Integrating carbon into the Rainforest Alliance sustainability certification: A focus on coffee farmers in Kenya

Columbia SIPA Capstone Project
Executive Summary

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Fieldwork Location:
Kenya

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Abstract

Our capstone team of 8 students has been conducting intensive research on integrating carbon accounting into the agricultural commodity certification program of our client, the Rainforest Alliance. Our theory of change is to transform agricultural systems from carbon emission sources into carbon sequestration sinks to address climate change, incentivize regenerative farming practices, and improve farmer's livelihoods. Our advisor, Dr. Benjamin Bostick of the Lamont-Doherty Earth Observatory, has ensured we are pursuing research of exceptional quality and scientific rigor that not only meet, but exceed, our client's requirements. Through our fieldwork and data collection in Kenya, we have developed a unique three-pronged methodology for carbon accounting for the Rainforest Alliance: interviews, soil sampling, and spatial data analysis. Our framework provides an evidence-based roadmap for our client to enter the voluntary carbon market as a project developer in addition to a crucial baseline level of agricultural data. Our recommendations leverage the Rainforest Alliance's unique position to aggregate smallholder farm plots and increase access to carbon credit finance among their certified farmers to advance regenerative agriculture practices. Our project pioneers incentive mechanisms for measuring carbon and developing a new carbon credit program to unlock opportunities for increased access to finance for farmers to promote regenerative agriculture and climate resilience.

Our research questions are as follows: How can carbon accounting be integrated into the Rainforest Alliance certification system? Could the Rainforest Alliance support farmers in adapting to climate change through a Verified Carbon Standard project?

Introduction

Scope

The global agricultural sector has contributed significantly to the forces driving climate change and environmental degradation, equivalent to 25% of total historic greenhouse gas emissions and one-third of global arable land (IPCC, 2023; Nayak et al., 2019). Agriculture also represents one of the sectors most vulnerable to climate change, and smallholder farmers' crop yields and soil health are particularly affected by increasingly frequent climate-driven events such as droughts, floods, and heat stress. These stressors compel many farmers toward more intensive cultivation and risks further soil degradation, deforestation, and biodiversity loss. Addressing these issues requires innovative approaches such as regenerative and climate-smart agricultural practices to build soil health while restoring ecosystem services, improving crop yields, and supporting farmer livelihoods. These approaches can also contribute significantly to the sequestration of atmospheric carbon in soils, which represents one of the largest global stocks of carbon and can rapidly improve their sequestration potential with appropriate management practices. Globally, soil organic carbon represents a stock of around 5,500 to 8,800 gigatons of carbon dioxide. On the low end, this stock is three times the capacity of vegetation and twice that of the atmosphere (Smith et al., 2020). Small changes in these stocks can have significant effects on the global carbon cycle. Poor management practices have led to historic losses of 140 to 150 total gigatons, while researchers estimate improved management practices could recapture two to five gigatons per year (Fuss et al., 2018). Therefore, the agricultural sector also contains significant potential for climate change mitigation through appropriate land use management practices.

The Rainforest Alliance and sustainability certification systems

For the Rainforest Alliance, "regenerative agriculture" comprises a broad set of principles and practices under the umbrella of climate-smart agriculture. Taking an agroecology and integrated system management approach, regenerative agriculture aims to increase biodiversity, enhance ecosystem services, and increase agroecosystem resilience thus leading to resilient livelihoods. This way of farming is based on enhancing the inherent strengths of agroecosystems, ultimately enabling a reduction of external inputs (synthetic fertilizers and pesticides) and increasing farm net income by reducing costs (Rainforest Alliance, 2023). The Rainforest Alliance certification program has been adopted by farmers globally, yet the impact of these programs on soil organic carbon and biomass carbon sequestration are not quantified.

The coffee sector in Kenya

More than 70% of the rural population of Kenya participates in the agricultural sector. Agriculture is responsible for 33% of GDP (FAO Kenya, 2023). Coffee is an important commodity that provides livelihoods for more than 700,000 households in Kenya (Karuri, 2022). As the 4th largest export, coffee makes up about 22% of national income equivalent to $230 million in foreign exchange revenue (Wanzala et al., 2022).

Coffee value chain

Kenya's coffee supply chain can be divided into five main stages: production, processing, marketing, and consumption. Kenya has a dual production system consisting of approximately 3,000 coffee estate farmers, and 800,000 smallholder farmers grouped under 500 co-operative societies. Smallholder farmers produce more than half of the country's coffee and account for 75% of the coffee planted land (Adil, 2020). After picking the ripe cherry, smallholder farmers take it to the factory owned by the co-operative society. At the factory, it undergoes a wet processing method to remove the skin and pulp. After pulping, coffee is fermented, cleaned, soaked, and spread out on drying tables, where it remains for 7 to 15 days (Kenya Chorongi, 2021). Then, the co-operative takes the parchment coffee – coffee whose red skin has been removed and has been dried – to a miller, where it undergoes a dry process (destoning, hulling, and polishing process), leaving only green coffee beans at the end. Coffee is then graded according to size, a proxy for better quality, and packed accordingly (Sauer, 2021). After the dry processing stage, cooperatives or state farmers are required by the Kenyan government to contract an authorized and licensed marketing agent to offer coffee for sale at auctions held at the Nairobi Coffee Exchange (NCE) on their behalf. Although marketing agents can directly sell the coffee to traders, 85% of the country's coffee is auctioned at the NCE, where traders bid for the coffee based on quality and quantity. During this process, marketing agents have no ownership over the coffee, which still belongs to the cooperatives or state farmers. After the auction, traders gain ownership over the coffee, and proceed to sell it into local or international markets (Gakuo, n.d.).

Kenya's coffee value chain is characterized by large differences in prices and revenues among actors. Empirical cost analysis conducted by Aragie (2018) shows that coffee farmers spend on average Ksh 35.0 on intermediate inputs per kilogram of coffee. Farmers received on average Ksh 76.3/kg from cooperatives, implying that the value added at the farmers' level is around Ksh 41.5/kg. After the wet processing, cooperatives receive approximately Ksh 94.5/kg from millers, adding Ksh 18.0/kg in value. Millers incur an additional cost of Ksh 38.4/kg of coffee on top of a payment of 94.5/kg for cooperatives. The net value addition at this stage is estimated to be around Ksh 465/kg. Finally, the price of roasted coffee at the local level is estimated to be Ksh 3,025/kg, five times the price of green coffee (Ksh 604/kg) paid at the auctions. As can be seen in *Figure 2,* farmers and cooperatives receive the lowest level of profits along the coffee value chain. This can be explained by low rates of productivity, increasing cost of inputs, and market power of actors in higher stages of the supply chain. On the contrary, millers and coffee roasters activities account for more than 90% of the added value of coffee. However, a more thorough analysis should be conducted to include in the cost structure the fees paid to intermediaries such as marketing agents and traders (Aragie, 2018).

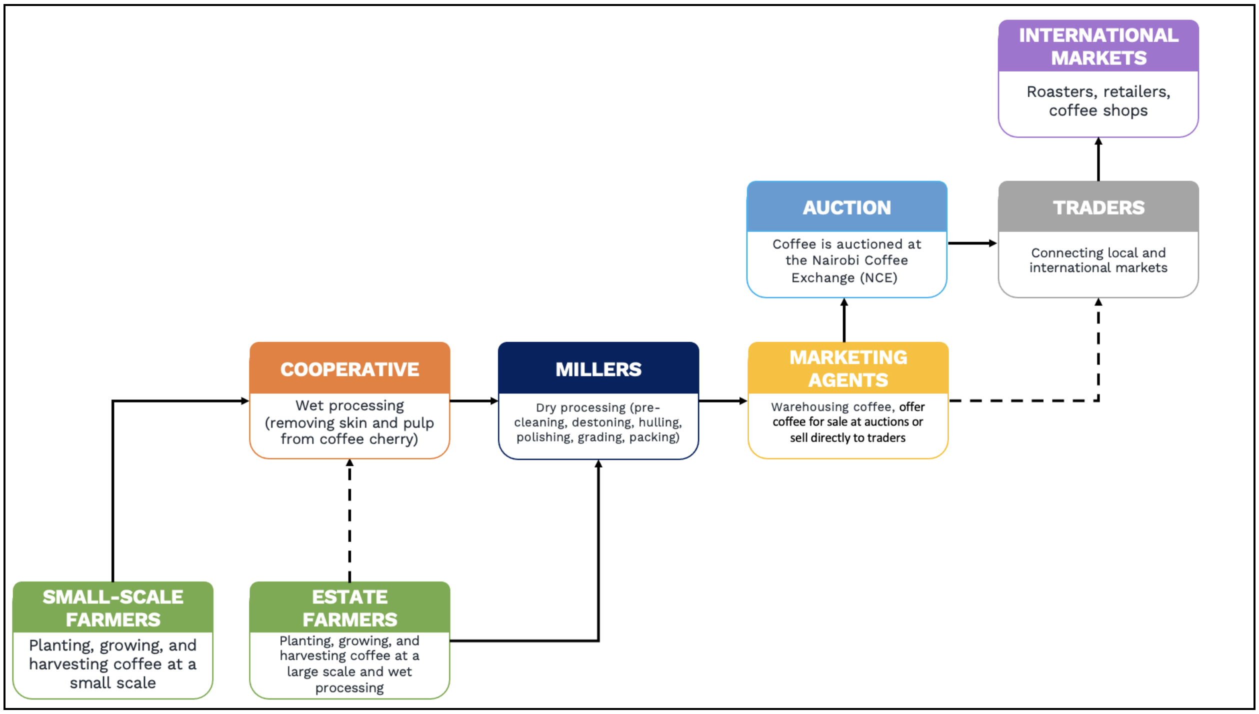

Figure 1. *Kenya's Coffee Supply Chain*
Source: Own elaboration based on interviews with stakeholders

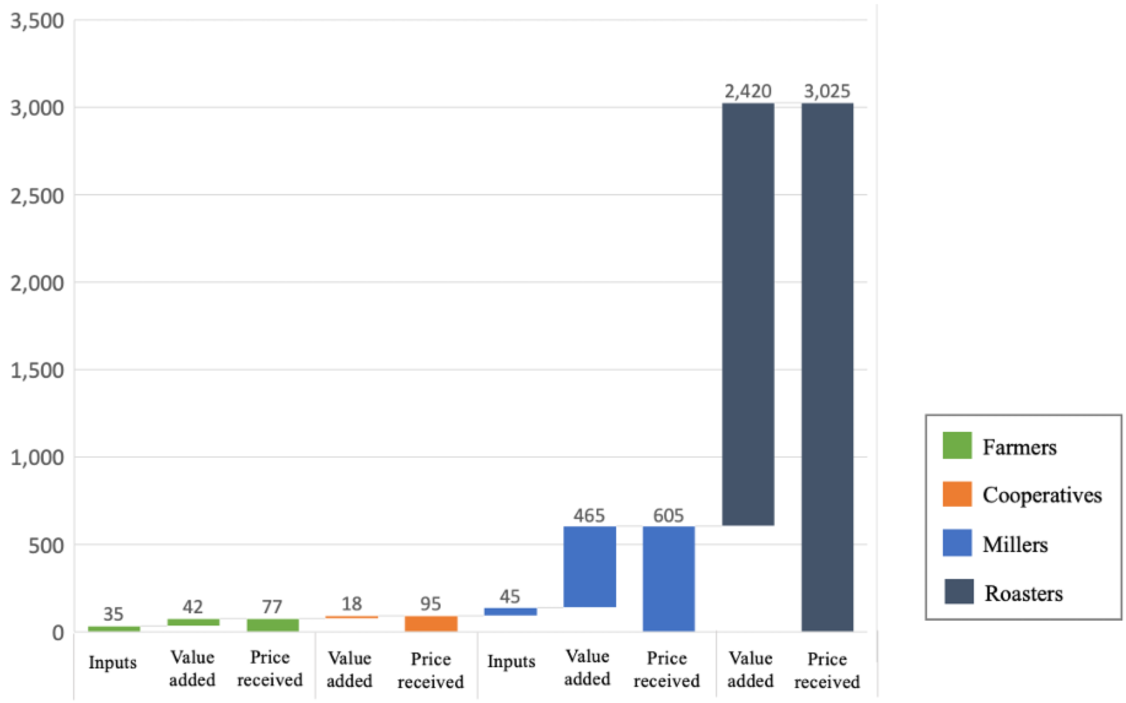

Figure 2. *Prices and Contribution to the Coffee Production in Kenya along the Value Chain, in Ksh/Kg*
Source: Own elaboration based on (Aragie, 2018)

Carbon markets

Voluntary carbon markets (VCM) are growing rapidly in response to increasing corporate net zero commitments. Carbon credit markets grew 48% in 2021, with the total number of credits issued increasing from 327 million to 478 million. VCM comprised 74% of the credits issued in 2021, consolidating it as the dominant crediting mechanism in the carbon markets above the international mechanism and the domestic mechanism, which represented 11% and 15% of total issuances, respectively (World Bank, 2022). Credit issuance from VCM grew at a record pace in 2021, reaching $2 billion, and is expected to reach between $10 - $40 billion by 2030 (BCG & Shell, 2022). The rapid increase in corporate voluntary net zero commitments has been the main diver for increasing carbon credits demand. Corporations are relying on carbon credits to compensate for emissions or remove unabated emissions, with the goal of achieving their net zero commitments. Demand for carbon credits is expected to increase by a 15-fold (1.5 – 2 gigatons of carbon dioxide) per year by 2030, and by a 100-fold (7 – 13 gigatons of carbon dioxide) by 2050 (World Bank, 2022).

Carbon credits issued in the VCM have significantly increased in the past decade, with renewable energy and nature-based solution activities accounting for the largest share. As can be seen in *Figure 3*, the issuing of carbon credits expanded after 2016 driven by the signature of the Paris Agreement in COP15. Renewable energy and nature-based solutions credits have since then increased, accounting for over 80% of the total credits issued. The VCM hit a historic record high with over 350 M carbon credits issued in the year 2021. Nature-based solution credits represented 45.3% of the total carbon credits issued in the year 2021, followed by renewable energy (38.4%) and waste (4.1%) credits. Within the nature-based solutions carbon credits, credits are issued mainly due to avoided deforestation, avoided conversion, and afforestation/reforestation, which accounted for 55.6%, 26.5% and 13.1% of all NBS credits in 2021 (Climate Focus, 2023).

Although still relatively low, carbon credits issued for soil carbon sequestration are growing, offering new opportunities for the agricultural sector. As can be seen in *Figure 4*, in 2018, 0M credits were issued due to carbon sequestration in agriculture. This figure increased to 6.1M in 2022, a historical record high. In terms of credit issuance, carbon sequestration in agriculture increased by 135% between 2021 and 2022, even though overall carbon credits issued declined. Although avoided deforestation, avoided conversion, and afforestation/reforestation are still the activities that most contribute to NBS credits, carbon sequestration accounted for 6% of the total NBS credits issued in 2022. However, this figure rises to 22% when considering only the NBS issuances in 2022 that came from carbon removal projects (Climate Focus, 2023). Given the polarized debates around carbon credits from projects to avoid deforestation and land use conversions, projects to remove atmospheric emissions have gained popularity among corporations with net zero commitments. Being carbon sequestration in agriculture among the emissions removal projects, the demand for these types of projects is expected to increase in the following years.

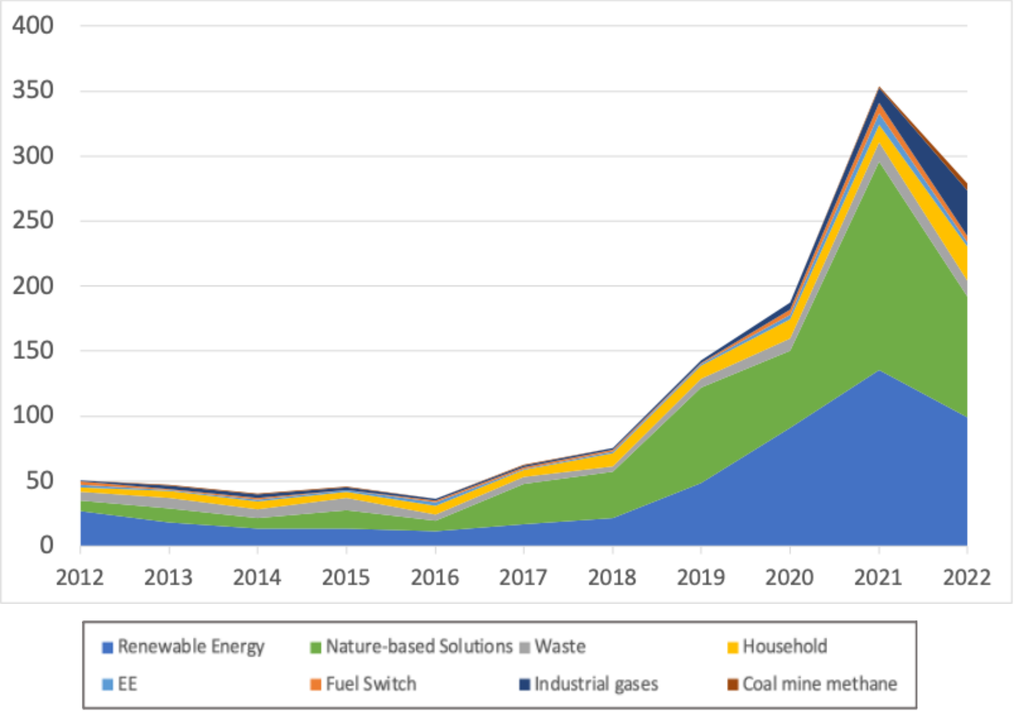

Figure 3. *Carbon Credits Issued in the Voluntary Carbon Market, by Activity in Millions (2012—2022)*
Source: Own elaboration based on (Climate Focus, 2023)

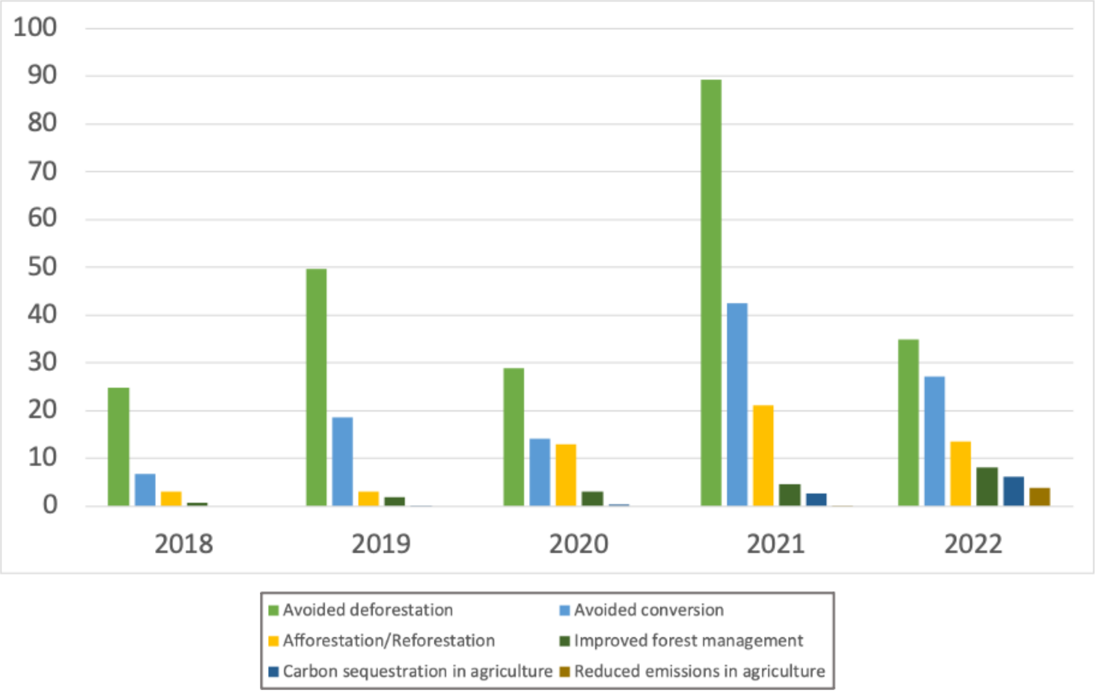

Figure 4. *Nature-Based Solutions Carbon Credits issued in the Voluntary Carbon Market, by activity in millions (2018—2022)*
Source: Own elaboration based on (Climate Focus, 2023)

The carbon market value chain involves multiple stakeholders with differentiated roles and responsibilities. Project owners operate and own the project implementation and assets. In the case of agriculture carbon credits, project owners are commonly responsible for running the project activities. Farmers partner with a project developer to assess the potential for carbon crediting within their project and to guide them through the registration, validation, and verification processes. Project developers are entities, both for-profit and nonprofit, engaged in various stages of the project. They are responsible for designing and submitting the project to standard-setting entities such as Verra, Gold Standard, and Climate Action Reserve. Project developers are usually the project's funders, although funders can be different from project developers, providing the necessary investment to develop the carbon credit project. They bear the risks associated with project development, but their initial investment is recouped through revenue from carbon credit sales. They also collaborate with farmers to ensure the correct implementation of project activities and provide Validation and Verification Bodies with the necessary information to measure and monitor the outcomes of the carbon project. Carbon Standards, such as Verra and Gold Standard, operate the registries on which carbon credits are issued, transferred, and retired. They also establish the rules of the projects, defining the methodologies that projects need to follow. Carbon Standards also determine which Validation and Verification Bodies can audit the carbon projects. Validation and Verification Bodies (VVBs) support the project developer by ensuring that the carbon project complies with the standard's methodology and accurately represents the project's characteristics in terms of emission reduction or removal capacity. After validation from the Carbon Standard, verification occurs on an ongoing basis throughout the project's lifetime to ensure that it continues to operate as initially planned. VVBs are audited by Carbon Standards to ensure that they have the capacity to verify the methodologies set by the standard-setting bodies (Allied Offsets, 2023).

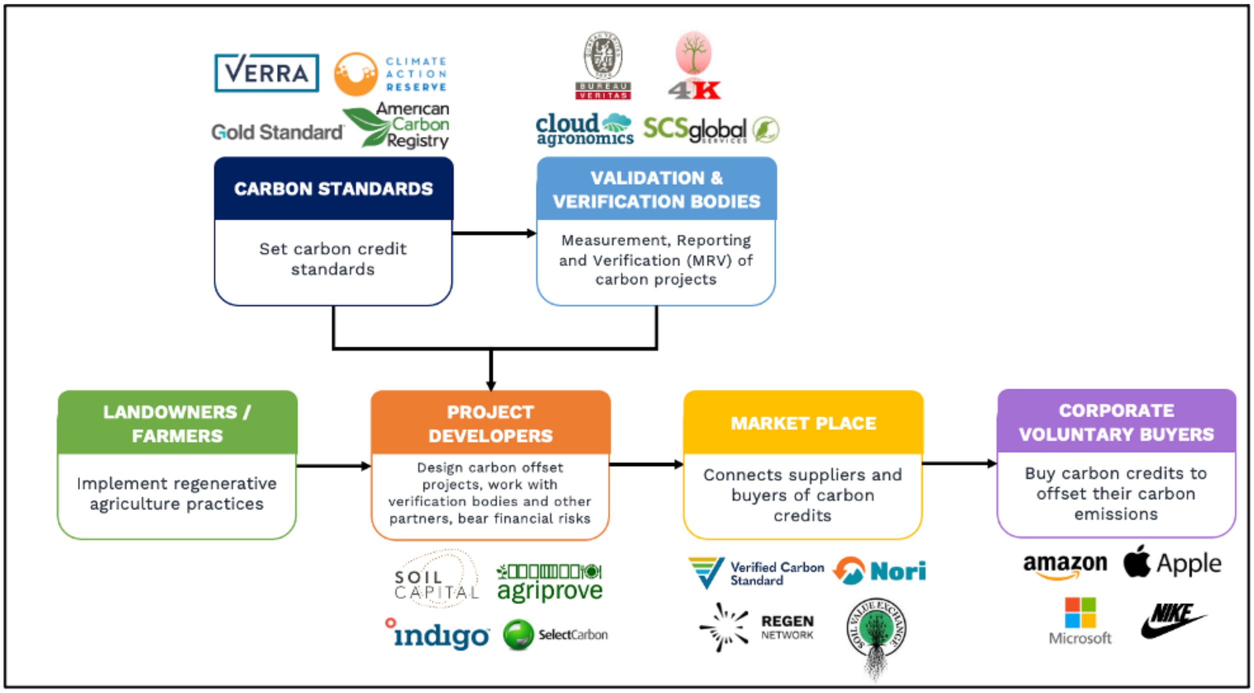

Figure 5. *Voluntary Carbon Market Value Chain*
Source: Own elaboration adapted from (Zou & Purdom, 2021)

Methodology

Certification programs can play a key role in achieving restorative agricultural practices that (a) enhance agricultural sustainability, (b) reward small stakeholder farmers with benefits including increased prices, yields, and crop quality, and (c) help protect high value ecosystems near agricultural lands. Today, most certification programs are based on best practices, but there is little or no accounting for quantifiable changes in environmental conditions in either the farm or the surrounding environment that are directly tied to certification. This project is based on the assertion that a key step in certification should be verifiable restoration of the agricultural lands that are used. While there are many potential targets for how best to verify this, one of the most basic measures of agricultural land protection is the concentration of soil carbon. Soil carbon levels are commonly depleted by standard agricultural practices, and its return is associated with decreases in erosion, increases in soil fertility and yield, and a healthier soil microbiome REFS. Soil carbon also serves as a measure of overall carbon storage in a landscape that, if quantified, has a direct relationship to overall carbon in that landscape (typically the soil represents at least 75% of the overall carbon in the landscape).

At its core, verification requires measurement. Moreover, verifying and quantifying soil carbon storage as part of a certification program about restorative agriculture requires methodologies that are effective at measuring the increases in soil carbon over time at specific locations and across a landscape. The comparison of measured soil carbon at specific sites provides an important parallel opportunity if we know about land practices that are encouraged at each site–it allows us to establish the link specific land management practices to carbon storage. Our research team thus developed a framework for carbon storage metrics to help establish a system of soil carbon measurements that are representative, scalable, and tied to a wide range of agricultural practices.

Our capstone team has developed a framework to incorporate soil carbon storage metrics into Rainforest Alliance's coffee certification program in Kenya. Our objective is to develop methods to integrate local knowledge of agricultural practices with soil carbon measurements at coffee farms. We tested these methods using soil sampling, remote sensing, and by conducting more than 29 interviews with smallholder farmers at 4 cooperatives and 2 counties in Kenya. We also visited the first REDD+ carbon crediting program in Africa to gain local insights on how Rainforest Alliance could develop their own program in partnership with Verra given our carbon accounting framework. Our research entailed conducting interviews regarding farming practice and taking soil samples of coffee farms and control plots with both certified and non-certified coffee farmers to compare soil quality across multiple variables, including soil organic carbon (SOC). This data is linked to and verified by Geographic Information Systems (GIS) that are critical to upscaling the point measurements made of soil carbon to the scale of farms. This GIS also makes it possible to apply findings from detailed studies to other sites where data is not available and potentially to better understand the effects of certification on the areas surrounding agricultural fields.

Farmer interview methodology

At each small stakeholder farm, a farmer or farmers were interviewed to learn more about their baseline knowledge of coffee industry, environmental and climate issues. The interview also probed their farming practices and attitudes about how their farms were impacted by environmental and climate risks, and how thow risks were mitigated. These interviews were coded to yield quantifiable data, but were free form to allow each participant to respond freely and to bring up issues they felt were critical.

Soil sampling methodology

A subset of coffee farms were selected in collaboration with the RA Kenya team taking into account environmental conditions and certification status. 29 selected farms were distributed in four clusters across Meru and Embu counties. In each farm, we collected duplicate samples from each of the sites to a depth of 5 cm. Two soil samples are collected from sites used for coffee production (referred to as "coffee" sample) and two "control" soil samples of nearby areas with similar conditions that were not used for coffee production, usually within 50 meters of the coffee field. The control sites were occasionally bare soils, cropped with alternative crops, or occasionally forested. In our methodology, we assume that our control sites sample represent the same soils but prior to coffee production and certification.

Soil samples were analyzed using different approaches. One set of soil samples to World Agroforestry Centre (ICRAF) in Kenya for further chemical analysis, including soil organic carbon, total nitrogen content, and soil texture. The duplicate set of soil samples was analyzed at Columbia University to obtain soil pH, color, and chemical compositions (the concentration of K, Fe, Ca, Ba, Cu, etc. in mg/kg). For each of the soil properties, we calculated the mean and standard deviation of two coffee samples and control samples within each farm. The effectiveness of RA certification was assessed by comparing the coffee and control averages.

Geographic Information Systems analysis

It is critical to establish the spatial context for soil carbon measurements within a larger farm. To do so, the coordinates of each soil sample and the geographic coordinates of field edges of each coffee field at each farm was manually input by GPS during sampling using FieldMargin. ArcGIS was used to transform the output of FieldMargin data into shapefiles and/or raster data for other uses. The slope of each farm, a key feature that indicates susceptibility to erosion, was derived from the World Resources Institute's open-source raster data. Remote sensing data was obtained from tiles from monthly composite Planet Labs satellite data. Images were obtained for the same date as soil sampling occurred (March 2023). Imagery (geotiff format) was analyzed in ArcGIS to extract remote sensor channel output at the locations of the soil sampling and within field polygons.

Results and Key Insights

Sampling locations and sites

The sampling sites were selected within four clusters around Mt. Kenya. These sites were all at similar elevation (the coffee belt around Mt. Kenya) where coffee and, to some extent, tea was produced. Most farms were one to two hectares in size, with only a small portion of the farm used for coffee production. These coffee fields were mapped at high resolution to calculate their areas and to identify areas for remote sensing and GIS analysis. Visually, there were few identifiable differences between the soil or growing conditions across the sampled farms, though farming practices varied.

Figure 6*. (Left) A map of soil sampling sites to the east and southeast of Mount Kenya. This region is about 100 km northwest of Nairobi, Kenya. (Right) A map of an example site showing the mapping areas of specific fields under coffee production, and soil samples that were collected from those sites (paired control and coffee sites). The map scale varies by a factor of 400 from left to right to make it possible to view several coffee field polygons.*

Insights from farmer interviews

Six key trends emerged after analyzing responses from our 29 farmer interviews. The first is that smallholder farmers are witnessing in real time, and experiencing the negative consequences of, the climate crisis. Harrowing testimonies described how, in the duration of the farmer's working life, coffee yields and thus revenues have decreased while inputs and thus expenses have increased. A stark change in rain patterns, with more extended droughts, has been the key driver of this issue.

The second is that farmers use a range of agricultural practices, with more incentive to do so with the support of the Rainforest Alliance certification. As seen in the table below, activities such as mulching, manuring, and pesticide use are much more likely on RA certified farms than non-certified farms.

Practices	Total number	RA Farms *16 in total*	Non-RA Farms *13 in total*
Planting Leguminous Trees	3	1	2
Mulching	15	10	5
Manuring	13	8	5
Irrigation	4	1	3
Pruning	9	6	3
Terracing	6	3	3
Shading	6	3	3
Grafting	2	1	1
Pesticide	10	8	2
Water Catchment	0	0	0
Weeding	4	4	0
Soil Erosion Control	1	1	0

Table 1 - Farming Practice Summary Statistics

The third takeaway is that price is the ultimate driver of farmer behavior. Directly related to the table above, there is a 30% difference in the price a RA-certified farmer receives compared to a non-RA certified farmer and thus a greater incentive to practice more regenerative farming techniques. Farmer responses to their greatest challenge was consistently: climate and securing a fair price for their coffee cherry.

The fourth takeaway is that the role of the coffee cooperative, by which the smallholder farmer is a member, is critically important. Farmers are reliant on the cooperative for their inputs, for getting their crop to the market, and for ongoing training. Thus, the cooperative holds a significant amount of leverage over the farmer and has the potential to dictate the types of farming practices their farmers must commit to.

The fifth takeaway is that access to soil data to know soil health is of critical importance. Our soil sample data not only quantifies the carbon storage potential of coffee farms, but it also directly provides the farmers we interviewed with a nutrient and quality report of their soil. This allows them to act based on that information to, for example, improve soil fertility and agricultural yield while minimizing the impacts of fertilization on the surrounding environments. Accessing this comprehensive knowledge of their soil is rare or non-existent, yet this data is invaluable for farmers in order to improve their practices, adjust their inputs for efficiency, and identify how they could sustainably intensify the yield of coffee production, in turn uplifting their family's income, education, and livelihoods.

Verified Carbon Standard project interviews

Through conversations with a VCS project developer, Wildlife Works, as well as with partners of the project and members of the community where the project takes place, we learned about the benefits and drawbacks of such carbon credit projects. The benefits revolve around increasing the community's access to funding via the sale of locally produced carbon credits. The revenue goes toward community-driven projects, which has a wide range of benefits. However, there are many challenges with properly designing such community-driven projects that go well beyond the capabilities of a typical carbon credit project developer. Further, such projects do have the potential to genuinely halt environmentally degrading practices, such as deforestation for charcoal production.

The negatives focus on project transparency and relevance to the community. Local partners developing the carbon credits for Wildlife Works, for example, do not know if they are getting a fair price for their credits. Additionally, in a community of ranchers and farmers, the carbon credit program has no element of supporting farming. It asks community members to change the way they have been going about livestock and agriculture production, without providing solutions or alternatives.

Coffee supply chain interviews

In addition to gaining insights on the coffee supply chain from farmers and cooperatives, we spoke with one of Kenya's largest buyers and international traders of coffee, Sucafina, as well as with DAI, an international development firm involved in coffee and commodity supply chain projects around the world. Our two key takeaways from these interviews include: the limited voice of the smallholder farmer and the importance of traceability in the future of coffee and commodity markets.

It became abundantly clear to us that certifications and changing farmer practices are ultimately market driven, with the most influence being held at the very top of the supply chain where international buyers dictate to their domestic partners what kind of coffee they are looking for. The smallholder farmer only has the ability to react, they do not currently hold the power to negotiate their terms.

Secondly, with it becoming commonplace for companies to make sustainability commitments, the next evolution will be holding accountable such commitments which, in the coffee market, means traceability. Our interviews highlighted the increase in investment going towards scalable technology specifically for the purpose of monitoring where a given commodity is coming from.

Soil analysis

Soil carbon concentrations (SOC) varied considerably across all plots and farms but were generally above 2% for most samples. The soil is considered in a good condition with a 2% or higher SOC. A high SOC suggests robust soil structure, high buffering capacity, and improved water holding capacity. Figure 7 shows the comparative results of the SOC averages across all samples collected between RA associated and non-RA farms. On average, the carbon stock in RA associated farms is higher than in non-RA farms. This could be the result of different land management practices, but also could result from differences in geography, the cooperatives were in distinct regions and watersheds, each of which also had unique soil environments, and presumably different levels of soil carbon at baseline.

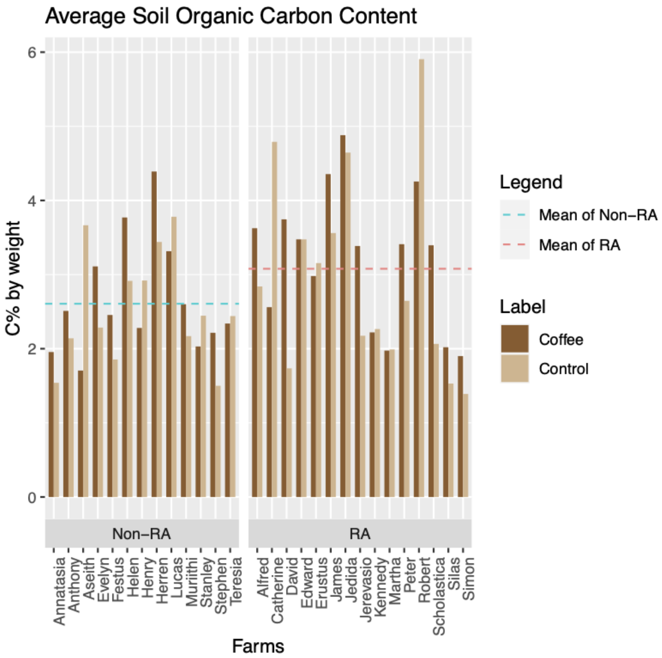

***Figure 7: Average Soil Organic Carbon** summarizes SOC content coffee and control sites at the farm scale and segregated by whether the farm was a part of a cooperative that was RA-certified. Data reveals overall high levels of SOC (usually >2% organic carbon by weight), but significant variation between farms, even within certified or non-certified farm plots.*

To differentiate between background levels in soil carbon and the effect of management, we attempted a regression analysis based on the reported practices that were used on each farm. This regression analysis yielded few significant management variables that influence soil carbon levels, suggesting that background carbon contents rather than practices were more important. We thus need to account for spatial variation in background conditions to properly assess the effect of management and certification on soil carbon storage.

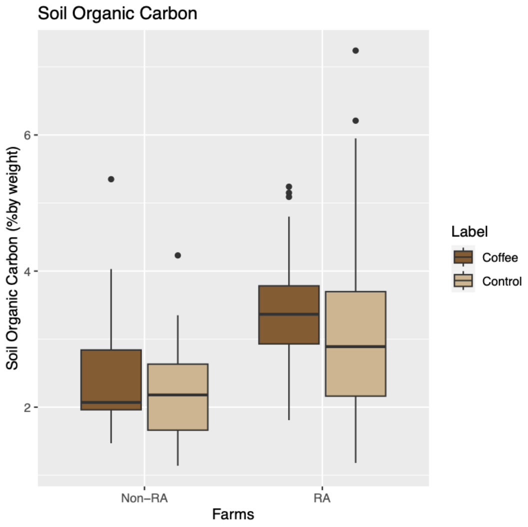

Figure 8. Soil Organic Carbon between RA and Non-RA Farms *shows a box and whisker plot for SOC content coffee and control sites segregated by whether the farm was a part of a cooperative that was RA-certified. The boxes display the interquartile range. Data reveals a clear increase in the SOC content of coffee sites in RA-certified farms relative to those in non-RA-certified farms.*

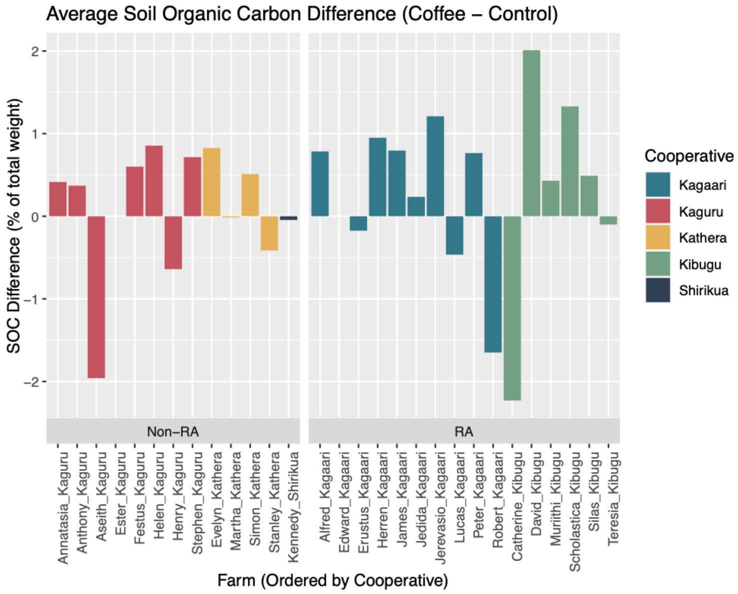

Figure 9. Average Soil Organic Carbon difference. *Differences in mean soil carbon concentration (in percent) between coffee sites and control sites at a range of coffee farms from both RA-certified and non-RA-certified cooperatives. Results show highly variable effects of farming on soil carbon content of coffee areas relative to controls.*

The second approach accounts for this by comparing the coffee and control sites at specific farms, since they would have similar background levels (Figure 9). The average differences between coffee and control samples were independent of total carbon in both groups, suggesting the difference between SOC in coffee and control sites was related to management or other factors.. For RA-associated farms, the SOC of coffee sites is higher than that of control sites. This positive difference for RA-certified coffee farms indicates that management of the coffee plots improved their soil carbon status in surficial soils. For Non-RA farms, the amount of SOC in control samples slightly exceeds coffee samples, this insignificant difference indicates that the management practices in the non-RA certified farms was not effective in restoring soil carbon, and possibly could have further diminished soil quality.

In principle, it should be possible to link highly beneficial or deleterious practices to large positive or negative changes in SOC content. For example, perhaps mulching with leaf litter is a key practice in gaining soil carbon, or a lack of terracing leads to high levels of erosion that removes surficial soils that have high soil carbon. The surveys of farming practices suggest similar management practices to non RA-certified farms, the coffee farming practices at RA-certified farms seem to have more effect based on their measurable increase in SOC relative to control site.. The change in SOC, however, did not correlate clearly to any management practices that could be identified. The positive and higher differences between coffee and control sites at RA-certified farms likely result from differences in how the practice is done. For example, although all farmers recognize that fertilizer helps increase production and yield, RA-certified farms might have more access to fertilizer, and thus use it at a higher rate. Such differences could not be established in the limited scope of this work, though, as detailed characterization of management was not analyzed at the farm scale, nor was it established where in a given farm plot the practices were implemented. Future work would be invaluable in establishing the degree to which RA-associated farms have better overall performance (and carbon storage) and better quantify the link between specific farming practices and their resulting influence on the farm’s sustainability and the surrounding environment.

Additionally, care should be used in interpreting these differences given the limited sampling size. Although results are broadly consistent, site specific variation could result from a single sample having uncharacteristically high or low levels of SOC because of sampling. Thus, additional sampling would be important for future work.

Scaling soil measurements

Soil sampling to measure SOC is an essential part of measurement, reporting and verification. Soil OC is also variable across even small farms. Thus, accurate assessment of soil carbon inventories require extensive sampling and/or accurate estimation tools based on externally measured variables that are available at the length-scale of SOC content variation. Most existing programs depend on large-scale averaging rather than actual accounting; however, soil restoration depends on improving all lands, including marginal lands. We thus, focus our efforts on remote sensing as a tool to estimate conditions at each farm and field. Critically, that remote sensing tool must be available at the scale of our farms. Since our farms typically are quite small (0.1-0.3 ha typical areas), many have dimensions of 10-20 m on a side. This means that conventional remote sensing products like LANDSAT, which have 30 m spatial resolution, are inadequate to sample a coffee field without spectral contributions (interferences) from surrounding areas. For that reason, we have used high spatial resolution PLANET labs data, which has 4 band imagery available at 3-4 m spatial resolution.

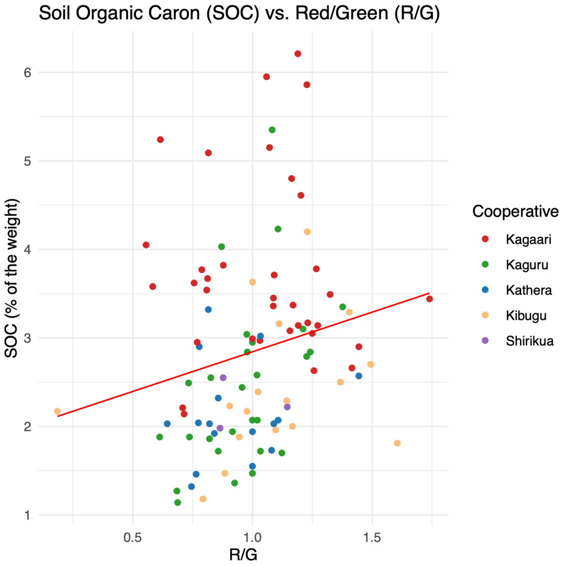

Figure 10. *Relationship between SOC content (in %, w/w) vs the ratio of remotely sensed red to green band intensity ratio (R/G, from PLANET satellite imagery, March 2023 composite). There is a weak and insignificant positive correlation of SOC vs R/G ratios obtained from the image. The lack of clear relationship at this overarching scale suggests that a single R/G ratio is ineffective at predicting SOC concentrations. There are increasingly clearer relationships between SOC and R/G at the scale of cooperative (symbols colored by cooperative). Thus, finer scales can reveal more significant relationships (and increased data density).*

PLANET data from each sampling site reveals considerable variation in pixel color at each sampled site Figure 10. Pixel color, as indicated by the ratio of red to green band intensity, is quite variable in space (and time) in that it is dominated by small features (for example a single tree). This variation was not obviously correlated to measured SOC at each site despite the assertion that darker soils (which have red/green ratios near 1) would have higher SOC than red soils (with red/green ratios much greater than 1). This difference is not surprising given that the pixel color is affected more by vegetation that covers much of the bare soil under it.

The lack of a clear correlation between remotely sensed pixel colors and SOC could be inferred as saying it is not possible to predict SOC based on this variable alone. In our case, it suggests that alternative approaches are needed to properly develop models of estimating SOC based on remotely sensed data. First, those models are not generalizable, and must be developed within smaller areas where correlations could be apparent. Second, since land cover on coffee sites and control sites differ, it is not straightforward to use even a single relationship between remotely sensed imagery (which is impacted by land cover) and SOC content on a given farm. Thus, better correlations need to reflect what is known about each site. Last, changes in remotely sensed data enhance the signal of changes in the plot occurring over time, and remove the potential bias based on land cover. Although we have not yet probed these changes in detail, it is likely that these changes in remote sensing data better reflect both organic carbon content and changes in that SOC content. Thus, temporal remote sensing data needs to be correlated with temporal changes in SOC to create site-specific relationships between SOC and remotely sensed data.

Recommendations for the Rainforest Alliance

Trainings, capacity building, and insurance for farmers on climate adaptation

Coffee farmers are highly climate-sensitive, as the vast majority rely on rain-fed agriculture. The increased average temperatures and variable rainfall as a result of climate change adversely affects the coffee sector through increased prevalence of pests and diseases, sporadic flowering patterns, and farming range shifts to higher altitudes. In the coffee value chain in Kenya, cooperative societies are the integral point where the national and county governments should leverage the most institutional support. Coffee cooperatives are the most direct stakeholders for capacity-building; however they significantly vary in governance and resource access. The role of a high integrity cooperative is to support farmers in training and practices, accessing farm inputs, growing crop varieties, wet milling coffee cherries post-harvest, and financing. Cooperatives should be supported by county governments and NGOs to provide training on climate-smart agricultural practices regarding the application of manure, mulch, fertilizer, and pesticides in order to improve sustainability and productivity.

In the face of climate variability, smallholder coffee farmers are constrained by high costs of inputs, especially for fertilizers, improved crop varieties, and pesticides. Farmers typically do not have access to sufficient capital to make the investment towards climate-smart practices. Since coffee is only harvested twice per year, income is not frequent or consistent despite being the main income source for many smallholder farmers. To cushion the risk of coffee farming in the future, the Rainforest Alliance could work with the local governments to implement affordable crop insurance programs and a stable line of credit for small-scale farmers.

Estimate carbon through multi-model remote-sensing

Including soil carbon inventories into certification requires us to measure total carbon stored within an agricultural area, and then determine how that total carbon content changes over time. Our team's carbon accounting methodology involved a three-pronged approach: measuring soil carbon though soil sampling, and then linking that in situ soil sampling data to remote sensing data and qualitative interview data. We need to measure the soil carbon on a farm to unlock the benefits of certification and carbon credits. However, soil organic carbon (SOC) is dynamic and direct soil sampling, while accurate, can be expensive and labor-intensive, particularly given the difficulty in obtaining representative or composite samples. Our team proposes a SOC multi-model approach using remote sensing to estimate higher-resolution ecological dynamics within each farm and to use this dynamic change to predict soil carbon sequestration of regenerative agricultural practices of coffee farms in Kenya.

Input carbon data into a dashboard for baseline measurements and monitoring

Measuring the carbon sequestration progress of a farm over time is impossible without a baseline level with which to compare measured values. This baseline does not exist now. Although we used control sites as somewhat representative of baseline levels, this is clearly an oversimplification, and a potential source of error in establishing the effect of land management on soil quality and restoration. We recommend creating a data dashboard and repository for data to ensure that it is maximally valued, available, and utilized in quantitative models. This data also should be available to the farmer to enhance their ability to act based on their farm's data. For example, fertilizer data is useful to constrain how best to estimate nutrient demand and thus fertilizer rates that will be effective for future crops while minimizing environmental risks of off-site fertilizer transport. This dashboard can include information about practices used (for example, recording fertilizer rates) to better establish links between carbon accounting and outcomes to practices. A system that ensures long-term data collection on carbon storage aligns with the Rainforest Alliance's existing mission to develop a backend dashboard for data storage. This consistent data measurement framework will verify that the regenerative practices of coffee farmers maintain the longevity and permanence of carbon sequestration.

Leverage the position of the Rainforest Alliance to engage in the carbon market as a Verified Carbon Standard project developer

Our project proposes incentive mechanisms for measuring carbon and entering Verified Carbon Standard (VCS) project development to unlock opportunities for increased access to finance for farmers to build climate resilience. Coffee farmers in Kenya are given a low price for their raw coffee cherries relative to the total economic productivity they enable. To incentivize them to adopt regenerative practices they need supplemental compensation for the positive externalities they produce. Our carbon accounting framework is actionable in internalizing the positive externality of carbon sequestration in the agricultural sector. Carbon crediting programs are the perfect market-based opportunity to give farmers access to Payment for Ecosystem Services and additional income sources. These economic incentives and the increased efficiency of smallholder farming practices translates into sequestering more soil carbon and improving livelihoods.

Potential opportunities as a Verified Carbon Standard project developer

Given the projected growth of prices in the carbon market and the increasing need for the energy sector and corporations to offset their emissions after exhausting all decarbonization possibilities, the soil carbon economy emerges as a crucial economic instrument that should be leveraged in the favor of smallholder farmers. RA is in a favorable position to launch a Verified Carbon Standard (VCS) project and become a carbon credit project developer in the carbon value chain. RA already has the tools necessary for accreditation of sustainability practices. Along with our carbon accounting framework, RA can aggregate the polygons of their certified smallholder farms in Kenya and submit a large-scale VCS project proposal to Verra for accessing carbon credits from the voluntary market. Providing access to VCM credits also adds explicit climate value to certification.

Verra Verified Carbon Standard Project Development Cost Structure (Verra, 2023)

Fixed costs: Account opening fee and Methodology review	$500 + $15,000 Total: $15,500
Recurring costs: Annual fee	$2,500 per year
Variable costs: VCU issuance Methodology levy	Depending on scale of project: $0.025 to $0.14 per VCU (tonne CO_2) $0.008 to $0.02 per VCU (tonne CO_2) Range from 1 million to 10 million
Hypothetical example: Project of 670,000 tons For coffee farms in Kenya (based on increase in soil carbon of 1% organic carbon (w/w), 2000 kg of soil per ha, and 160,000 ha of land used to produce coffee in Kenya)	Fixed first year: $15,500 One year: $2,500 Variable: Issuance levy of 670,000 ton project: $0.14 Methods levy for 670,000 ton project: $0.02 Total costs for first year in operation: **$125,200** Fixed/recurring: $18K Variable: $0.16 (670,000 tons) = $107,200 Potential revenue: $14 per tonne of carbon removed/sequestered $9.38 million - $125,200 = **$9.25 million at scale** Divide revenue by thirds across RA, farmers/cooperatives, and community development projects Hypothetically **$3.1 million** each excluding likely external costs of implementation, fees, salaries, data collection

Develop a net-positive carbon neutral certification and branded product line

The recognition and legitimacy of the Rainforest Alliance stamp is significant across the world. After implementing our carbon accounting framework and unlocking carbon credit finance for farmers, the Rainforest Alliance will have robust data from the verification bodies of their carbon credit program to design their own net-positive or carbon-neutral branded products. With these evidence-backed commitments, the Rainforest Alliance will then be able to acquire additional recognition, access to markets, and appeal for concerned consumers through international programs such as Climate Neutral Certified, the Climate Pledge, and the Science Based Targets Initiative. The environmental and social benefits of incentivizing farmers to improve their climate mitigation practices multiplies with the added premium they receive from the additional branding of a carbon certification, without requiring consumers to pay a premium on the front end.

Key takeaways

Sustainability certification and its associated premium price are effective incentive mechanisms for farmers to adopt regenerative agricultural practices and mitigate climate change. Carbon accounting can be integrated into the Rainforest Alliance commodity certification programs to increase carbon sequestration potential, establish a robust data baseline, and increase financial sustainability for farmers. Farmers can improve their livelihoods through carbon crediting systems and enhance capacity to implement regenerative farming practices.

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Appendix

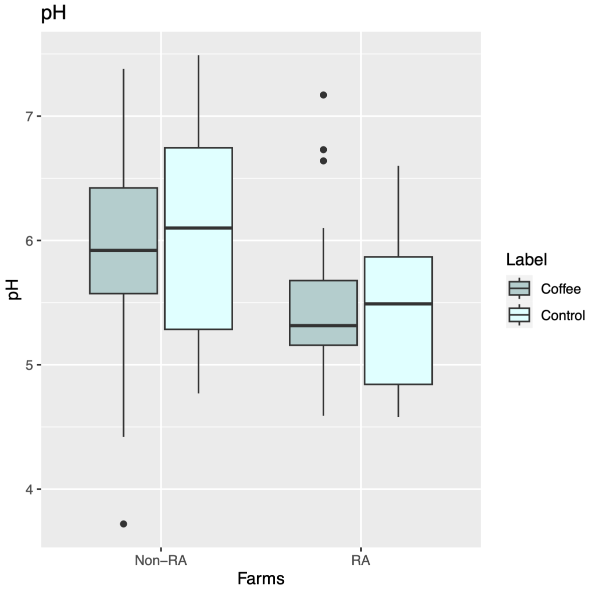


Figure 11. Soil property comparisons. *Our soil samples exhibited a range of pH values, ranging from highly acidic (pH<5.1) to mildly alkaline (pH>7.0-8.0). Most soil samples are acidic, which could be attributed to various factors, including 1) the leaching of basic ions, such as calcium, magnesium, potassium, and sodium, due to rainfall; 2) the formation of potent organic and inorganic acids resulting from the presence of organic acids and/or the oxidation of ammonium and sulfur-based fertilizers; and 3) root respiration and the breakdown of organic matter to humic acids or small molecular-weight acids. The majority of plant species thrive in environments with a pH value between 5.5 and 8.*

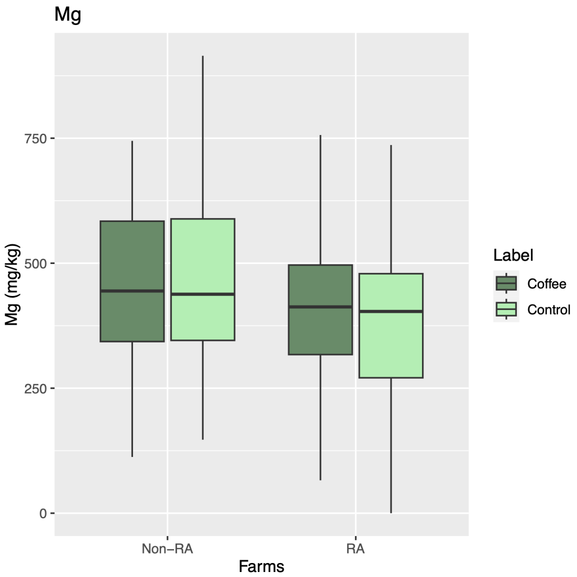


Figure 12. Magnesium. *Magnesium is the central core of the chlorophyll molecule in plant tissue. However, the high levels of magnesium in our samples might lead to multiple issues, such as reduced availability of other essential nutrients, decreased yield, and quality of crops. Several strategies could be implemented in future to lower magnesium concentrations, such as crop rotation.*

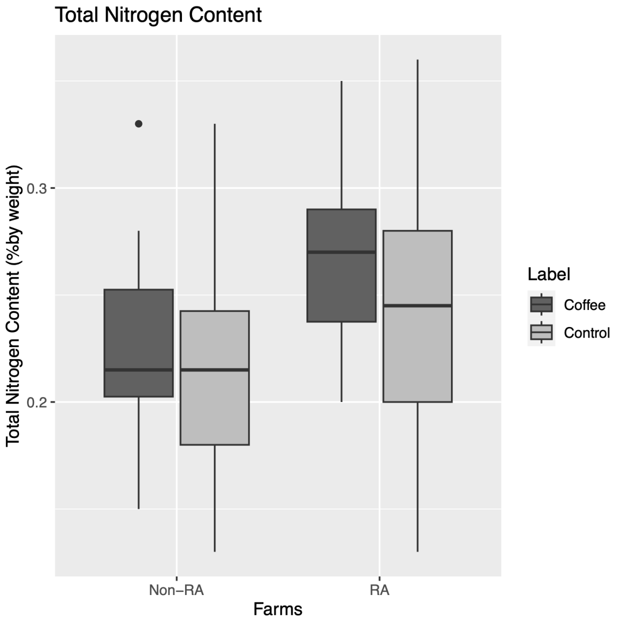


Figure 13.

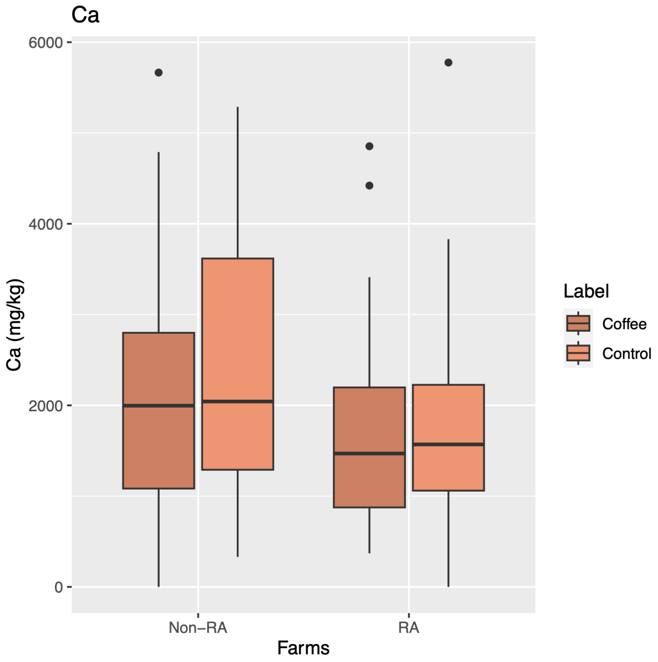
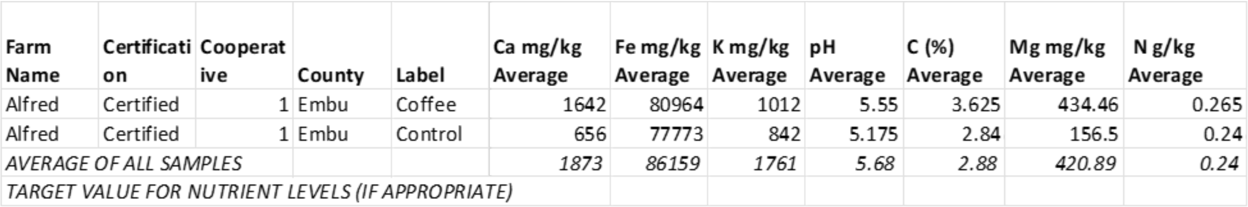


Figure 14. *Calcium helps regulate soil pH and is an essential nutrient for plant growth and development. Based on the low predicted Ca values, some suggestions to increase it are to add agricultural lime, incorporate eggshells/oyster shells, use compost or well-rotted manure to improve soil fertility, and apply calcium-rich soil amendments (e.g. wood ash).*

Template for farmer output

Here is selected soil chemical data about the soil samples we collected from your farm, as well as a summary of the soil fertility information from all soil samples (n=120 samples):



Farm Name	Certification	Cooperative	County	Label	Ca mg/kg Average	Fe mg/kg Average	K mg/kg Average	pH Average	C (%) Average	Mg mg/kg Average	N g/kg Average
Alfred	Certified	1	Embu	Coffee	1642	80964	1012	5.55	3.625	434.46	0.265
Alfred	Certified	1	Embu	Control	656	77773	842	5.175	2.84	156.5	0.24
AVERAGE OF ALL SAMPLES					*1873*	*86159*	*1761*	*5.68*	*2.88*	*420.89*	*0.24*
TARGET VALUE FOR NUTRIENT LEVELS (IF APPROPRIATE)											

Interpretation:

Calcium (Ca) is an essential nutrient for plant growth that is often deficient in tropical environments because it is easily dissolved from soil. Most calcium in Fe-rich agricultural soils is obtained from organic matter turnover or the addition of lime. Calcium concentrations higher than 1000 mg/kg suggest that the fields have been fertilized, and that lime or ash has been used to increase soil pH. Lower levels of calcium require fertilization.

Iron (Fe) concentrations are usually high in weathered tropical soils because iron is ubiquitous in rocks, and soil formation concentrates that iron. Iron oxides serve important roles in soil, they retain nutrients and form aggregates. They also are responsible for organic matter retention. Concentrations of iron around 80,000 mg/kg (equal to 8% by weight) indicate that the soil is highly weathered. Lower concentrations indicate the soil is less so, either from erosion of surface soils, tillage that brings deeper soils to the surface since deeper soils generally are less weathered and contain less iron.

Potassium (K) is a critical soil nutrient that is commonly present in fertilizers (N-P-K). This nutrient is often quite low in tropical soils because it is soluble and thus leached from soils. In our analysis, concentrations of K exceeding 500 mg/kg probably indicate active fertilization with potassium-bearing fertilizer. Levels lower than 1000 mg/kg probably require fertilizer applications to achieve maximum yields, while higher levels likely will be lost through leaching.

Soil pH is an effective measure of soil health overall because it changes quickly in response to management. Neutral pH is ideal for most agriculture, though coffee likes somewhat more acidic soil pH. Soil pH decreases over time in a soil because rain removes carbonate from the soil as it passes through soils. Acidification can also result from excess fertilization with sulfur or nitrogen fertilizers, particularly urea and manures containing organic nitrogen. Often this acidification is countered by adding calcium carbonate (limestone) or lime (calcium hydroxide). Soil pH less than 5 likely reflects ineffective management, and yields would improve with liming to increase soil pH.

Carbon content (in percent by weight) is an integrating variable that records the overall soil quality, because the carbon content increases.

NOTES on Methods: Soil organic carbon and nitrogen contents were determined using spectroscopic estimation methods that have been calibrated based on regional relationships. Elemental concentrations are determined by X-ray fluorescence and are above detection limits for most samples (though some samples contain less Ca than is easily detected).