Loan repayments for received financial support	
Taxes								E.g., Local and state taxes	
Permits & Licenses								E.g., Cost of permits or licenses to operate business	
Other Costs (if any)								Any other recurring costs	
Total Recurring Costs	Yes								
Total Costs	Yes								
Cumulative Total Costs									
Investee-Level Benefits		(GHC)	(GHC)	(GHC)	(GHC)	(GHC)	(GHC)		
Non-Recurring Benefits									
Subsidies (if any)								E.g., One-off subsidies received by the (local) government	
Grants (if any)								E.g., One-off grants received to support business operations	
Other revenue (if any)								E.g., One-off payments received, such as for equipment sold or for a fundraiser	
Total Non-Recurring Benefits	Yes	(GHC)	(GHC)	(GHC)	(GHC)	(GHC)	(GHC)		
Recurring Benefits (Annual)								Multiply monthly (x12), biweekly (x26), or weekly (x52) to obtain annual benefits	
Clients - Principal Repayment	Yes							Total value of client/farmer principal repayments	
Clients - Interest Repayment	Yes							Total value of client/farmer interest repayments	
Clients - Services Fees (if any)	Yes							Total value of clients payments received for mechanized services	
Clients - Fees (if any)	Yes							Additional fees paid by clients that are not include above for	

Parameter		2021 (Year 1)			2022 (Year 2) *Optional*			Description	Source (Document, Page Number)
		In-grower	Out-grower	Total	In-grower	Out-grower	Total		
								e.g., late payments.	
Subsidies (if any)								E.g., Subsidies received by the (local) government	
Grants (if any)								E.g., Grants received to support business operations	
Other revenue (if any)								Any other revenue flows	
Total Recurring Benefits	Yes								
Total Benefits	Yes								
Cumulative Total Benefits									

APPENDIX D: ADDITIONAL TABLES

Exhibit D.1. Summary statistics across comparison and treatment households from SLUF Farmer Survey

		(1) Comparison		(2) Treatment		(1)-(2) Pairwise t-test
Variable	N	Mean/(SE)	N	Mean/(SE)	N	Mean difference
Female	133	0.226	110	0.482	243	-0.256***
		(0.036)		(0.048)		
Household size	133	6.647	110	6.209	243	0.438
		(0.251)		(0.242)		
Cultivates any maize	133	0.767	110	0.718	243	0.049
		(0.037)		(0.043)		
Cultivates any soybean	133	0.579	110	0.873	243	-0.294***
		(0.043)		(0.032)		
Cultivates any rice	133	0.361	110	0.264	243	0.097
		(0.042)		(0.042)		
Total number of plots	133	1.669	110	1.682	243	-0.013
		(0.073)		(0.084)		
Plot size (ha., self-reported)	133	1.712	110	1.194	243	0.518***
		(0.126)		(0.077)		
Plot size (ha., GPS-measured)	89	1.348	82	1.235	171	0.113
		(0.255)		(0.077)		
Rented plot (May-Dec 2021)	133	0.038	110	0.055	243	-0.017
		(0.017)		(0.022)		
Plot owned by household head	133	0.662	110	0.555	243	0.107*
		(0.041)		(0.048)		
Used irrigation on plot	133	0.000	110	0.000	.n	.n
		(0.000)		(0.000)		
Used mechanical tilling on plot	130	0.731	110	0.709	240	0.022
		(0.039)		(0.044)		
Applied chemical fertilizers (NPK, TSP, urea)	133	0.519	110	0.273	243	0.246***
		(0.043)		(0.043)		
Percentage of harvest sold	106	78.377	99	71.566	205	6.812*
		(2.256)		(2.693)		
Rainfall total for May-December 2021 (mm)	133	1003.716	110	986.533	243	17.183***
		(3.947)		(4.313)		
Agro-ecological zone AEZ-03 (tropical, lowland, sub-humid with no/slight soil/terrain limitations)	133	0.000	110	0.445	243	-0.445***
		(0.000)		(0.048)		
Agro-ecological zone AEZ-04 (tropical, lowland, sub-humid with moderate soil/terrain limitations)	133	1.000	110	0.555	243	0.445***
		(0.000)		(0.048)		

*** = 0.01, ** = 0.05, * = 0.1.

Exhibit D.2. District-level area under maize and soybean cultivation

District	Maize cropped area ('000 hectares)	Soybean cropped area ('000 hectares)
North East region		
Bunkpurugu Nakpanduri	3.4	3.2
Yunyoo-Nasuan	5.3	4.8
East Mamprusi	5.9	4.7
Chereponi	3.8	4.8
West Mamprusi	6.8	3.0
Mamprugu Moagduri	7.6	0.0
Region total	**32.8**	**20.4**
Northern region		
Kpandai	2.6	3.0
Gushiegu	10.9	5.4
Karaga	10.0	5.4
Nanumba North	8.8	4.9
Nanumba South	7.9	2.3
Saboba	3.3	3.0
Savelugu	10.3	5.3
Nanton	9.5	2.3
Tamale Metro	8.8	2.2
Sagnerigu	6.9	0.5
Tolon	9.2	5.1
Kumbungu	8.5	1.4
Yendi	8.3	5.4
Mion	12.2	6.1
Tatale Sanguli	5.9	1.2
Zabzugu	7.7	0.6
Region total	**130.7**	**54.0**

Source: Ministry of Food and Agriculture (2022).

Exhibit D.3. Incremental financial benefits per hectare from adoption of technology package (2023 USD)

Actor	Technology package	Type of benefit	Crop	Present value (covering 2023–2042)
Farmer	IMP	Value of crop yield	Maize	-$281
			Soybean	-$995
		Earnings fodder sold	Maize	$0
			Soybean	$0
		Carbon credits	Maize	$48
			Soybean	$15
		Total financial benefits	Maize	**-$233**
			Soybean	**-$980**
		Net financial benefits	Maize	**-$96**
			Soybean	**-$1,134**
	ETP	Value of crop yield increase	Maize	$0
			Soybean	$0
		Value of tree products	Maize	$137
			Soybean	$137
		Carbon credits	Maize	$197
			Soybean	$197
		Total financial benefits	Maize	**$334**
			Soybean	**$334**
		Net financial benefits	Maize	**$241**
			Soybean	**$241**
	Soybean-maize CR	Value of increase in maize yield	Both	$652
		Value of maize fertilizer cost savings	Maize and soybean	$139
		Carbon credits		$15
		Total financial benefits		**$807**
		Net financial benefits		**$807**
Investee: Idan Agro	IMP	Out-grower principal repayment	Maize, soybean, and rice	$4,527
		Out-grower interest repayment		$33
		Other benefits (for example, sales of grain)		$24,946
		Total financial benefits		**$29,507**
		Net financial benefits		**$6,708**
Investee: Clean Savana	IMP	Out-grower principal repayment	Soybean	$294
		Out-grower interest repayment		$149
		Other benefits		$1,798
		Total financial benefits		**$2,241**
		Net financial benefits		**$986**

Note: Discount rate = 12 percent; climate scenario = optimistic; carbon credit price = USD $30. The "value of crop yield" is the average yield (different for BAU and IMP) multiplied by the crop sale price. Since investees offer IMP farmers a price premium, their crop yield value is calculated by multiplying average IMP yields with the average off-taking price offered by investees. For BAU crop yield value, we apply the average crop price for non-investee buyer options, including roadside, local market, main market, and private trader. All BAU and IMP data is based on household survey and investee survey responses. Investees are not involved in the BAU technology and so their incremental values are actual, not marginal, benefits.

BAU = business-as-usual; CR = crop rotation; ETP = enhanced tree planting; IMP = improved systems; USD = United States dollar.

Exhibit D.4. Incremental per-hectare economic NPV under varying SCC values (2023 USD)

Actor	Technology	Crop	SCC value		
			$51	$125	$185
Farmer	IMP	Maize	-$62	$57	$153
		Soybean	-$1,123	-$1,085	-$1,055
	ETP	Maize	$379	$866	$1,260
		Soybean	$379	$866	$1,260
	Soybean-maize CR	Both	$817	$855	$886
Investee: Idan Agro	Technology package	Maize, soybean, and rice	$6,708	$6,708	$6,708
Investee: Clean Savana	Technology package	Soybean	$986	$986	$986

BAU = business-as-usual; CR = crop rotation; ETP = enhanced tree planting; IMP = improved systems; SCC = social cost of carbon; USD = United States dollar.

Exhibit D.5. Incremental regional NPV under main scenario (2023 USD)

Actor	Technology package	Crop	Region	Financial NPV (millions)	Economic NPV		
					$51 carbon price (millions)	$125 carbon price (millions)	$185 carbon price (millions)
Farmer	IMP	Maize	Northern	-$7.5	-$4.9	$4.5	$12.0
			North East	-$1.9	-$1.2	$1.1	$3.0
		Soybean	Northern	-$36.7	-$36.4	-$35.2	-$34.2
			North East	-$13.9	-$13.8	-$13.3	-$12.9
	ETP	Maize	Northern	$18.9	$29.7	$67.9	$98.8
			North East	$4.7	$7.5	$17.0	$24.8
		Soybean	Northern	$7.8	$12.3	$28.1	$40.9
			North East	$3.0	$4.7	$10.6	$15.5
	Soybean-maize CR	Both	Northern	$89.4	$90.6	$94.8	$98.2
			North East	$25.8	$26.1	$27.3	$28.3
Investee: Idan Agro	IMP	Maize, soybean, and rice	Northern	$743.3	$743.3	$743.3	$743.3
			North East	$214.1	$214.1	$214.1	$214.1
Investee: Clean Savana	IMP	Soybean	Northern	$32.0	$32.0	$32.0	$32.0
			North East	$12.1	$12.1	$12.1	$12.1

Note: 12 percent discount rate; "optimistic" climate scenario; technology package adoption rate of 60 percent of a region's cropped area for the specified crop.

CR = crop rotation; ETP = enhanced tree planting; IMP = improved systems; NPV = net present value; USD = United States dollar.