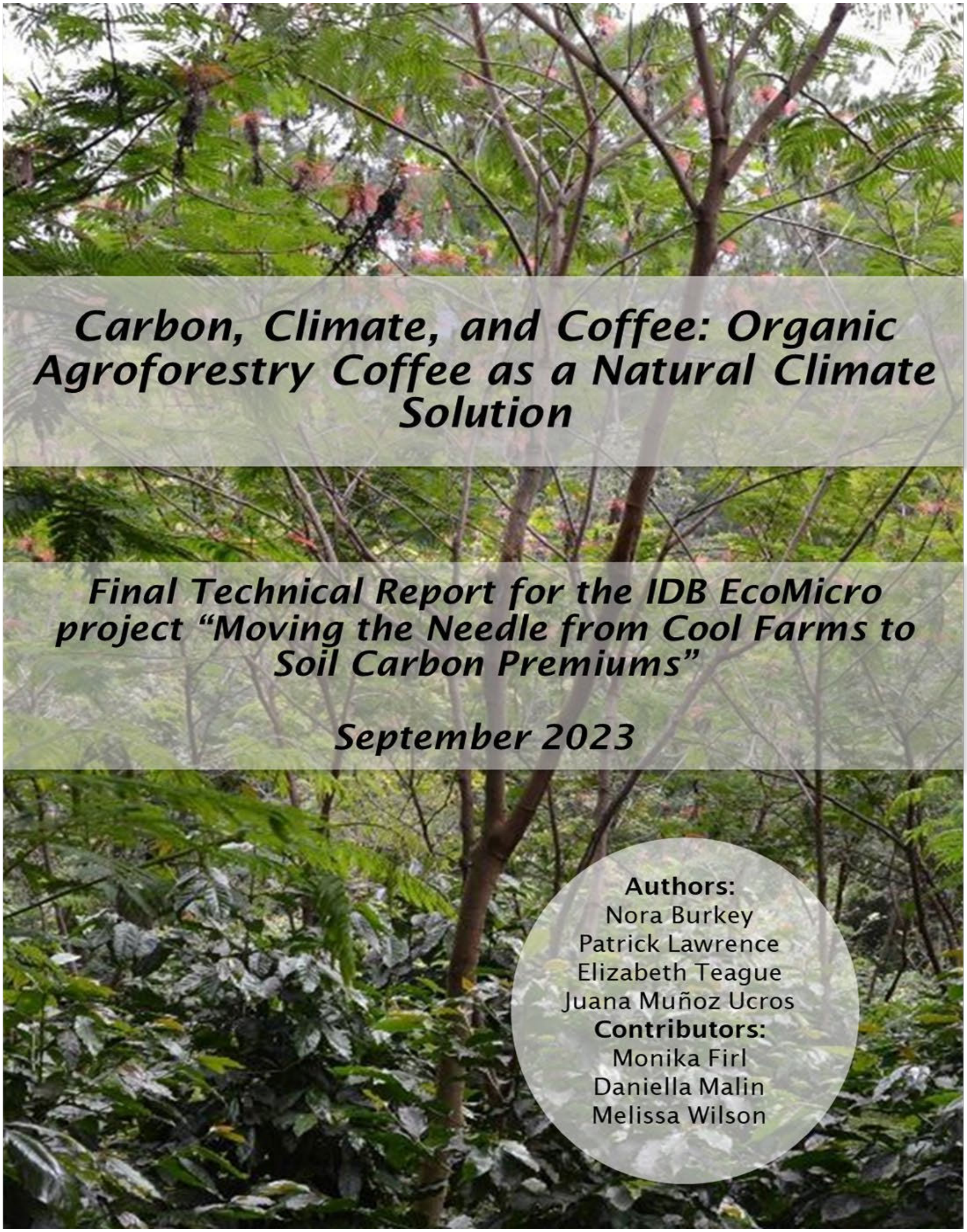

Carbon, Climate, and Coffee: Organic Agroforestry Coffee as a Natural Climate Solution

Final Technical Report for the IDB EcoMicro project "Moving the Needle from Cool Farms to Soil Carbon Premiums"

September 2023

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1. Introduction

The specialty coffee industry sits at the intersection of dual crises: the climate crisis and a livelihood crisis. Climate change threatens the future viability of coffee as a crop. Changing weather patterns are already decreasing coffee production and quality; as these changes accelerate, an estimated 50 percent of current coffee-growing area may become unsuitable for the crop by mid-century (Bunn et al. 89). Meanwhile, rising production costs and volatile commodity prices mean coffee producers do not reliably earn a profit (Panhuysen and Pierrot 16-17). Many of the estimated 12.5 million smallholder coffee producers do not earn a living income from their coffee farms and increasingly struggle to support themselves and their families.[1]

Fortunately, the specialty coffee industry is aware of these crises and is starting to act. Over the last five years, commitments to reduce greenhouse gas (GHG) emissions to mitigate the climate crisis have proliferated across the sector. Many actors have committed to reducing their emissions to "net zero" by 2050 or earlier; others have carbon goals within larger initiatives related to regenerative agriculture or biodiversity conservation. Similarly, the concept of living income has gained traction as a core tenet of sustainable supply chains, with multiple communities of practice emerging and an increasing number of buyers adopting goals related to greater value distribution to producers.

For many in the industry, the two frontlines of climate action and improved producer livelihoods remain separate areas of work. Yet the climate and livelihoods crises are interdependent and must be solved together. Without sufficient resources recognizing their labor, coffee producers cannot invest in climate action, whether related to decarbonization or—more urgent for producer communities—adaptation to shifting farming conditions and increasingly severe climate shocks.

There is, however, an opportunity to leverage the symbiotic nature of these two frontlines by recognizing that climate action can improve producer livelihoods if pursued in a manner that centers producer voices and prioritizes their needs. Leading coffee farmers have already demonstrated that regenerative agroforestry practices—such as planting shade and applying organic compost to build soil health—lead to numerous social and economic benefits. In addition, these practices can draw down carbon from the atmosphere and increase resilience to climate shocks. Yet the industry largely does not recognize the value generated by agroforestry practices, including contributions toward corporate net zero and/or supply resilience objectives. Should the industry compensate producers for their work to combat climate change, they could support producer livelihoods and climate action in concert.

In 2019, Cooperative Coffees—a cooperative of 23 community-based coffee roasters—presented an initial roadmap to turn this vision into a reality. Through their "Carbon, Climate, and Coffee Initiative," the roaster cooperative established a fund to compensate producer partners for the environmental benefits generated by their farming practices. As Cooperative Coffees wrote, "Smallholder producers are the solution to climate change, not the cause. Paying them for their environmental efforts

[1] Living income is defined by the Sustainable Food Lab as "the net income a household would need to earn to enable all members of the household to afford a decent standard of living."

is key to promoting carbon sequestering activities they currently perform while incentivising more effort in the future" (Canty).

To realize their vision of carbon-based payments for producer partners, Cooperative Coffees needed to answer three questions:

1. **How can we collect highly technical carbon data from hundreds of smallholder producers?** As a trader working with fair trade- and organic-certified smallholder producer organizations, Cooperative Coffees relies on their suppliers' internal control systems to collect data from individual producers and report aggregated information. While producer cooperatives already collect comprehensive production and demographic data from farmer members, they had limited or no experience with carbon accounting prior to this project.

2. **What is the carbon footprint of our suppliers?** Benchmark carbon footprint data exists for coffee, but most represent "average" national or global production systems rather than the small-scale, organic, agroforestry production systems that characterize Cooperative Coffees' supply chain. Moreover, most footprints do not account for carbon removals associated with coffee production, thereby misrepresenting the crop's climate impact. As World Coffee Research concluded in 2021, "We should consider that there are no accurate estimates of coffee's carbon footprint" (Acharya and Lal 1).

3. **How can we translate carbon performance into just compensation for producer partners?** Compensating producers for their carbon performance is considered a form of "insetting" – an investment in carbon reductions or removals within one's own supply chain.[2] Few guidelines exist on how companies should design insetting interventions, and fewer still on how companies should price carbon-based incentives for suppliers.[3] As a result, Cooperative Coffees needed to design their own approach to compensating producer partners, which presented both challenges and opportunities.

To answer these questions, Cooperative Coffees partnered with six producer organizations: producer organizations CAC Pangoa (Peru), CENFROCAFE (Peru), COMSA (Honduras), Manos Campesinas (Guatemala), Norandino (Peru), and Sol y Café (Peru); and sought the support of four industry allies also working at the intersection of producer livelihoods and climate action: the Cool Farm Alliance, Root Capital, the Sustainable Food Lab, and The Chain Collaborative.

Together, with funding from the EcoMicro program, housed in the Inter-American Development Bank, project partners designed and piloted a carbon insetting approach to compensate producers for their work as climate and environmental stewards. The pilot used the Cool Farm Tool, a greenhouse gas calculator, to measure producers' carbon performance—including its new methodology tailored to perennial crops like

[2] Carbon benefits generated through insetting interventions may or may not be verified as carbon credits or offsets, depending on how companies wish to claim the benefits. In this project, Cooperative Coffees did not seek to generate carbon credits; rather, they sought to report supply chain carbon benefits against their own corporate carbon footprint in service of a net zero commitment in place at the start of this project.
[3] Readers interested in emerging guidelines may wish to reference the International Platform for Insetting and the Value Change Initiative.

coffee. This project was the first to test the new Cool Farm Tool perennials methodology for smallholder coffee production, presenting an opportunity to contribute novel primary data to the industry.[4]

In total, the project worked with 253 coffee producers across Guatemala, Honduras, and Peru, representing around two percent of the six cooperatives' aggregate membership. Producers managed small coffee farms: on average, 1 hectare in Guatemala, 2 hectares in Honduras, and 3 hectares in Peru. Across the cooperatives, the median yield per farmer ranged between 0.4 and 0.7 metric tons of green bean equivalent coffee per hectare. All farmers were fair trade and organic certified, and all produced coffee under agroforestry conditions, with an average of 140 shade trees per hectare. Sixty-five producers (25 percent of project participants) were women. See Annex B for additional details on participating farmers.

As participating producers likely were not representative of each cooperative's full membership, project results should be seen as illustrative of the potential carbon performance of organic, agroforestry coffee production rather than indicative of the performance of each cooperative.

[4] As of the publication of this report, the Cool Farm Tool perennials methodology remains a prototype, subject to ongoing modification and improvement by the Cool Farm Alliance. Future changes in the Cool Farm Tool perennials methodology could affect carbon footprint results for coffee production, including the results shared in this report.

2. Project Summary

2.1 Project Origins

The idea for the "Moving the Needle from Cool Farms to Soil Carbon Premiums" project, funded by IDB Lab's EcoMicro program, originated from discussions between Cooperative Coffees and producer cooperatives about how to measure and reward producers' climate-friendly farming practices. Universally, producer cooperatives stated their primary objective was to help producer members remain on their land, sustain their way of life, and create better opportunities for their families through regenerative, resilient agriculture.

For decades, Cooperative Coffees had helped supply chain partners invest in improved agroforestry practices through regenerative terms of trade[5], industry-leading prices, direct grant-making, and farmer-to-farmer training.[6] Cooperative Coffees knew that further improvements to carbon performance were possible, but that the producers in their supply chain deserved recognition and compensation for their existing and decades-long environmental stewardship. Cooperative Coffees wanted to include carbon payments as a premium per pound of coffee, thereby normalizing ecosystem service payments as a cost of doing business.

To make this vision a reality, Cooperative Coffees approached the Sustainable Food Lab to assess whether the Cool Farm Tool and its latest perennials methodology[7] could answer the three driving questions of their Carbon, Climate, and Coffee initiative noted on page 4. Cooperative Coffees appreciated the Cool Farm Tool's capacity to both assess current GHG footprints (including removals) and to run forward-looking, "what-if" scenarios to identify opportunities for improvement. They liked that the tool could help users establish carbon baselines, as well as set and monitor progress toward future goals.

The Cool Farm Tool was created in 2010 to help agricultural actors estimate GHG emissions following calculation methods developed by the Intergovernmental Panel on Climate Change (IPCC). Originally a tool in Microsoft Excel, the Cool Farm Tool has since evolved into an online tool used by farmers, companies, and consultants worldwide to estimate GHG emissions and removals and identify opportunities for emissions reduction. As of 2023, the tool has over 30,000 registered users across 150 countries and is deployed in over 17 languages.

Once Cooperative Coffees had identified the Cool Farm Tool as their carbon accounting methodology, the organization needed a way to apply the tool with producer partners. Here, Cooperative Coffees turned to longtime ally Root Capital, a business lender and trainer supporting many of their producer suppliers. In particular, through its Digital Business Intelligence (DBI) Advisory, Root Capital helps coffee cooperatives and other smallholder enterprises digitize farm-level data collection, such as data collection for certification compliance. Root Capital also provides enterprises with an online data platform ("Cultivar") to store, analyze, and visualize their data; and provides capacity

[5] Cooperative Coffees believes there is no sustainability without regenerating the natural and economic wealth that has been extracted from coffee growing communities since colonial times. Beyond covering costs of production, regenerative trade enables investment for recovery. More information on Cooperative Coffee's position is available on their website.
[6] As one example, Cooperative Coffees has supported farmer-to-farmer training in COMSA's 5M methodology.
[7] When originally developed, the Cool Farm Tool primarily targeted annual crops. In recent years, however, increased interest in reporting emissions from perennial crops like coffee led to the development and addition of more sophisticated methods capable of accounting for multi-year crop lifespans.

building on data analysis and interpretation. By training cooperative staff to collect, manage, and interpret farmer data, Root Capital empowers organizations to own their data and leverage it to inform decision-making and communication with partners. Of relevance to this project, data in Cultivar can be linked to other applications, such as the Cool Farm Tool.

Given the project's interest in generating insights for the larger coffee industry, Cooperative Coffees brought on The Chain Collaborative to lead knowledge management and sharing for the project.

See Annex A for details on project partners and their roles.

2.2 Project Implementation

The three-year project was divided into two phases. Phase I focused on developing and piloting a prototype digital survey tool with a small number of farmers, allowing the partners to validate and refine the survey before scaling. Phase II focused on deploying the survey at scale to obtain carbon footprints for each cooperative and considering carbon payments based on the results.

Throughout the project, partners shared learning and insights through public webinars, blogs, and reports. See Annex C for a list of resources.

2.2.1 Phase I: Developing and piloting a prototype survey tool

The Cool Farm Tool was designed as a web-based, interactive tool to enable data collection from numerous land users. Many smallholder producers, however, live in communities without internet or cellular data access, making online data collection tools impractical. Moreover, some producers are not literate, meaning self-administered surveys are not accessible. Project partners designed for these realities by developing a mobile Cool Farm Tool survey to be administered offline by cooperative staff, with results uploaded once staff reached a site with internet access.

Root Capital led the team in developing the mobile survey using the iFormBuilder platform (see Figure 1). iFormBuilder was chosen because it can be used offline; because it allows for data export to other applications, such as the Cool Farm Tool web portal; and because most of the cooperatives were already familiar with the platform through prior work with Root Capital's DBI Advisory service.

Root Capital and the Sustainable Food Lab worked together to translate the online, self-administered Cool Farm Tool in English, into an offline, enumerator-administered, survey in Spanish that was relevant to smallholder coffee production. The survey included Cool Farm Tool's prototype perennials methodology, which was not then available in the tool's online version.

Project partners originally sought to incorporate the Cool Farm Tool survey into annual compliance monitoring for producers' fair trade and organic certifications, but found insufficient overlap in content between the two tools. As a result, project partners designed a separate digital survey to be administered by cooperative staff. Throughout this process, project team members engaged technical experts from participating cooperatives and the Cool Farm Tool methods committee, managed by Cool Farm Alliance.

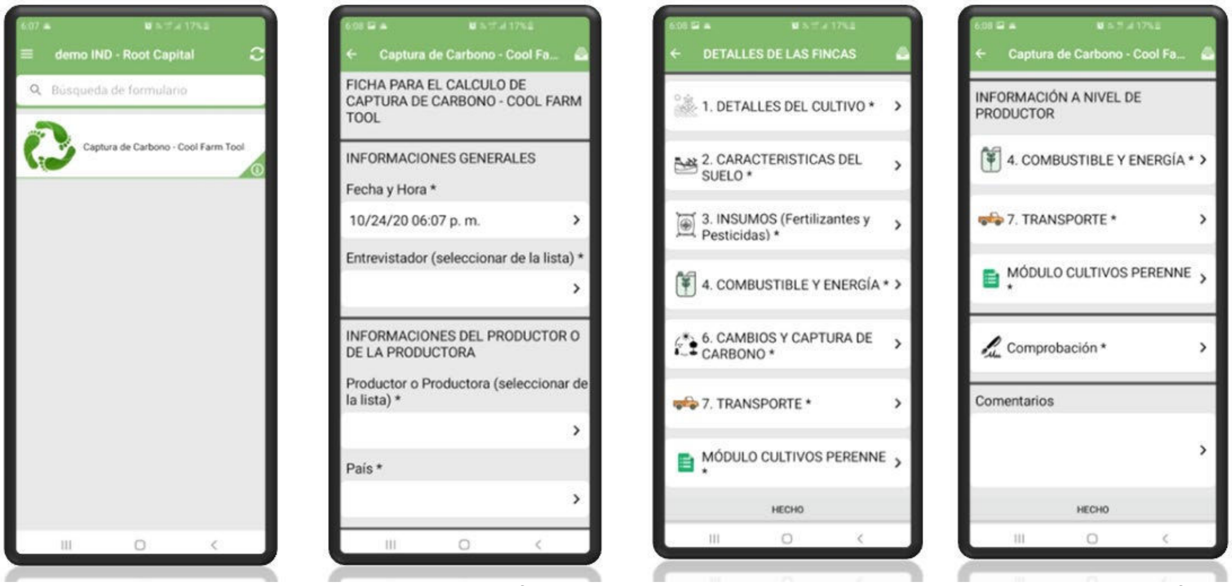

Figure 1: Cool Farm Tool digital survey developed for this project in iFormBuilder, showing high-level categories of data collection.

After creating the initial Cool Farm Tool survey, Root Capital's DBI Advisory team validated the survey with the six participating cooperatives and trained cooperative enumerators on data collection in the field.

Given that most farmers did not have experience with carbon accounting prior to this project, the project team decided to pilot the survey with a subset of approximately 60 farmers to test questions and answer sets before scaling to the full sample of farmers. Pilot data collection started at the end of 2020 and ran into the early months of 2021. Root Capital and the Sustainable Food Lab analyzed the resulting data, with a focus on identifying data quality concerns for discussion and interpretation with cooperative partners.

Based on producer feedback, the project partners modified select survey questions[8] and components of the data processing methodology to improve tool relevance for the context of smallholder coffee production in Guatemala, Honduras, and Peru. Partners provided training on the updated survey to each cooperative, including a detailed user manual for enumerators and surveyed farmers.

[8] For example, project partners modified answer presets for questions related to fertilizer usage to include local names for roughly two dozen common fertilizers. Partners also rephrased questions about the frequency and intensity of coffee tree pruning—a practice particularly important for emissions associated with organic residue management—after feedback that these questions had not been clear for producers.

2.2.2 Phase II: Scaling the survey tool, interpreting results, and designing carbon payments

Cooperative technical teams used the final Cool Farm Tool survey to collect data from 370 farms managed by 253 farmers.[9] Cooperatives selected the farmers to be surveyed, inviting a selection of their total membership that aimed for diversity in both farm characteristics and farmer demographics. In particular, cooperatives made an intentional effort to include women members in this project. While the participation of women varied by cooperative—ranging from 15 percent in Cooperative 5 to 50 percent in Cooperatives 2 and 4—the project collected data from 65 women producers, representing 25 percent of the total project sample.

Data collection occurred from October 2021 through February 2022. Data collection generally required an extra visit of at least one hour to each participating farm, plus additional time to travel to remote communities. In total, producer organizations spent several weeks in data collection.

Farmer data was uploaded into Root Capital's Cultivar platform. Once data was available for all farmers, the cooperatives, Root Capital, and the Sustainable Food Lab collectively cleaned the data. The Sustainable Food Lab then processed farmer data to calculate carbon footprints for each producer and each cooperative.[10] See section 3.1 for footprint results.

Project partners shared the carbon footprint results with the six cooperatives via a combination of group workshops and bilateral discussions, presenting data in aggregate for each cooperative and individually for each participating producer.

Cooperative Coffees then used the results to design environmental service payments for the six participating cooperatives. Payments were disbursed in the middle of 2022. See section 3.2 for details.

Producer cooperatives used the payments to fund climate action opportunities informed by the carbon footprint results, as well as larger priorities for member services. Opportunities generally related to cooperatives' technical assistance programs for farmer members. Four cooperatives invested more in shade trees, aiming to increase shade tree number and/or diversity to provide both carbon and food security benefits. Relatedly, one of these cooperatives also invested in a broader de-growth strategy to convert coffee land into conservation areas in the face of ongoing labor shortages due to migration. Other investment priorities included expanding the production of organic fertilizer for farmers and making direct bonus payments to farmers.

Looking beyond this project's immediate impacts, by testing the Cool Farm Tool's new perennials methodology, project partners supported the continuous improvement and expanded accessibility of the Cool Farm Tool. The Cool Farm Alliance is currently incorporating the enhanced perennials methodology into the online version of the Cool

[9] Many farmers managed multiple coffee farm plots or parcels, especially in Guatemala.
[10] Results should be considered final within the context of this project, even as the methodology behind the Cool Farm Tool's perennials methodology will evolve and improve over time.

Farm Tool to make it available to other users. These refinements provide a more complete picture of coffee emissions than is available from other agricultural GHG quantification tools.[11] The Cool Farm Alliance continues to pursue research and methodological advancements to improve the perennials methodology's underlying calculation models. While future improvements will likely impact the emissions results presented here, high-level project results and takeaways are expected to remain valid.

3. Results

3.1 Carbon footprint results

3.1.1 Summary

This project is one of the first to quantify both carbon emissions *and removals* associated with coffee production,[12] resulting in a more accurate understanding of the net carbon footprint of coffee production at the farm level.

An important note on results presented below: as in other carbon footprints for coffee production, land use change (LUC) in the form of deforestation represented a significant source of emissions for select coffee farms in the project sample. Following common carbon accounting standards, the Cool Farm Tool counts deforestation emissions if they occurred within the last 20 years, meaning newer coffee farms report significant land use change emissions while "legacy" coffee farms report none. While important for net zero accounting, project partners believe such a system does not support forward-looking action, especially with producers across different geographies with different deforestation histories. Within this project, the partners decided to treat deforestation emissions as a "sunk cost" for all coffee production, excluding deforestation from footprint analysis for the purpose of considering incentives or other support for producer partners. This report therefore presents data both with and without LUC emissions from deforestation.

Most coffee farms in the project sample operated at carbon negative. Including emissions from historical deforestation, across the 370 coffee farms assessed, the median carbon footprint was -0.6 kilograms (kg) of carbon dioxide equivalent (CO_2e) per kg of coffee green bean equivalent (GBE).[13] Fifty-five percent of farms removed more carbon than they emitted. An additional 20 percent were carbon neutral, with net emissions ranging from 0 to 1 kg CO_2e per kg GBE.

[11] Some of the method refinements sparked by this project include improvements to the Cool Farm Tool's ability to quantify the impact of perennial crop residue management, a process for managing inter-annual variation during crop establishment and maturity, and techniques for holistically assessing emissions and carbon fluctuations over longer periods of time. Based on improved user-supplied information on yields and typical residue management, the model uses age-based allometric curves to estimate biomass growth and the quantity of residue. Advanced input from users about how residues are managed enable the tool to calculate emissions or sequestration from residues burned, composted, spread on the soil, or removed from the farm (Ledo et al., 2018). The tool also incorporates information on inputs (fertilizer, pesticides, etc.), energy usage, wastewater management, growth, and yields, to estimate emissions from the crop over its lifespan.

[12] Previous efforts to use the Cool Farm Tool to quantify both carbon emissions and removals from coffee used an earlier, simplified methodology that accounted for one type of organic residue managed in one way, and that did not consider residue end-of-life.

[13] GBE was used to standardize reporting across the cooperatives. Farmers reported coffee yields in parchment or cherry depending on the form in which they sold their coffee.

Table 1 Median carbon footprint per unit of coffee produced (in kilograms green bean equivalent, or kg GBE) for each of the participating cooperatives. Carbon footprints are provided with (+LUC) and without (-LUC) emissions associated with reported land use change from forest to agroforestry.

	Coop1		Coop2		Coop3		Coop4		Coop5		Coop6	
	+ LUC	- LUC	+ LUC	- LUC	+ LUC	- LUC	+ LUC	- LUC	+ LUC	- LUC	+ LUC	- LUC
Total C footprint (kg CO2e / kg GBE)	9.68	-4.20	-4.00	-4.00	-0.15	-1.20	10.21	-6.80	67.92	-2.30	2.16	-3.80
Total C footprint (kg CO2e / ha)	109.30	-47.36	-71.55	-71.55	-2.17	-17.00	82.81	-55.36	542.75	-18.42	24.20	-42.20
Annual yield (MT GBE)	84		92		30		19		84		67	
Total area (ha)	140		103		40		47		209		120	
Productivity (MT GBE / ha / yr)	0.6		0.9		0.7		0.4		0.4		0.6	

Looking across cooperatives, median carbon intensity ranged from -6.80 to -1.20 kg CO2e per GBE excluding deforestation emissions—or from -0.15 to 67.92 kg CO2e per GBE including deforestation emissions (Table 1, Figure 2). All cooperatives had a significant percentage of farmers with net emissions below zero, with Cooperative 2 leading the sample with 100 percent of farmers operating at carbon negative.

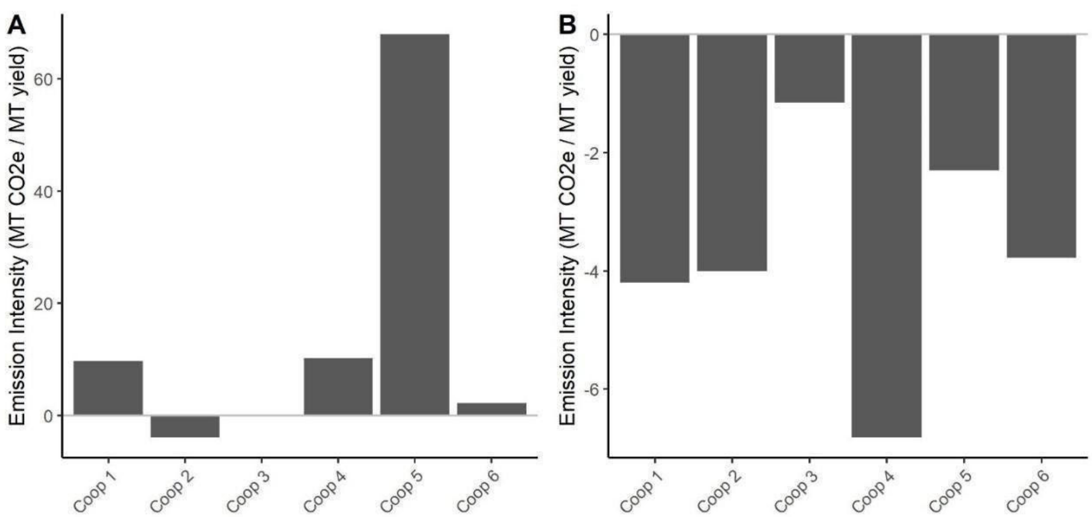

Figure 2 Net emissions intensity for each cooperative, including (A) and excluding (B) emissions associated with land use change from deforestation.

Looking within each cooperative, the carbon footprint of individual farm plots was quite variable (Figure 3). Other users of the Cool Farm Tool have seen similarly variable results with smallholder coffee producers.[11] At a time when primary carbon footprint data for coffee supply chains remains limited, this variability highlights the ongoing importance of site-specific data collection to understand the carbon performance of different coffee supply chains.

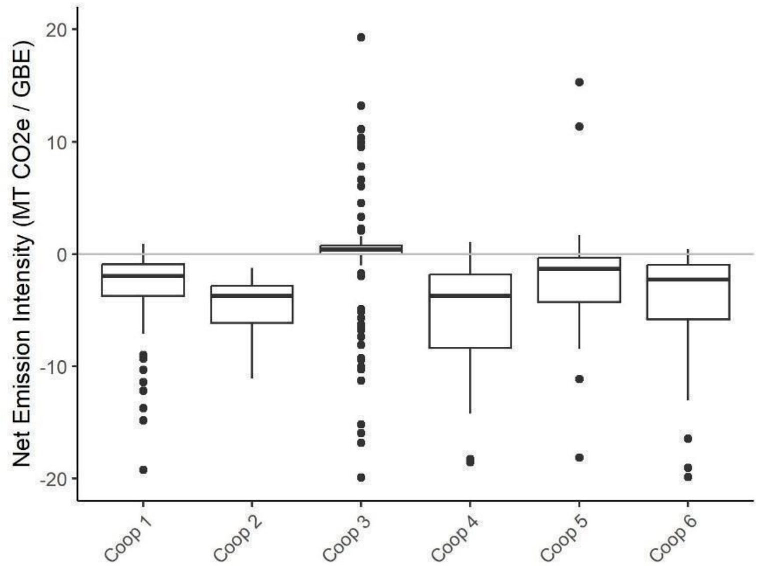

Figure 3 Individual farm results for emission intensity (emissions per unit of coffee produced) excluding emissions associated with deforestation. Points truncated past -20 and 20 MT CO_2e for visualization purposes (excludes 6 points). See footnote for guidance on reading whisker plots.[14]

Carbon footprint results did not appear closely linked to coffee productivity, especially when evaluated on a per hectare basis. These results suggest that farmers need not sacrifice yields to achieve carbon benefits. In fact, practices associated with higher productivity, like organic fertilization and regular pruning, can also drive greater carbon removals. See section 3.1.2 for details.

Carbon results did not differ significantly by gender (Figure 4).[15] Farms of women cooperative members showed similar performance on carbon emissions, carbon removals, and net carbon footprint per unit of coffee produced. Farms of women cooperative members also showed similar performance on coffee yield relative to farms of male cooperative members. These results are encouraging within the context of ongoing inequities faced by women coffee producers, including unequal access to technical training or resources, which often result in depressed yields for women producers (see section 4.4 for details)

[14] Box and whisker plots show the spread of data, where 50 percent of the plots fall within the box and the remaining 50 percent lie within the range of the lines ("the whiskers"). Individual points past this range represent parcels with extreme values in relation to the majority of the points within each coop (referred to as statistical outliers).

[15] Results according to a PERMANOVA analysis. This non-parametric test allowed project partners to evaluate whether gender or cooperative membership affected carbon emissions, carbon removals, or coffee yields, regardless of the distribution of the responses. In the model, the cooperative membership explained 25 percent of the differences in the data ($p<0.001$), but the effect of farmer gender on coffee yield or carbon footprint of the plot was not significant ($p=0.675$).

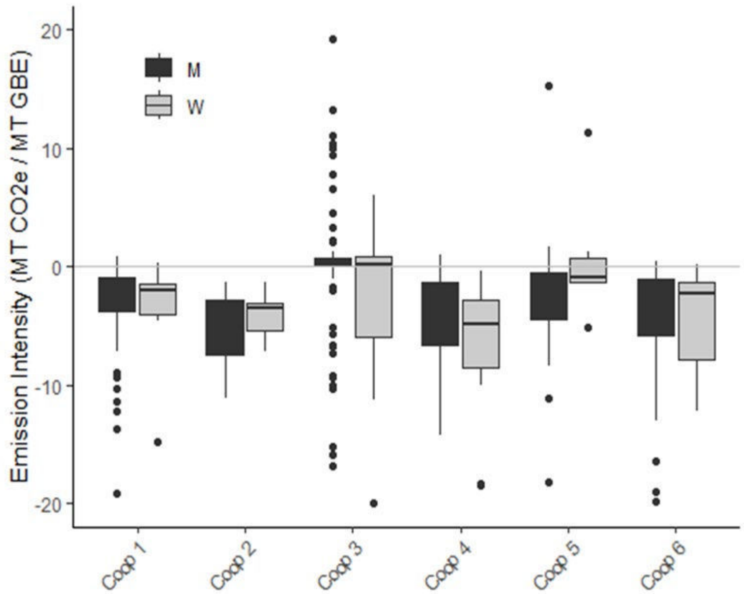

Figure 4 Farm results by emission intensity (emissions per unit of coffee produced) by gender. Farms managed by women are in light gray; farms managed by men are in dark gray. Results exclude emissions associated with deforestation. Points truncated past -20 and 20 MT CO_2e for visualization purposes (excludes 6 points). See footnote 13 for guidance on reading box and whisker plots.

3.1.2 Results by emissions source

The main drivers of carbon emissions were land use change (LUC), crop residue management, shade tree management, and fertilizer application.

LUC was the largest driver of emissions for most cooperatives (Figure 5). Large positive emissions from LUC were caused by forest removal; large negative emissions were caused by farmers switching from growing annual crops to growing coffee using agroforestry.[16] A significant quantity of biomass is stored within standing trees in subtropical dry forests, all of which is lost during forest conversion. By contrast, converting from growing annual crops to growing perennial crops like coffee results in a large increase in carbon stock in above and below ground plant material, especially when perennials are grown in conjunction with shade trees.

[16] Importantly, data indicates that all deforestation occurred outside of protected areas. In some cases, such as in Peru, it also came to light that deforestation had previously been encouraged by local regulations as a means of claiming land tenure.

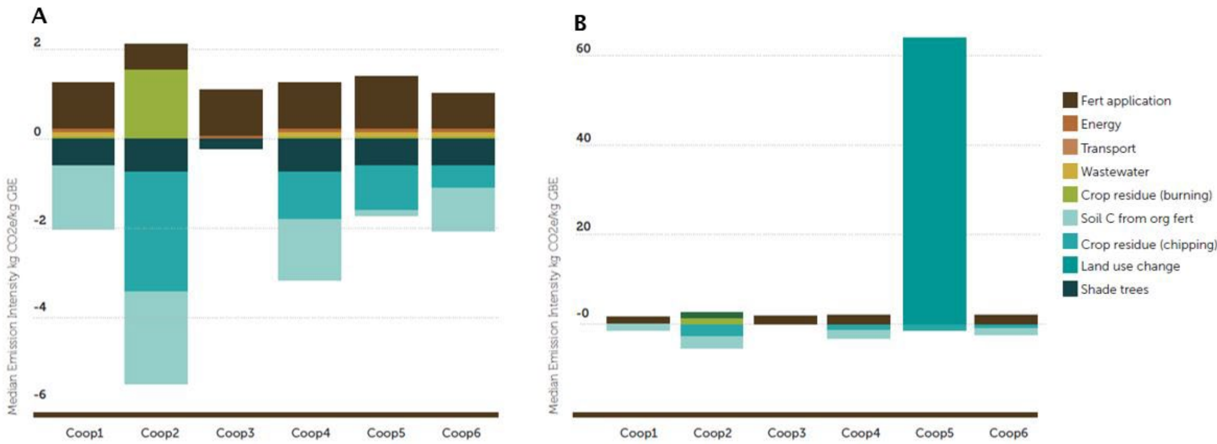

Figure 5 Median emissions intensities per cooperative showing emissions associated with different farm management activities, including (A) and excluding (B) emissions from deforestation.

Of the 370 farm plots in our sample, 73 (20 percent) reported conversion of forest to agroforestry coffee production in the past 20 years, resulting in emissions an order of magnitude higher than emissions from any other source (Figure 5.2). Forest conversion primarily occurred in Peru. Notably, Peruvian producers reported that much of the land had been deforested by other actors, mostly loggers; when converted by cooperative members, local regulations prompted farmers to clear the land to secure land titles.

Conversely, 53 plots (14 percent) reported conversion of annual crops to agroforestry coffee production, and 7 (2 percent) reported conversion of pasture to agroforestry, both of which resulted in significant carbon capture. These negative LUC emissions were primarily observed within Cooperative 3.

Crop residue[17] management was the second largest driver of emissions. Following GHG reporting conventions, biogenic CO_2 emissions are excluded from the calculations;[18] Therefore, all residue emissions are driven by methane (CH_4) and nitrous oxide (N_2O), which originate from burning and composting. In the context of coffee production, the most important source of crop residue comes from pruning coffee plants to improve plant health and yield and reduce disease risk.[19] Best practice recommends that producers prune a subset of coffee plants each year, creating a significant volume of organic residue to be disposed of or repurposed.

When burned or composted, pruning residue generated meaningful GHG emissions. Conversely, pruning residues that were chipped and spread on the soil resulted in negative emissions by increasing soil carbon. However, uncertainty remains about the net balance of soil carbon accumulation due to the preliminary methods used to estimate decomposition.[20] Similarly, composted pulp residues applied as an

[17] Crop residue refers to organic waste matter resulting from farm management activities, such as weeding or pruning.
[18] Plants uptake CO_2 during growth and the CO_2 is then released during eventual decomposition, burning, or composting. Correspondingly, atmospheric CO_2 is reduced and then increases, resulting in no net change. Due to this "zeroing out," the emissions from plants (referred to as biogenic CO_2) are typically ignored.
[19] The Cool Farm Tool does not currently consider crop residues from shade trees, which producers also prune to manage shade levels.
[20] When pruning residues are chipped and spread, the perennial methodology assumes the residues increase the amount of carbon stored in the system beyond the rate at which that carbon is lost through decomposition. The Cool

amendment can contribute to soil organic carbon (SOC) along with C from other organic fertilizers.[21]

Farmers' crop residue management practices were linked to cooperative membership. Some cooperatives have achieved greater rates of farmer adoption of annual coffee pruning, likely through ongoing farmer training. In these cooperatives, farmers pruned more coffee trees and produced a greater quantity of organic residue, which they could then chip and spread on the soil—resulting in increased rates of soil carbon accumulation.

Shade trees were a leading driver of negative emissions and were instrumental in reducing net emissions intensities across all cooperatives. Given the limited availability of age-based allometric models for different shade tree species, farmers' trees were grouped into four broad categories of tropical shade species. This generalization enabled estimation of carbon accumulation for less common tree species, but also resulted in greater homogeneity of results. Several cooperatives in Peru believed this approach underestimated the carbon benefits of their members' shade trees, as these cooperatives promoted the planting of larger, taller hardwood trees with greater biomass than the proxy species used in the Cool Farm Tool. In the end, sequestration results across the cooperatives were proportional to the reported density of shade trees.

The final notable contributor to emissions was the use of fertilizer. In conventional systems, chemical fertilizer use often represents a leading source of GHG emissions. For example, according to Cool Farm Tool data collected from conventional Arabica coffee farms in Colombia and Honduras, fertilizer production and application accounted for over 80 percent of the average footprint (Rainforest Alliance, 9). Farmers participating in this project, however, used only organic fertilizers, mostly in the form of composted coffee pulp residue. As a result, emissions from organic fertilizer production were negligible. Modest emissions still occurred from organic fertilizer application due to interactions with soil and microbial action.[22]

Fertilizer use also contributed to negative GHG emissions. If farmers introduced organic fertilizer application within the last 20 years,[23] organic fertilizers added carbon to the soil and contributed to sequestration. In most cases, negative emissions associated with increased soil carbon from organic fertilizers more than offset emissions from the application of these same fertilizers.

As other emissions categories—(organic) pesticide and herbicide use, energy use, wastewater, and transportation—contributed very little to emissions in the project sample, they are not discussed here. See Annex B for details.

Farm Alliance plans to further refine this methodology during the next development cycle for the Cool Farm Tool's perennial methodology.

[21] Usually, within the Cool Farm Tool, these contributions from organic fertilizers are only counted if the practice was initiated in the last 20 years due to soil SOC saturation. For this project, it was assumed that all organic additions to the soil were added within the last 20 years due to uncertainty about when farmers adopted specific practices.

[22] Soils also emit a small, but notable, level of background CO_2, CH_4, and N_2O emissions, which are encompassed in the "Fertilizer application" and "Soil C from org fert" bars of Figure 5.

[23] After 20 years, the Cool Farm Tool assumes a new equilibrium in SOC has been reached, in accordance with guidance from the IPCC.

3.1.3 Comparison of carbon emissions and carbon stocks

To recognize producers' past investments in sequestering and conserving carbon on their farms, project partners sought to complement data on farm-level carbon emissions with data on standing carbon stocks.

As with many carbon accounting tools, the Cool Farm Tool focuses on annual fluxes in GHG emissions and carbon sequestration rather than carbon accumulated prior to the reporting year. As such, the tool's standard outputs do not include quantification of standing carbon stock. However, it is possible to estimate carbon stocks based on data collected for carbon footprints. The Sustainable Food Lab therefore calculated carbon stocks for participating farmers in this project, resulting in estimated carbon stock intensities (metric tons of carbon per hectare) for each farm plot.

The median estimated carbon stock was approximately 4.5 metric tons of carbon per hectare. Results ranged widely, from under 1 to over 100 metric tons per hectare.

To understand how carbon stocks might relate to other indicators of interest, the Sustainable Food Lab also evaluated the relationship among carbon stocks, annual carbon emissions, and annual coffee yields across the 370 farm plots surveyed. Each indicator was divided into three performance categories (low-1, medium-2, and high-3), with each category representing one-third of the plots. As larger numerical values are considered better for coffee yields and carbon stocks, 1 was low and 3 was high for these indicators; as smaller or negative numerical values are considered better for carbon emissions, 1 referred to high emissions intensities and 3 referred to low or negative emissions intensities.

As seen in Figure 6, carbon emissions performance is not clearly linked with crop yields or carbon stocks in the project sample. Figures 6A and 6B show wide variation in coffee yields and carbon stocks across every carbon emissions performance category. If emissions performance were linked with coffee yields or carbon stocks, the data should show a linear trend, i.e., increasing carbon stocks with decreasing emissions.

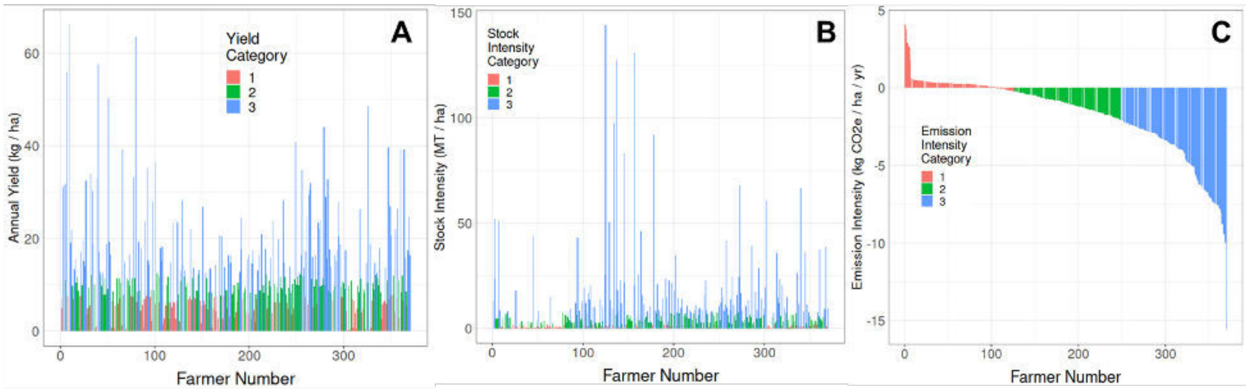

Figure 6 Farm performance based on coffee yield, carbon stocks, and carbon emissions per hectare. Farmers are ordered by carbon emissions intensity in all three graphs, as shown in Figure C—i.e., farmer 100 in Figure 6C is also farmer 100 in Figures 6A and 6B.
A) Coffee yields and yield categories for all farm parcels (1 indicates low yields, 3 indicates high yields).
B) Carbon stock intensities and stock intensity categories for all farm parcels (1 indicates low carbon stocks, 3 indicates high carbon stocks).
C) Carbon emission intensities for all farm parcels (1 indicates high positive emissions, 3 indicates low- to negative emissions).

Recognizing project limitations related to sample size and methodology, results suggest that coffee yields may not need to be compromised in the pursuit of better carbon performance. The variable nature of the results also indicates the need for more research into the relationships among carbon emissions, carbon stocks, and crop yields.

3.2 Carbon payments for producer partners

Cooperative Coffees initiated this project with the dual objectives of compensating organic smallholder farmers for their environmental contributions and addressing the critical challenges of farm profitability and climate change adaptation. The organization aimed to advance their mission and 10-year goals[24] while generating insights for the broader coffee industry.

When designing their payment model, Cooperative Coffees considered two main goals.

First, they aimed to recognize previous and ongoing environmental efforts while also incentivizing future improvements. As such, they envisioned a two-part payment model consisting of a one-time payment for baseline carbon performance, including carbon stocks conserved; followed by ongoing annual payments for improved carbon performance. The data collected through this project would serve as the data for the initial, baseline payment. Subsequent annual payments would fall outside the scope of this project, with a goal of implementation throughout Cooperative Coffees' supply chain by 2025.

[24] Cooperative Coffee's mission is to "continuously improving the livelihood of small-scale coffee farmers and services to our members through relationships that foster regenerative and sustainable impact." Their 10-year goals include serving as "a model of regenerative trade anchored in climate justice, building industry leading terms of trade with producer cooperatives who are stakeholders in our organization." See the Cooperative Coffees website for details.

Second, Cooperative Coffees sought to provide payments in a manner aligned with their cooperative principles and values.[25] Cooperative Coffees believed their cooperative partners were best positioned to determine the equitable distribution of benefits within their organizations. Some cooperatives expressed reservations about the fairness of individual compensation—given that many farmers engage in the same good practices, yet only a small subset had their carbon footprints calculated—and wished to use payments to invest in programs benefiting their broader memberships. Others wished to distribute payments to individual farmers to recognize their efforts in the project. As a result, Cooperative Coffees chose to provide carbon-based payments to cooperatives rather than directly to individual farmers, for cooperatives to distribute as they thought best.

Once producers' carbon footprints became available, Cooperative Coffees needed to determine how to calculate the specific payment for each cooperative. Given the variability of results, the project's small sample size relative to the cooperatives' total membership bases, and the influence of external factors over which cooperatives may have limited control, Cooperative Coffees decided to use a uniform, conservative benchmark for carbon performance across all six cooperatives of 1 pound (lb) of CO_2e removed per 1 lb of GBE.

To determine carbon pricing, Cooperative Coffees turned to the "Social Cost of Carbon": an estimate of the cost of the damage done by each additional ton of carbon emissions or, conversely, of the value of actions to reduce a ton of carbon emissions.[26] In 2022, when Cooperative Coffees was designing their payments, the United States Government used a Social Cost of Carbon of $51 per metric ton CO_2e or $0.023 per lb CO_2e. To recognize increased costs for cooperatives and farmers associated with data collection, Cooperative Coffees rounded up the price to $0.03 per lb CO_2e.

Cooperative Coffees applied the price of $0.03 per lb CO_2e removed to each cooperative's sales to the importer during the 2020-2022 coffee harvests. Carbon-based payments totaled over $150,000, ranging from $16,000 to $36,000 per cooperative. See Table 2 for details.

Table 2 Environmental service payments and impact investments made by Cooperative Coffees during the project.[27]

[25] For more information, visit the International Cooperative Alliance.
[26] For more information, refer to The Brookings Institution.
[27] As information on impact payments made by Cooperative Coffees is publicly available, this table uses cooperative names to maintain the anonymity of carbon footprint results shared elsewhere in the report. The order of cooperative

Cooperative	Carbon Payments	Additional Impact Fund Investments
Norandino	$16,173	$10,000 to respond to a climate emergency
CENFROCAFÉ	$20,605	Increased trade price
Sol y Café	$23,865	$8,020 for satellite imaging; $10,000 to inventory shade trees
Manos Campesinas	$29,390	$25,000 for a food security baseline
CAC Pangoa	$31,945	$7,000 for food support during COVID
COMSA	$36,751	$10,000 for reforestation efforts; $5,000 to respond to a climate emergency

In addition to the carbon-based premiums, over the course of the project, Cooperative Coffees supported participating cooperatives across three urgent action lines related to climate change, with a focus on gender equity and youth inclusion:

- Resilience: Addressing food security, income diversification, infrastructure adaptation, productivity, and quality;
- Regeneration: Promoting best practices in organic agroforestry, soil health, reforestation, biodiversity conservation, watershed protection, and carbon performance;
- Emergency response: Providing humanitarian aid, healthcare and education support, housing and livelihood recovery.

During the three-year project, participating cooperatives suffered from natural disasters exacerbated by climate change, ranging from landslides to droughts. Cooperatives were also impacted by the COVID-19 pandemic, which disrupted the global coffee supply chain and producer livelihoods. Through its broader impact investing activities, Cooperative Coffees granted over $75,000 to help the six participating cooperatives respond to these concurrent crises. To avoid disadvantaging smaller organizations, Cooperative Coffees applied the same investment terms to all supply partners regardless of the size of their commercial relationship.

Through this project, Cooperative Coffees made strides in designing a flexible climate investment model directed by farmer leaders and prioritizing climate justice. Yet as Cooperative Coffees considered scaling this model beyond the six cooperatives involved in this pilot, they encountered several challenges and complicating dynamics—most notably the desire to look beyond carbon to broader environmental performance to avoid "not seeing the forest for the trees." Other challenges remain related to the logistics and cost of scaling carbon accounting across smallholder supply chains. Challenges and potential paths forward are discussed in the next section.

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names in this table does not match the order used elsewhere in the report (i.e., Norandino is not Coop A). For more information on Cooperative Coffees' impact payments, please refer to cooperative factsheets at www.carbonclimateandcoffee.com

4. Lessons & Suggested Paths Forward

Project results demonstrate the important role organic agroforestry coffee production can play in reducing and storing carbon emissions. Additionally, agroforestry systems provide multiple other environmental and livelihood benefits, ranging from biodiversity conservation to diversified income and food security for producers.

Yet agroforestry coffee farms have been disappearing over the last several decades. Today, approximately 24 percent of the world's coffee area is managed under traditional, diverse shade and 35 percent under limited shade, representing a decrease of around 20 percent since the 1990s (Jah et al.). Producers who continue to grow agroforestry coffee face an increasingly dire confluence of challenges, including rising production costs, commodity prices often below the cost of production, and climate change. If unaddressed, these challenges may prompt producers to abandon coffee. Project partners have already encountered coffee smallholders turning to cacao, pineapple, sweet potato, ginger, or urban migration because they do not see a future in coffee.

Carbon pricing can help change this trajectory for the benefit of people and the planet. As the world races to achieve net zero, much of the attention in agricultural supply chains has rightly been focused on transitioning high-emission producers to lower-carbon practices. In specialty coffee supply chains, for example, many initiatives focus on (re)introducing agroforestry models in origins where full-sun, monoculture coffee has become the norm. This work is critical. At the same time, there is a need to help existing agroforestry producers conserve and improve their farms, which provide important benefits to producer communities, supply chains, and the environment.

Specifically, project partners encourage coffee industry actors interested in net zero, resilient supply chains to provide preferential pricing to good carbon performers—on top of living income prices—to incentivize producers to maintain and further improve regenerative, agroforestry systems. Preferential pricing refers to the practice of buyers offering better prices for supply characteristics they value, such as quality. A price premium tied to good carbon performance would recognize the value of low-carbon or carbon-negative coffee to buyers' sustainability commitments and overall supply resilience. Beyond the importance of recognizing its inherent value, carbon pricing could incentivize producers to adopt or sustain good carbon practices, such as mulching organic matter, that involve additional costs in inputs or labor.

To implement carbon pricing, however, coffee industry actors need carbon footprint data at scale and guidance on how to use carbon footprint data within their operations. This project collected carbon footprint data for two percent of the farmers represented by the six cooperative partners—scaling across each cooperative's full membership or an entire smallholder supply chain appears daunting with the tools available today. Yet project partners see the following opportunities to work toward scaled carbon measurement and, most importantly, scaled carbon compensation for coffee producers. Recognizing the diversity of coffee supply chains, this report does not attempt to provide one pathway to scale, but rather suggests multiple avenues for consideration.

4.1 How to collect highly technical carbon data from smallholder farmers

Partner with producer organizations to collect, report, and (most importantly) act on carbon accounting data. As mentioned above, this project originated from discussions with producer cooperatives who wanted to better understand, be recognized for, and improve their efforts to support climate-friendly, regenerative coffee farms. These cooperatives play a critical role in smallholder supply chains, providing market access, agronomic training, financing, and other support to otherwise hard-to-reach farmers. Because they are owned and largely led by producers, they also uniquely understand producers' context and needs. By partnering with these critical actors in smallholder supply chains, the project was able to collect data from hundreds of producers across Guatemala, Honduras, and Peru.

More importantly, the cooperatives' insights were critical to contextualizing carbon footprint results and identifying opportunities for action aligned with producers' needs. Collaboration and learning across the supply chain requires including producer voices throughout the process, ensuring producers have access to their own carbon data, and investing time in joint analysis and interpretation of results so producers can make informed decisions.

Build fit-for-purpose data collection tools for rural communities. As discussed in section 2.2, many smallholder producers live in communities without internet or cellular data access, making online data collection tools impractical. Moreover, some producers are not literate, meaning self-administered surveys are not accessible. Project partners designed for these realities by developing a mobile Cool Farm Tool survey to be administered offline by cooperative staff, with results uploaded once staff reached a site with internet access. When choosing our data collection system, we prioritized adaptability, so that questions could be modified based on local context; ease-of-use for cooperative staff managing data collection; and compatibility with other systems, most notably the Cool Farm Tool web application and cooperative data collection systems managed through Root Capital's Cultivar data platform.

Co-develop and share carbon footprint benchmarks to inform industry decarbonization efforts while reducing data collection burden for producers. As discussed in section 3.1.1, carbon footprint results were quite variable both within and across cooperatives, showing the importance of site-specific data collection to establish baselines for specific coffee supply chains. Project partners see an opportunity for industry actors to collaborate pre-competitively to create and share carbon footprints for different coffee supply chain segments. Coordinated research would provide buyers and other industry actors with data to advance corporate climate strategies without overburdening producers with duplicative data requests.

Encouragingly, several platforms are already promoting the creation of industry carbon benchmarks, including the Cool Farm Alliance, the Sustainable Coffee Challenge, and USAID Green Invest Asia. These efforts would also help build the evidence base for organic, agroforestry coffee as a natural climate solution, adding nuance to the magnitude of impact and the key drivers of carbon emissions and removals across coffee origins.

Beyond carbon footprint benchmarks, however, industry actors also need guidance on how to appropriately use these data in their environmental reporting. In particular, questions remain around how companies should use benchmarks to estimate carbon performance across entire supply chains, and when companies should supplement secondary data with primary data collection.

After developing baselines, focus scaled data collection on key drivers of emissions and removals. The full Cool Farm Tool requires high-resolution data on every aspect of crop production. Yet this project and others using the Cool Farm Tool[17] have found that a handful of practices drive the majority of coffee production's carbon footprint, although which set of practices varies by context. After using the full Cool Farm Tool to establish a baseline for a particular supply chain, project partners see an opportunity to focus recurring data collection on the main drivers of emissions and removals to reduce the time and cost burden for producers and supply chain partners. Using this simplified approach, there is potential to integrate carbon accounting and reporting into certification standards, as recommended by groups like the Value Change Initiative.

4.2 Opportunities to improve the carbon footprint of smallholder coffee suppliers

Project results (see section 3.1) demonstrate that organic agroforestry farming can be an important natural climate solution, with the potential to sequester more carbon than it emits. These results suggest that the production stage presents the greatest opportunity for carbon removals within the coffee supply chain—a striking result against the backdrop of other studies of coffee's carbon footprint pointing to production as the leading source of supply chain emissions.[28]

In particular, as discussed in section 3.1.2, project data suggests opportunities to improve coffee production's carbon performance related to: **avoiding future deforestation; transitioning to all- or mostly-organic management practices; increasing farm vegetation, such as shade trees, windbreaks, or living fences; and transitioning from burning pruning residue to chipping and spreading it on the soil.**

While noting these general opportunities, the broad distribution of emissions results suggests that **improving coffee production's carbon performance requires a customized, site-specific approach rather than a "one-size-fits all" strategy**. In addition, this variability confirms that opportunity for improvement exists within each cooperative, and that region-specific factors do not prevent any producer from achieving net negative emissions values.

[28]Acosta-Alba et al.; Nab & Maslin.

When considering opportunities to improve coffee production's coffee footprint, project partners suggest supply chain stakeholders consider several factors.

Look beyond carbon performance to consider the larger set of forces influencing producer decisions—most importantly, producers' own priorities for their households and communities. Coffee producers are likely not optimizing around carbon performance, but around their household prosperity, food security, and resilience. Supply chain partners should evaluate the potential impacts of carbon reduction strategies on producers' broader priorities and context to determine which strategies align with the ultimate goals of climate action in service of improved producer livelihoods. Given producers' limited historical role in causing climate change, carbon reduction should not come at the expense of producer wellbeing or resilience.

Shade tree management represents an interesting example. Increased shade tree density is associated with greater carbon removal. Some producers, however, may be in locations too cloudy or humid for intense shade, which can reduce yields and therefore income in these contexts. For these producers, the use of windbreak trees or live fencing may be a better way to increase carbon capture and farm resilience to weather shocks without depressing producer income.

Consider the carbon footprint of alternative management practices. Fertilization serves as a notable example. While reducing fertilizer application would lower total emissions on a per hectare basis, it would also likely lower crop yields, as most producers in this project likely under-fertilized their plots. In other words, project data suggests producers did not apply enough compost or other fertilizer to the soil to replace the nutrients removed by their coffee plants each year (see Figure 7). If yields decline more than emissions, carbon emissions *intensity* per unit of coffee produced may increase. Moreover, project data suggest that applying organic fertilizer results in increased carbon capture by soils. Therefore, most producers in the project should likely apply more organic fertilizer to improve yields and thus carbon performance.

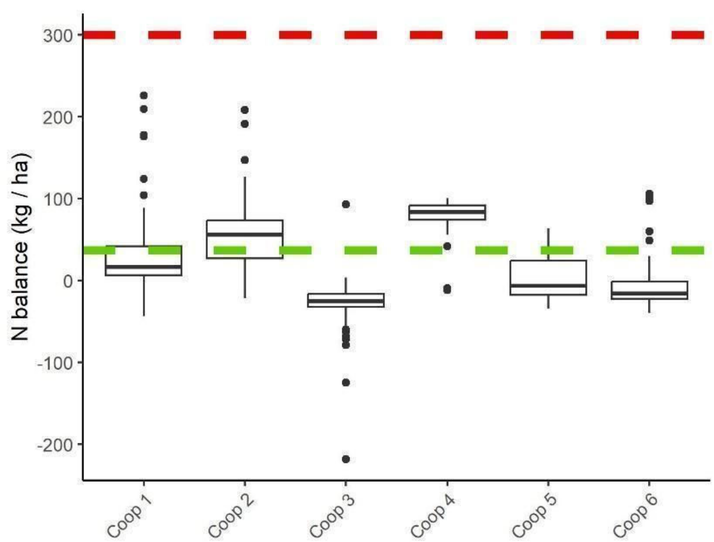

Figure 7 N balance (N applied in fertilizer of any kind minus N removed in the form of the harvested crop) of plots surveyed across the six cooperatives. The green line represents the average N applied by all farmers in the sample, while the red line represents the recommended annual application rate to replace nutrients lost for a 5,000-coffee tree per hectare farm (Salazar-Gutierrez and Siavosh).

Similarly, transitioning producers from burning woody crop residue to chipping and spreading the residue can significantly reduce emissions. However, the availability of alternative sources of fuel for cooking or heating must be considered, as some may be more carbon intensive.

Consider practical feasibility alongside the potential carbon benefits. Producers may not be able to change certain production practices without additional support, because they do not fully control decision-making related to these practices or because they simply lack the resources. For example, if producers rely on cooperatives to process their coffee, individual producers may not have direct influence over crop residue management decisions. Changing practices can also require additional technical assistance or new investments in labor or equipment, such as chippers. More fundamentally, smallholders may be limited by their available farming area, as noted above.

4.3 How to translate carbon performance data into compensation for producer partners

Consider compensation models based on producer typologies or performance categories rather than individual results. As the science and best practice around carbon measurement and compensation continue to evolve, and as the coffee industry continues to gain visibility into the carbon footprint of specific supply chains, there is a potential to consider carbon valuation based on performance categories (i.e., low-, medium-, and high-emission categories) rather than site-specific individual results. For example, buyers could pay a premium to all low-carbon organic, agroforestry producers to recognize their contributions related to decarbonization and supply resilience. Such a premium would resource producers to maintain and improve their agroforestry farms, while sending a market signal to higher-emitting producers to invest in carbon reductions or removals.

In terms of practicality and scalability, a premium based on performance categories could leverage less precise, but directionally accurate carbon data focused on key drivers of results (as mentioned above). This would significantly reduce the costs and complexity of data collection and reporting for producers and supply chain partners.

Discount land use change when considering compensation for producers. As noted in section 3.1.1, project partners decided to treat deforestation emissions as a "sunk cost" for all coffee production, excluding deforestation from footprint analysis for the purpose of considering incentives or other support for producer partners. Partners made this decision for three reasons: First, given the nature of coffee as a tropical tree crop, all coffee farms likely originated from conversion of tropical forests. Second, coffee producers may not be responsible for the initial deforestation; by planting agroforestry coffee after deforestation events, they are regenerating degraded landscapes. Third, even when smallholder coffee producers were responsible for deforestation, they were often responding to supply chain pressures to produce more coffee at lower costs. By excluding deforestation emissions from compensation models, supply chain partners can focus on practices that producers can adopt or improve now, while avoiding penalizing vulnerable producers for past actions perhaps beyond their control.

Account for systematic barriers limiting the carbon performance of marginalized producers. Systemic inequities such as limited access to land, education, or agricultural inputs may limit some producers' ability to achieve better carbon footprints and therefore performance-based incentives. For example, women producers are less likely to participate in agricultural training due to additional child-rearing and home-making duties, resulting in lower practice adoption, lower yields, and lower income—and perhaps in higher carbon footprints than their male peers. In addition to supporting existing good actors, compensation models should consider how to meet the needs of the most marginalized producers, for example through complementary investments in tailored training, to promote equitable climate action.

Pay for carbon data collection as well as for carbon. Carbon measurement requires material new investment by producers, above and beyond current reporting for certifications or other supply chain sustainability initiatives. As discussed in section 2.2, carbon data collection required several extra weeks in data collection by cooperatives, which represents time away from other responsibilities for both cooperative staff and producers. Beyond data collection, cooperatives also invested time in training surveyors and in aggregating and cleaning data. During this project, Root Capital provided $12,000 in grants to two cooperatives to cover increased costs related to carbon data collection and management.

Moreover, to scale carbon data collection across their membership, some cooperatives expressed a need to hire additional, specialized staff going forward. Given the importance of technology in this work, cooperatives suggested hiring community youth for these positions.

Going forward, producer organizations look to supply chain partners requesting carbon data for their own business needs to help cover these new costs. Producers also request support in turning carbon data into climate action, for example through training on how to interpret carbon footprint results or funds to introduce new technical assistance activities focused on good carbon practices.

Finally, while this project focused on carbon emissions, project partners recognize carbon represents only one aspect of environmental performance. Coffee producers provide numerous other ecosystem services that should be valued to improve producer livelihoods and sustain their environmental benefits. **Many in the coffee industry are expanding their ambitions beyond net zero to pursue a "nature-positive" future**—a world where we halt and reverse nature loss so that ecosystems can begin to recover.[29] Under a nature-positive approach, industry actors might measure biodiversity levels, soil health, or water quality alongside carbon and consider compensation models across these interrelated indicators.

[29] For details, see "Towards an IUCN nature-positive approach", a 2022 working paper that proposes a rights-based, socially focused push towards nature-positive impact of value chains.

Project partners welcome this trend, as it could address limitations of a narrow focus on carbon—for example, overlooking the environmental benefits of forest stands planted and conserved by farmers outside of their coffee plots. Cooperative Coffees, for example, is interested in incorporating carbon stocks or biodiversity richness into its future climate investment work. While quantitative methodologies to measure progress toward nature-positive goals remain extremely nascent, project insights related to carbon measurement and compensation for smallholder coffee farmers could be transferrable to broader environmental compensation models.

4.4 Gender dynamics in carbon measurement and compensation

According to a gender analysis conducted at the beginning of this project, gender inequities persist in the member communities of the six participating cooperatives that mirror industry-wide trends.[30] Even when they are not named cooperative members, women are disproportionately responsible for the earlier stages of coffee production, yet generally do not receive recognition—financially or otherwise—for their contributions. In many cases, lack of recognition stems from the fact that women producers in male-headed households are excluded from direct market participation and household economic administration. Even when women are recognized as the primary coffee farm owner or manager, many lack access to resources to invest in their farms.

As mentioned in section 2.2, the project partners made an intentional effort to include both women and men cooperative members in this project. During the course of the project, however, partners also saw a need to take a broader view of gender inclusion, looking beyond the gender of the registered cooperative member or land manager to involve all women participating in production activities.

First, participating cooperatives indicated that, in many cases, only female family members were able to answer Cool Farm Tool survey questions about certain farm management practices, because they were primarily responsible for these activities. As such, it is critical that women producers are included in carbon measurement efforts, even if they are not named as the farm owner or primary manager.

Second, more work remains to ensure women producers have equal access to the benefits of carbon compensation models. As noted above, women often do not receive the full benefits of participation in specialty coffee supply chains, in part due to limited access to direct market participation and limited decision-making power over household income. Broader gender-equity programming related to equitable market participation and distribution of household coffee income[31] will be critical to ensuring future carbon compensation models help close, versus widen, the gender gap in coffee.

[30] For a good summary of gender dynamics in the coffee supply chain, refer to "Gender Equality and Coffee: Minimizing the Gender Gap in Agriculture" from the Specialty Coffee Association.
[31] For example, the Gender Action Learning System (GALS) approach, which, as a household level methodology encourages shared decision-making and equitable distribution of earnings from coffee.

5. Conclusion

This is the decade for action. As the world rapidly approaches the 2030 deadline to achieve a key net zero milestone and the Sustainable Development Goals, the actors most responsible for climate change bear a responsibility to decarbonize in a manner that does not further jeopardize vulnerable communities. Carbon or broader environmental payments show significant potential to help address the interrelated crises of climate change and poverty in smallholder coffee communities—if implemented in partnership with producer communities and in a manner that centers their needs.

The Cool Farm Alliance, Cooperative Coffees, Root Capital, the Sustainable Food Lab, and The Chain Collaborative thank their producer organization partners—CAC Pangoa (Peru), CENFROCAFE (Peru), COMSA (Honduras), Manos Campesinas (Guatemala), Norandino (Peru), and Sol y Café (Peru)—and the 253 producers who shared their time, data, and expertise. Without producers' critical contributions, this project would not have been possible. Project partners also thank EcoMicro and the Inter-American Development Bank for their generous support of this work over the last three years. Project partners look forward to continuing to explore models that improve both climate action and producer livelihoods, and invite collaboration with others on this journey.

Annex A: Project Partner Roles and Responsibilities

Partner Name	Role in Project	Partner Description
Producer Cooperatives	Farmer data collection and interpretation; consultation on design of environmental service compensation model	Producer cooperatives CAC Pangoa, CENFROCAFÉ, COMSA, Manos Campesinas, Norandino, and Sol y Café played the most critical role in the project. Before the project began, cooperatives provided technical training, financing, and other resources to farmer members to adopt and maintain organic, agroforestry farming practices. During the project, they collected data from hundreds of producer members, informed data interpretation, and shared results with their farmer members. They also provided on improving Cool Farm Tool content and data collection process. In addition, through numerous workshops and consultations individually and as a group, their perspective informed the development of the environmental service payment piloted by Cooperative Coffees.
Cooperative Coffees	Project convener; environmental service compensation design and payment	Cooperative Coffees is a cooperative of 23 community-based coffee roasters. Within this project, Cooperative Coffees developed the project concept and convened its stakeholders, especially the cooperative partners who formed part of their coffee supply chain. Cooperative Coffees also provided counterpart funding for the environmental service premiums through their Impact Fund. Finally, Cooperative Coffees organized and facilitated the final in-person producer workshop for co-learning.
EcoMicro of the IDB Lab	Funder	EcoMicro is a $17-million technical cooperation facility implemented by the innovation laboratory of the Inter-American Development Bank Group (IDB Lab). EcoMicro is coordinated out of IDB's Barbados office. In addition to IDB Lab, EcoMicro funders include the Nordic Development Fund and Global Affairs Canada. By working with financial institutions, EcoMicro aims to support climate change adaptation for micro, small, and medium-sized enterprises (MSMEs), smallholder farmers, and low-income households.
Root Capital	Project lead; technical adviser for producer cooperatives on data digitization, and on climate change adaptation	Root Capital is a business lender and adviser seeking to build prosperous, resilient rural communities. Within the project, Root Capital served as project lead for funding from EcoMicro, organizing project workplans, managing funds for other partners, and ensuring project deliverables. In addition, Root Capital's Advisory team supported field data collection by producer cooperatives, creating a digital version of the Cool Farm Tool survey and providing training on survey implementation to cooperative staff. Where needed, Root Capital also provided grant funding to cooperatives to improve their data collection capacity. Root Capital worked with the Sustainable Food Lab and the cooperative partners to clean, analyze,

		and interpret the resulting data, providing feedback along the way on opportunities to refine questions to improve their relevance for smallholder coffee production. In parallel, Root Capital performed climate vulnerability assessments for each cooperative and organized workshops to build climate adaptation plans informed by these assessments.
Sustainable Food Lab	Carbon accounting tool developer; quantitative data analysis	The Sustainable Food Lab is a non-profit organization seeking to create a sustainable food system by helping organizations turn ideas into action. As one of the founders of the Cool Farm Tool, the Sustainable Food Lab plays a key role in the tool's continuous improvement and use, even after it spun the Cool Farm Tool off into its own legal entity, the Cool Farm Alliance. Within this project, the Sustainable Food Lab oversaw the technical implementation of the new perennials methodology of the Cool Farm Tool, including translating the new methodology from the original programming language R[32] into python[33] for ease of use. The Sustainable Food Lab also analyzed data collected from farmers and provided technical guidance on results interpretation. Throughout the project, the Sustainable Food Lab contributed greatly to the partners' understanding of carbon accounting and carbon markets.
The Chain Collaborative	Knowledge management and gender assessment	The mission of The Chain Collaborative is to co-create opportunities and strengthen capacities for community-led change in the coffee sector. The Chain Collaborative completed all donor reporting for the project, organized meetings between partners, and disseminated information to the industry through webinars and other live events. They also supported project partners to turn learning into recommendations for the broader industry. Finally, they conducted a gender assessment of the cooperatives and provided guidance on how to account for gender equity in the application and scale of the Cool Farm Tool.

[32] R Statistical Software (v4.1.2; R Core Team 2021).
[33] The Python programming Language. Van Rossum, G. (2007).

Annex B: Characteristics and management practices of participating farms

This annex presents details on the characteristics and managing practices of the 253 farmers and 370 farm plots participating in the project (Table A1) to help contextualize carbon footprint results.

Table A1. Number of participating farmers, farm plots, and total area for each coop.

Cooperative Name	Number of Farmers Surveyed	Number of Farm Plots Surveyed	Total Area Surveyed in Hectares (% of Total Area Represented by the Cooperative)
Cooperative 1	45	81	140 (21%)
Cooperative 2	45	46	103 (15%)
Cooperative 3	42	119	40 (6%)
Cooperative 4	30	30	47 (7%)
Cooperative 5	44	44	209 (56%)
Cooperative 6	47	50	120 (32%)
Total	**253**	**370**	**669**

Coffee plot sizes: Most coffee plots were small: 40 percent of sampled parcels were under 1 hectare, and 91 percent were under 5 hectares (Figure A1). The maximum plot size was just over 10 hectares, and the minimum was less than 0.2 hectares. Farmers in Coop 3 managed the smallest total area (although they managed the largest number of individual plots), while farmers in Cooperative 5 managed the largest total area (Table A1).

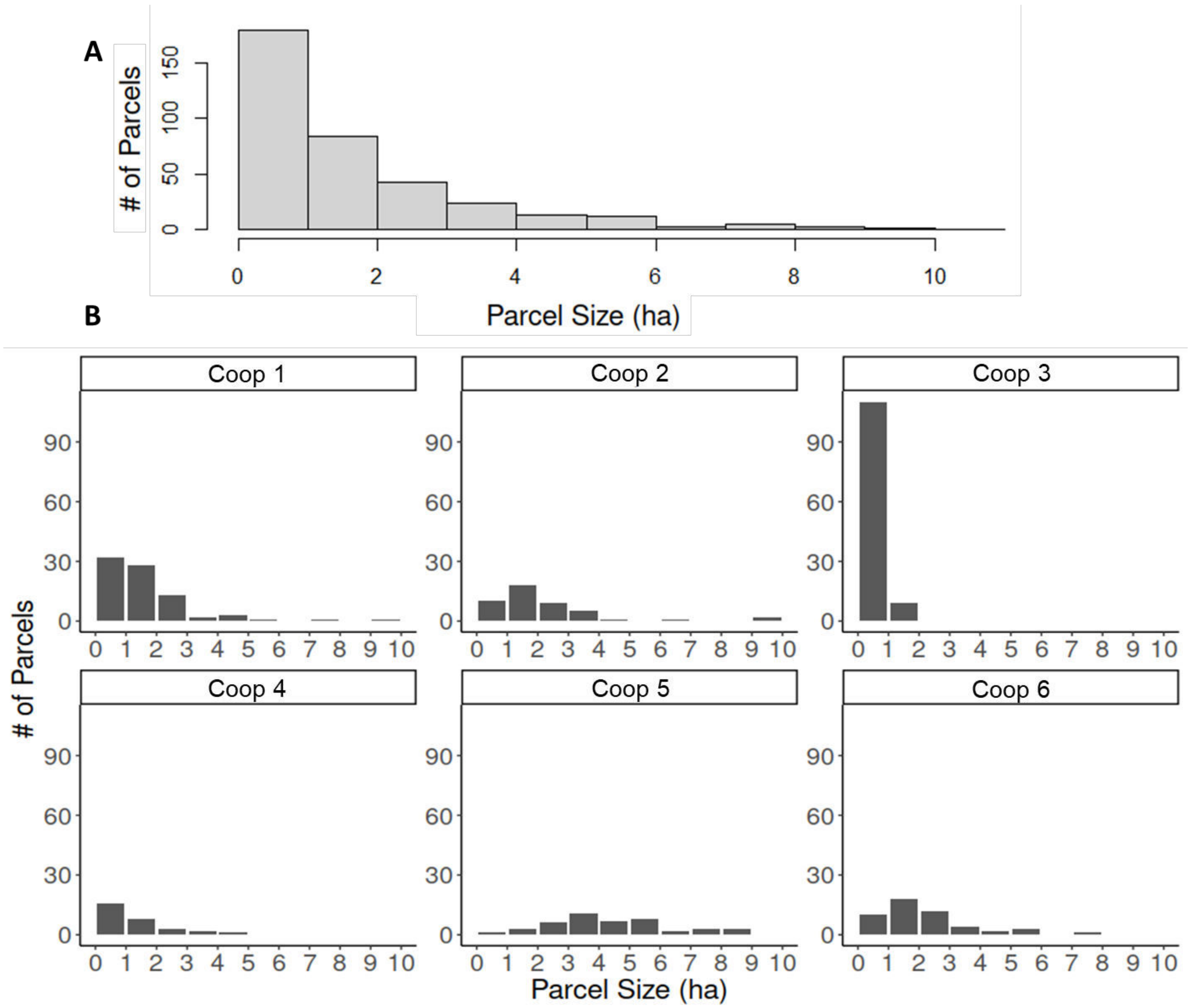

Figure A1. Parcel size distribution for each cooperative. A) frequency of parcels within area categories in the entire sample. B) Frequency of parcel size within each cooperative.

History of land use change: Land use change is a complex phenomenon, highly dependent on location, socioeconomics and history among other variables.[34] The Cool Farm Tool assessed land use change within the last 20 years, in keeping with carbon accounting guidance from the GHG Protocol and others. Within the project sample, 65 percent of coffee plots reported no land use changes within that period. Among the plots where significant land use change was reported, three specific histories emerged (Figure A2): conversion of pasture to agroforestry (2 percent, or 7 plots), annual crops to agroforestry (14 percent, or 53 plots), and forest to agroforestry (20 percent, or 73 plots).

[34] Bergeron, Gilles, & Pender, John. (2019)

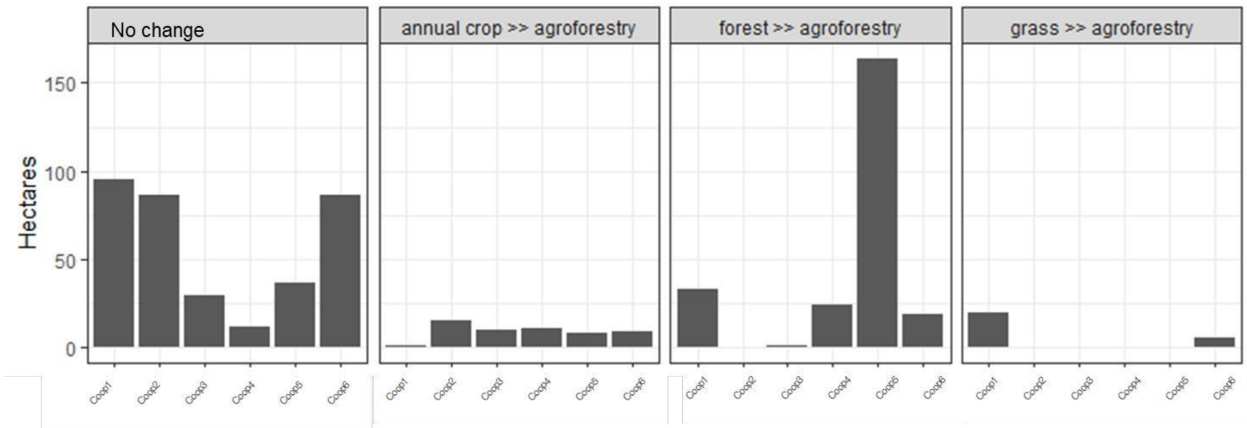

Figure A2: number of hectares in each cooperative where a recent history of land use change was reported. The change could be from annual crops or pastures to agroforestry, or from forest to agroforestry. Most hectares did not report a recent change.

Productivity: Coffee yield per area varied significantly by cooperative (Kruskal-Wallis rank sum test, $p < 0.001$; Figure A). Coop 2 had the highest total yield and the highest yield per hectare, while coop 5 had the biggest farms, but lowest yield per hectare. Most parcels produced less than one ton per hectare, which suggests that there may be room to promote sustainable intensification practices within all of the organizations.

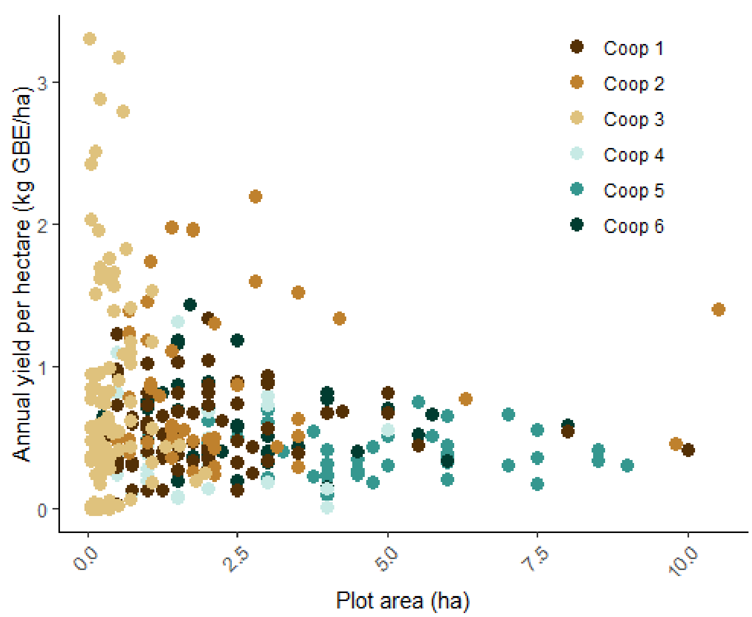

Figure A3. Yield (expressed in kg of GBE) by area (hectares) for each farm plot. Cooperative membership is coded by color.

Fertilizer Use: Farmers only applied organic fertilizers in line with the requirements of their organic certifications. Farmers used locally available products, primarily "pulp" from processing coffee. Not all farmers reported fertilizer use: 36 percent of farmers reported no application of nitrogen, 44 percent reported no application of phosphate, and 65 reported no application of potassium (Figure A4). Farmers in Cooperative 1 reported the highest application rates, applying all three macronutrients at similar rates. Farmer members of Cooperative 2 applied the highest rates of nitrogen, possibly explaining their higher yields.

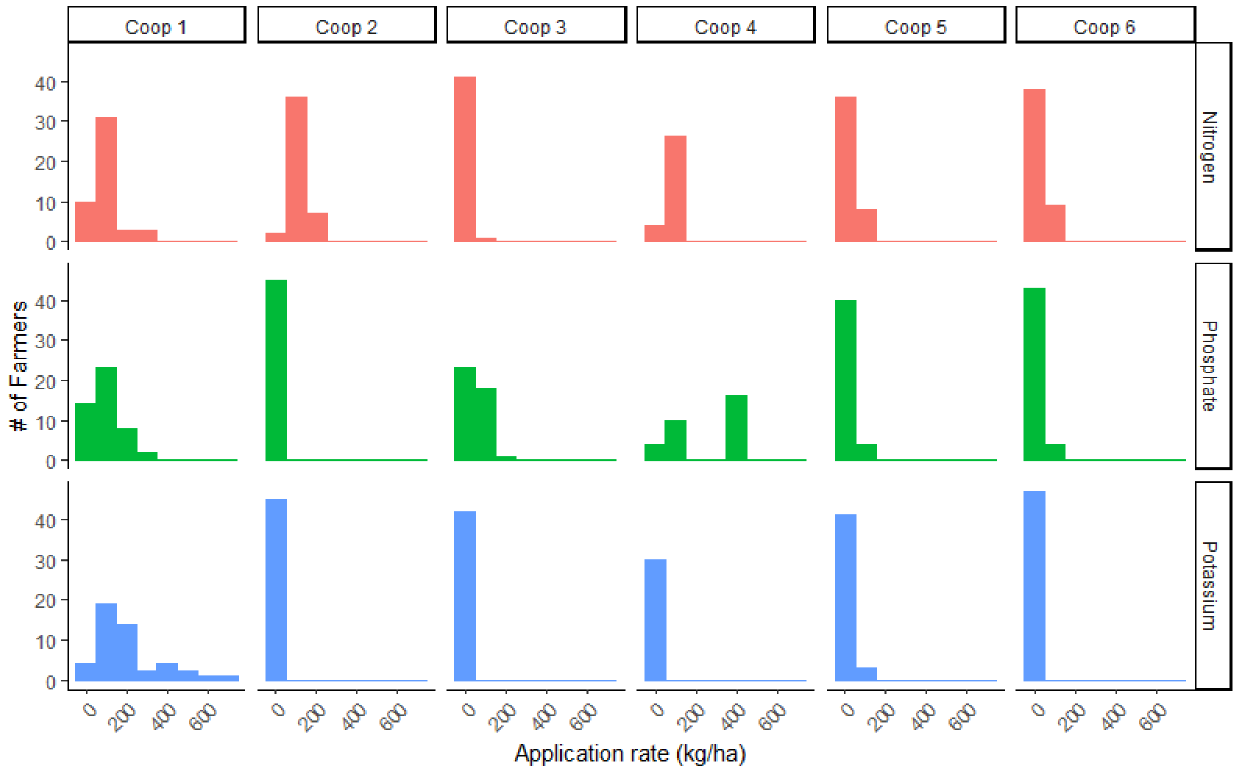

Figure A4: Farmer application rates for the principal nutrients. Farmers managing multiple plots in the study reported equal fertilization rates for all plots.

In most cases, farmers did not know the NPK composition of various organic fertilizers, so regional agronomists estimated NPK composition based on product information supplied by farmers. As the N component of fertilizers tends to drive emissions to a much greater degree than P or K, future efforts to improve the accuracy of N information would be valuable.

Coffee and shade tree density: Farmers surveyed reported coffee tree densities ranging from around 500 to 7,000 trees per hectare (Figure A5). Shade tree density was also highly variable within and across cooperatives, ranging from 0 to 925 trees per hectare. Interestingly, Cooperative 2 reported the highest density of shade trees, standing out significantly from the other organizations (Kruskal-Wallis rank sum test, $p<0.001$) with a median density of 284 trees per hectare. Cooperatives 1 and 2 had the highest coffee tree densities, with median values of 4,901 and 4,915 respectively. Cooperative 3 had the lowest density for both shade and coffee trees, at 22 and 3157 respectively.

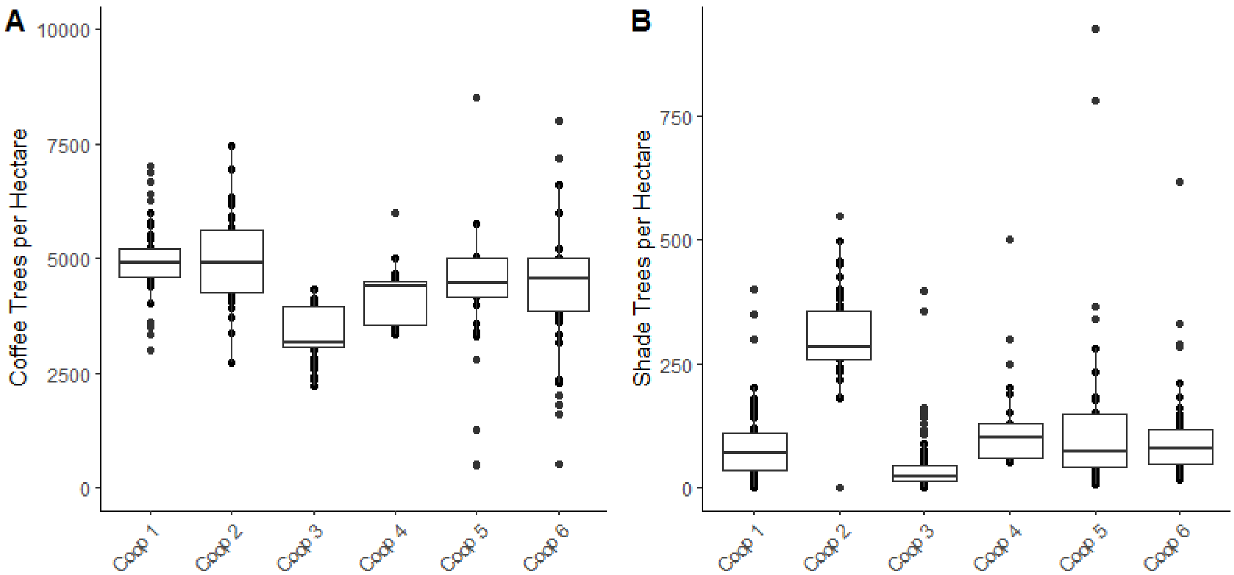

Figure A5: Coffee (A) and shade tree (B) densities for each parcel sampled. (Each dot represents a single farm plot. The line represents the median values for each cooperative, with the lower and upper boundaries of the box representing the 25th and 75th percentile respectively.)

Crop residue management: Within the context of coffee production, the most important sources of crop residue come from: coffee trees that have reached the natural end of their productive lifespans; branches from coffee trees pruned to improve tree health and yield; and "pulp" from processed coffee cherries. As residue generated by coffee or shade tree leaves or by *premature* coffee tree mortality tend to have little GHG impact, residue management selections for those residue types are not presented here. Note the Cool Farm Tool does not account for pruning residue from shade trees.

Given the significant volumes of organic residue generated by coffee tree pruning, the Cool Farm Tool collected detailed data on the intensity and frequency of pruning by producers. Pruning management varied widely within and between cooperatives (Figure A6). In some instances, as with most farmers in Cooperative 5, farmers only performed maintenance pruning—defined as removing up to 40 percent of the tree crown in a single year—with farmers pruning approximately 25 percent of each tree's woody biomass every year. In other cases, such as with Cooperative 6, farmers also performed stumping—cutting coffee plants down almost to the ground to stimulate new plant growth—every few years.

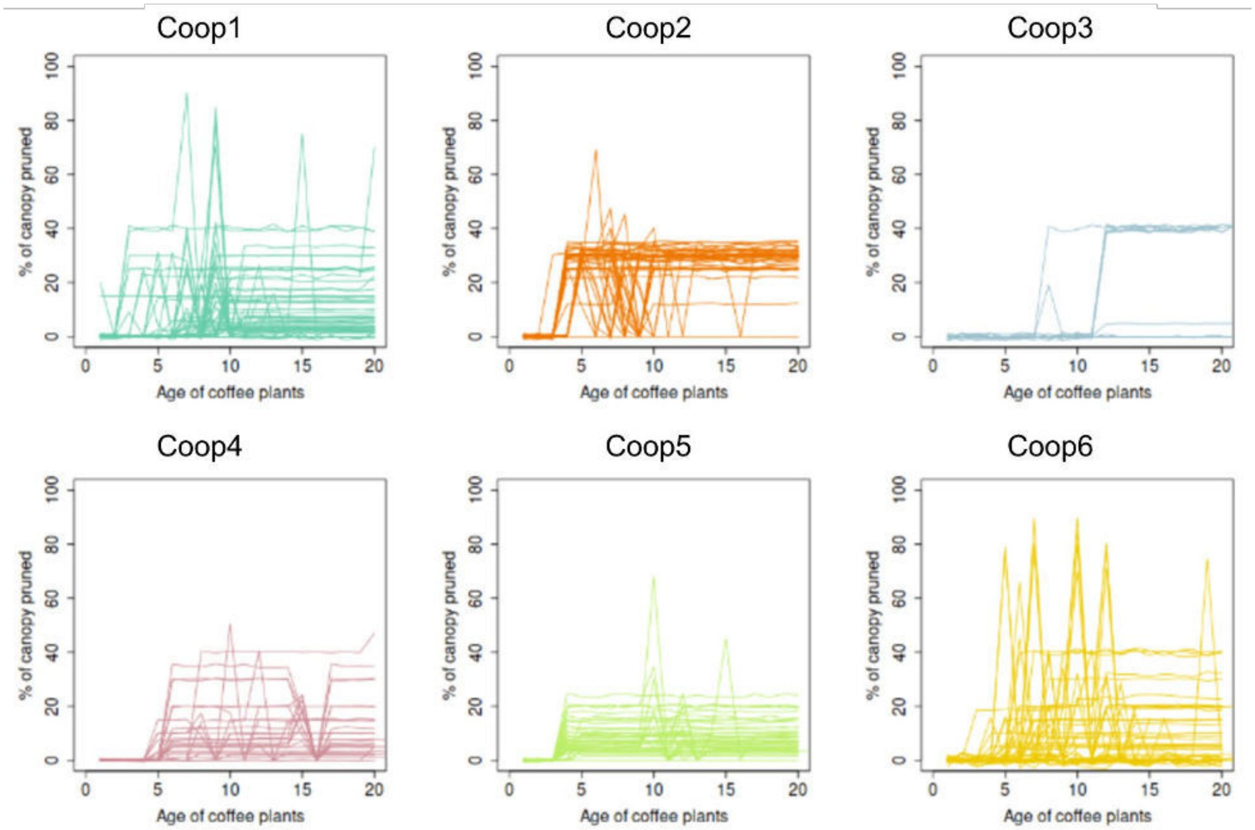

Figure A6: Coffee tree pruning frequency and intensity by cooperative. Each line represents a parcel in the sample, with peaks signaling pruning events. Peaks that reach above 80 percent of canopy pruned represent stumping, a common practice to rejuvenate coffee trees that reach a productivity plateau, usually around 8 years of age; smaller peaks show less intensive, annual pruning.

Across all types of crop residue, farmers may dispose of residue via burning, composting, chipping and spreading the residue on their soil, or removing residue from their farm. Again, farmer management choices were variable, especially across cooperatives. The most common choice for managing crop residues was composting. Cooperative 3 reported the highest percentage of composting, with nearly all members composting their own coffee pulp, end-of-life coffee trees, and most of their pruning residue. Most members of other cooperatives removed the pulp from the farms, often because they were not responsible for the initial processing that generates the pulp.

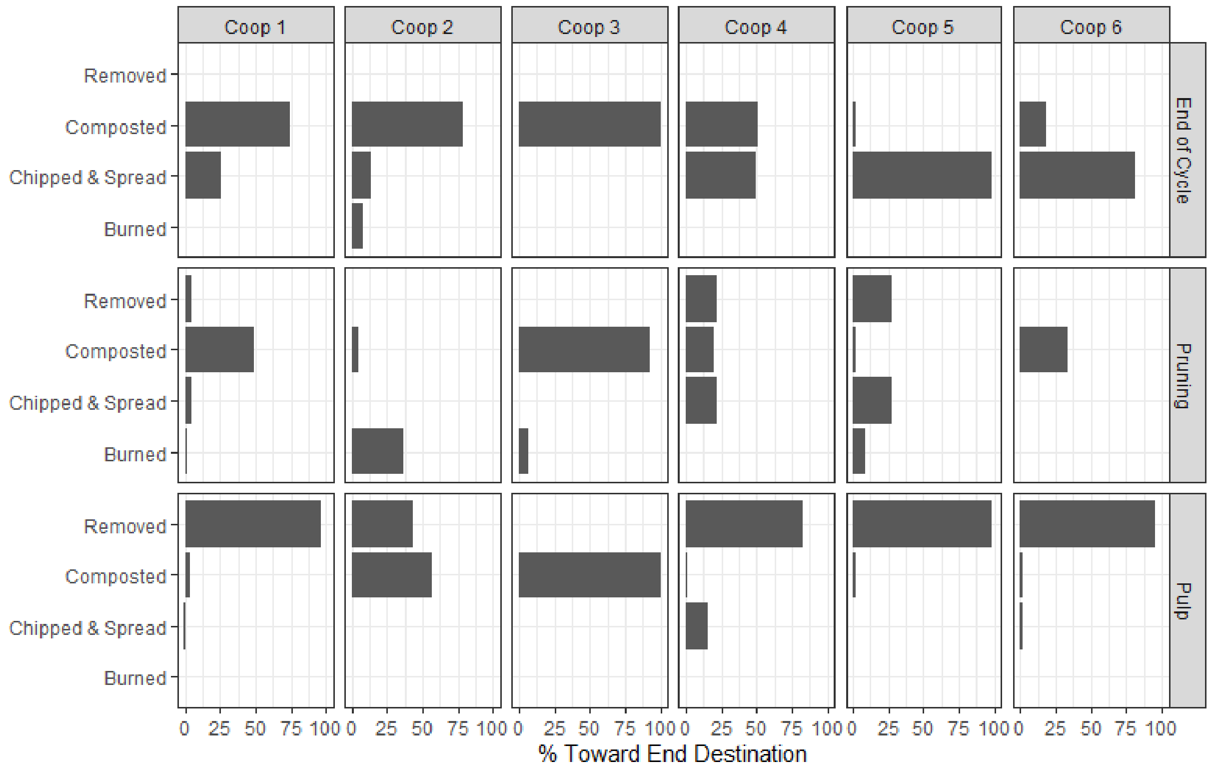

Figure A7: Average percentage of removed, composted, chipped, or burned crop residue according to management options for each participating cooperative. Note the Cool Farm Tool does not account for emissions generated off-farm by end-of-cycle coffee trees reported "removed" from the farm.

It is important to note that data collection on residue management practices is complex and may be a source of inaccuracy in the emission calculations. For example, producers commonly reported removing end-of-cycle coffee trees from their farm, yet some of these trees may have been burned on farms to generate energy. Additionally, it is unlikely that many of the coffee trees retired by Cooperatives 1-4 were composted due to very slow rates of decomposition; in this particular case, it was assumed that the trees were removed from the farm.

Transportation: Coffee was typically transported from farms to cooperative or other processing facilities by foot, animal power, or small trucks. Distances traveled tended to be small: under 100 kilometers for all but 22 farms. Relative to the other factors, transportation tended to have a negligible impact on emissions and therefore is not considered further in this report.

Wastewater: Coffee production can generate significant volumes of wastewater during the initial processing stage. Local culture determines whether farmers or their cooperatives (or another intermediary) process the coffee cherries and thus manage residual wastewater. However, for the purposes of consistent carbon accounting, the management of wastewater from coffee processing was incorporated into the farm footprint regardless of where processing occurred.

In the project sample, farmers overwhelmingly reported managing coffee processing wastewater using infiltration pits or centralized aerobic treatment plants, which are associated with low or zero methane emissions. As a result, wastewater had a negligible impact on emissions. Of note, however, farmers reported a wide range of wastewater volumes (Table A2), raising questions about data accuracy. —especially as other studies have found emissions from processing form a significant portion of coffee's carbon footprint.[35] Future applications of the Cool Farm Tool could consider additional work with producers to measure processing water volumes.

Table A2. Median wastewater usage for each cooperative.

Cooperative	Median Wastewater Use (liters/kg GBE)
Cooperative 1	9.6
Cooperative 2	0.1
Cooperative 3	55.2
Cooperative 4	3.6
Cooperative 5	6.5
Cooperative 6	14.2

[35] Acosta-Alba, Ivonne, et al. "Integrating diversity of smallholder coffee cropping systems in environmental analysis." *The International Journal of Life Cycle Assessment* 25 (2020): 252-266.

Annex C: Knowledge Sharing Resources

Cool Farm Tool Documentation:

- Cool Farm Tool – Coffee User Guide V3

Webinars:

- October 21, 2021: From Climate-Smart to Carbon-Smart Agriculture
- November 4, 2021: Tools for Carbon-Smart Agriculture
- November 18, 2021: Scaling Carbon-Smart Solutions
- December 8, 2022: Carbon and Coffee: GHG Emission Reductions Progress and Strategies Across the Value Chain Webinar
- February 16, 2023: Carbon, Climate, and Coffee: Moving the Needle from Cool Farms to Soil Carbon Premiums
- July 27, 2023: Carbon, Climate, and Coffee: Closing Insights and Scaling Recommendations from the Cool Farm Tool Pilot Project

Blog Posts:

- April 22, 2022: Join us on our Journey to Carbon Neutrality by 2025, Coop Coffees
- July 20, 2022: Gender Equity in the Cool Farm Tool Pilot Project, The Chain Collaborative
- March 21, 2023: Organic Agroforestry as a Climate Solution: Cool Farm Tool Pilot Project Findings and Lessons Learned, Coop Coffees & Root Capital

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