



A Study of Regenerative Farming Practices and Sustainable Coffee of Ethnic Minorities Farmers in the Central Highlands of Vietnam

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Specialty section:

This article was submitted to
Crop Biology and Sustainability,
a section of the journal
Frontiers in Sustainable Food Systems

Received: 10 June 2021

Accepted: 09 September 2021

Published: 08 October 2021

Citation:

Le QV, Cowal S, Jovanovic G and
Le D-T (2021) A Study of Regenerative
Farming Practices and Sustainable
Coffee of Ethnic Minorities Farmers in
the Central Highlands of Vietnam.
Front. Sustain. Food Syst. 5:712733.
doi: 10.3389/fsufs.2021.712733

Coffee is highly vulnerable to climate change, thus impacting coffee-dependent livelihoods and economies. As rising temperatures continue to reduce the suitability of many historical coffee-growing regions, some farmers are practicing regenerative, organic coffee farming as a means of climate change mitigation. In the Central Highlands, the primary coffee growing region of Vietnam, conventional sun-grown, monocrop coffee requires intensive inputs, including fertilizers, pesticides and water. However, some farmers are converting their conventional sun farms to organic shade farms utilizing regenerative farming techniques for both environmental and economic reasons. This study examined regenerative farming practices and sustainable coffee in a small ethnic minority village in Lâm Đồng province. The comparative analysis between soil samples taken from a regenerative shade-grown coffee farm and two conventional sun-grown coffee farms revealed that the soil of the regenerative farm, enriched with organic manure, is comparable to, or healthier than, the soil on the conventional farms enriched with chemical fertilizers. The results indicate that regenerative farming practices promote biodiversity; however, they also maintain microclimates that promote the growth of *Roya* fungus, which can decrease coffee yields. The economic analysis of farm costs and net returns found that regenerative farming practices decrease external inputs through a system of crop diversification and integrated livestock production that improves productivity and economic performance while preserving the ecological and environmental integrity of the landscape. Regenerative agriculture is an important step toward climate change adaptation and mitigation; however, in order for the farm communities in the Central Highlands to make the transition to regenerative agriculture, the success factors and benefits of this method must be demonstrated to the coffee farmers.

Keywords: regenerative agriculture, sustainability, coffee production, ethnic minority, Central Highlands, Vietnam

INTRODUCTION

Globally, the livelihoods of more than 125 million people depend on coffee (Voora et al., 2019), the second-largest traded commodity after crude oil. Coffee is the second-most produced agricultural product in Vietnam, and the world's second-largest coffee producer after Brazil [International Coffee Organization (ICO), 2019]. Ever since the French first introduced coffee in 1857, generations of ethnic minorities in the Central Highlands of Vietnam have cultivated coffee as a reliable source of livelihood. Today, the production of coffee in Vietnam is 95% privately-owned, involving 640,000 small farms [International Coffee Organization (ICO), 2019], of which only one percent of coffee farmers own more than five hectares of land. Eighty-five percent of all farms are smaller than two hectares (World Bank, 2004), which generate an average yield of 2.3 tons per hectare, one of the highest in the world [International Coffee Organization (ICO), 2019].

In the Central Highlands, the areas of coffee cultivation are ~583,000 hectares, accounting for 88% of the total cultivation area in the country [International Coffee Organization (ICO), 2019]. Sustainable coffee production has been certified by national and international organizations, such as VietGap, UTZ, Rainforest Alliance, and 4C. These farms account for more than 30% of the areas of cultivation [International Coffee Organization (ICO), 2019]. The coffee industry in Vietnam contributes significantly to the agricultural sector, in which share of coffee as percentage of agricultural GDP is about 12%. Vietnam's coffee export volume in recent years reaches about 1.5 million tons annually, with turnover of around USD 3 billion a year.

Climate change and related rising temperatures are changing the viability of farms in the Coffee Belt regions, creating less suitable environments for coffee cultivation and threatening the economies and livelihoods dependent on it (Bunn et al., 2015; Bejan et al., 2018). The primary coffee growing regions in Vietnam are located in five provinces collectively known as the Central Highlands, which historically have maintained ideal climates for *Coffea canephora* or Robusta coffee. Of all the coffee grown in Vietnam, 95% is Robusta and 5% is Arabica (Hagggar and Schepp, 2011). The density for Robusta is about 1,330 trees per hectare, while the density for Arabica varies between 2,660 and 6,660 trees per hectare, depending on the variety and environmental conditions (Primecoffee, 2019). Historically, Robusta has been cultivated in Vietnam as a monocrop with high yields that require intensive fertilizers, pesticides and water. These monocrop cultivation practices have made coffee production in this region especially vulnerable to the projected impacts of climate change (Hagggar and Schepp, 2011). The ethnic minorities who rely solely on coffee for their livelihoods suffer the most from climate change (Le et al., 2020). The better-off are those practicing sustainable intensification such as diversification of cropping systems and integration of livestock production systems as a means of adaption and mitigation to climate change.

The objective of this study is to examine regenerative farming practices and sustainable coffee in a small ethnic minority village in Lâm Đồng province of the Central Highlands. This study

includes a comparative analysis of soil samples taken from a regenerative shade-grown coffee farm and two conventional sun-grown coffee farms, in addition to an economic analysis of farm costs and net returns.

BACKGROUND

Coffee and Climate Change

Research indicates that coffee is highly sensitive to the impacts of climate change. A multimodal database that uses machine learning algorithms to derive functions of global climatic suitability from geo-referenced production locations found that higher temperatures are predicted to reduce yields and suitable growing area for both Arabica and Robusta coffee (Bunn et al., 2015). For the top two producers of coffee in the world, Brazil and Vietnam, researchers predicted that rising temperatures may cause both countries to become unsuitable for coffee growth in the foreseeable future (Bunn et al., 2015). Although higher latitudes and altitudes with lower temperatures may maintain suitable growing conditions, migration to these areas could threaten ecosystems through deforestation (Läderach et al., 2013) and reduce producer resilience to climate change due to migration-related lack of available family labor (Baca et al., 2014).

Robusta coffee thrives in ideal temperature ranges of 20–30°C (Hagggar and Schepp, 2012). However, 25% of global coffee growing regions currently reach temperatures higher than 30°C during the hottest month, and by 2050, this is projected to increase to 79% (World Coffee Research, 2017). These projected increases in temperature reduce suitability for coffee production, which will have major implications on coffee yields and coffee-dependent livelihoods in the future.

Since the 1960s, the average annual temperature in Vietnam has increased by 0.4°C, at a rate of about 0.09°C per decade, with the most rapid increase during the dry season between November and April (Hagggar and Schepp, 2011; data from the World Bank's Climate Change Knowledge Portal, n.d.). Although overall temperature increases are occurring most rapidly in the southern regions, the central coffee growing regions have experienced significant warming. In the Central Highlands, the frequency of hot days and nights has increased every season since 1960, with the average number of hot days per year increasing by 29 days and the average number of hot nights increasing by 49 days (Hagggar and Schepp, 2011). In contrast, the average number of cold days has decreased by 11 days and the average number of cold nights has decreased by 35 nights (Hagggar and Schepp, 2011). These trends are detrimental to coffee production because increased hot days extend the period of unideal temperature conditions, which decreases coffee yields.

Water usage is another factor that makes coffee plants vulnerable to climate change. Climate variability may threaten future coffee production due to competition for water. In the Central Highlands region, evapotranspiration is predicted to increase by 8.5% between 2040 and 2059, and by 14.47% from 2080 to 2099 (Hagggar and Schepp, 2011). Increased evapotranspiration will require increased irrigation to meet the water requirements necessary for healthy coffee plants, which increases environmental and economic costs.

Regenerative Agriculture and Shade Coffee as a Climate Change Mitigation Practice

Regenerative agriculture has five common goals according to Elevitch et al. (2018): “(1) Soil: contribute to building soils along with soil fertility and health; (2) Water: increase water percolation, water retention, and clean and safe water runoff; (3) Biodiversity: enhance and conserve biodiversity; (4) Ecosystem health: capacity for self-renewal and resiliency; (5) Carbon: sequester carbon.”

According to a study by Regeneration International (2017), regenerative agriculture is a dynamic and holistic land management practice, incorporating organic farming and permaculture to improve soil health and fertility, thus increasing food production and income for farmers while preserving the environment. The framework of regenerative agriculture is divided into four different levels: “(1) functional; (2) integrative; (3) systematic; and (4) evolutionary.” Level 1 focuses on reversing climate change through regenerating soils with best practices. Level 2 put an emphasis on integrative design and carbon farming to regenerate the ecosystem. Level 3 focuses on regenerating enterprise ecosystems with multi-capital flows and investments. Lastly, level 4 examines the regenerative cultural systems focusing on agriculture as ritual for the development of regenerative producer networks. Despite being multi-layered, each level is built upon the previous one, carrying the benefits onwards (Soloviev and Landua, 2016).

Sustainable coffee is an umbrella term that encompasses organic, fair and direct trade, eco-friendly, and shade-grown coffee production practices (Giovannucci and Koekoek, 2003). In principal, sustainable coffee ensures that production techniques and methods of distribution are enhancing the environmental, economic, and social well-being of all agents involved. Environmental sustainability represents the environment and ecological conditions of the farm; social sustainability describes the production system that maintains respect for social principles that are benefiting the community; and economic sustainability allows the farming management to be financially viable. Regenerative agriculture is an integral part of sustainable coffee. According to a previous study “there is now strong evidence that regenerative and resource conserving technologies and practices can bring both environmental and economic benefits to farmers, communities, and nations,” (Pretty, 1995, p. 1).

As climate change continues to reduce the suitability of coffee growing regions, human adaptation methods are necessary to reduce the vulnerability of coffee-based communities and economies. The incorporation of shade trees in coffee farms is one mitigation technique that encourages higher biodiversity, as shade trees provide habitat for diverse species and serve as carbon sinks. Studies within the last 25 years indicate that shaded coffee farms promote high biodiversity of invertebrates, vertebrates, and plants, which help maintain the health of coffee agroecosystems (Perfecto et al., 2007). Shade-grown coffee can be classified into different shade levels and management according to a study in Mexico by Moguel and Toledo (1996, 1998), and by Gobbi (2000) in El Salvador. The classification is as follows:

rustic (coffee is grown under the shade of a natural forest); traditional polyculture (similar to the rustic system in structure, but has a greater diversity of economically valuable shade trees planted by the farmer); commercial polyculture (shade trees are mostly planted as alternative commercial products); and technified shade (original forest has been completely removed and replaced with a few shade tree species). Most coffee farmers practice commercial polyculture by growing timber and fruit trees adaptive to the region because of the additional monetary benefits they provided (Albertin and Nair, 2004). Shade trees can also serve to regulate the stability of annual coffee yields (Albertin and Nair, 2004). The authors explained that instead of having an unpredicted low and high yield harvests under sun farms, shade farms have more stable annual yields.

Because shaded coffee systems promote biodiversity, they provide valuable ecosystem services that maintain complex invertebrate interaction webs, resulting in autonomous pest control (Vandermeer et al., 2010). In addition to promoting the presence of natural pest regulators, shaded systems promote higher diversity of native pollinators which contribute to higher coffee yields (Perfecto et al., 2007). Previous studies indicate that shaded coffee systems also help mitigate extreme temperature and precipitation changes, with high potential as an adaptation technique for projected climate change. The canopy cover of shade trees protects coffee plants from harsh sunlight and reduces temperatures by around 4°C (Läderach et al., 2013), which may improve the resilience of coffee plants in warmer regions. Shade canopies also improve soil moisture retention and protect coffee plants against erosion and landslides (Läderach et al., 2013).

In addition, shade trees increase bird habitat and abundance on coffee farms, which reduces coffee pests. Johnson et al. (2010) found that the presence of birds reduced the amount of coffee berry borer, *Hypothenemus hampei*, which is the most damaging coffee pest. The study also noted that the reduction of the borer pest by birds on coffee farms resulted in cost savings, illustrating the economic advantages of shade trees on coffee farms. As a natural form of pest prevention, shade-grown coffee farmers with increased bird abundance can reduce their pesticide input, thus reducing input costs and environmental damage. An additional study conducted in India found that reduced pesticide use in Robusta agroforests could lead to increased food resources for birds, thus improving biodiversity (Chang et al., 2018).

Although these benefits of shaded coffee production mitigate impacts of climate change, lower yields as a result of climate pressures have led to a shift toward coffee monoculture in traditionally shaded areas, reducing climate change resilience (Läderach et al., 2013). In comparison to shaded farms, the resilience of monoculture coffee farms to erosion, increased evapotranspiration, drought, and extreme weather events is very low (Haggard and Schepp, 2011).

Constraints of Sustainable Coffee Production

Sustainable coffee has clear benefits for farms and farming communities; however, there are disadvantages to certain methods of sustainable production. First, the initial transition

of a conventional farm to an organic or shade-grown farm can be labor intensive, expensive, and take several years to establish. The introduction of shade trees and other shade crops can have initial costs that require farmers to take out loans or find other means to finance the transition. Second, in order to obtain certifications such as organic or fair trade, farmers need to finance the certification organization to assess their farm, fill out detailed paperwork, and then address any requirements needed to become officially certified (Guthman, 2004). Certifications such as organic require farms to produce for 3 years without any pesticides or herbicides before officially being certified (Riddle, 2003). This can impact the economic viability of farms as they strive to transition, but lack the price premiums of organic sales initially (Le et al., 2017). Furthermore, farmers will need to improve productivity to maintain or increase their income as the sustainable coffee market will reach its maturity and price premiums will be expected to decrease (Kilian et al., 2006). Lastly, certifications have become a norm in some regions, forcing farmers to obtain certifications or not be able to sell their beans to exporters without them (Le and Jovanovic, 2019).

In terms of the farm itself, the initial transition from conventional to organic farming can increase susceptibility to various pests and diseases (Bengtsson et al., 2005). In addition, shade trees have shown increases in fungal attacks, specifically by the fungus *Mycena citricolor*, due to an increase in humidity on the farm (Beer, 1987). Furthermore, over-shading can reduce coffee yields significantly. For example, Soto-Pinto et al. (2000) found that shade cover above 50% can significantly limit coffee yields, while 30–45% shade cover promoted the highest yields. Another study found that competition for water between coffee plants and shade trees may reduce coffee health during the dry season (van der Vossen, 2005). Shade trees can also damage coffee plants with falling branches, and the need to prune shade trees regularly poses additional labor costs.

Roya Fungus in Shaded and Sun Agricultural Systems

The Roya fungus, also known as coffee leaf rust, *Hemileia vastatrix*, is one of coffee's largest pests and is believed to have originated in Africa (Kushalappa and Eskes, 1989; and McCook, 2006). Records indicate that rust first devastated coffee crops in Sri Lanka in the middle of the 19th century (Vandermeer et al., 2010). In 1970, the disease spread to Brazil, and later to both Central America and the Caribbean (Vandermeer et al., 2010). Between 1865 and 1985, the rust disease spread globally to all the coffee growing regions with varied degrees of biological and economic impact (van der Vossen, 2005). Rust primarily attacks the leaves of coffee plants, leaving yellow-orange spots usually 2–4 millimeters in diameter. Over time, the spots brown and eventually become necrotic; the diseased leaves fall prematurely (Kushalappa and Eskes, 1989). Severe cases of rust can cause delayed growth, defoliation of the entire plant, premature berry dropping, and can slowly kill the coffee plant (Kushalappa and Eskes, 1989).

The impact of shade management techniques on the presence of the Roya fungus is not currently well-known. Some studies

have indicated that shade management practices can reduce the risk of rust epidemics while others indicate intensification of coffee rust in shaded systems (Avelino et al., 2004). These inconsistencies are likely a result of the multifaceted effects shade has on coffee plants. Shade can reduce fruit loads, which decreases coffee leaf receptivity to Roya fungus; however, shaded systems can also cultivate suitable microclimates for the germination and colonization of the fungus (López-Bravo et al., 2012). A study that dissociated these factors by homogenizing fruit loads on shaded and full sun coffee plants found that shade does have negative effects on the presence of rust because the intensity of rust was greater in the shaded systems when both systems had equal fruit loads. The reduction of fruit loads associated with shaded plants mitigates the intensity of rust in shaded systems, but is accompanied by the disservice of reduced coffee yields (López-Bravo et al., 2012).

THE STUDY REGION

The study site was located in Lãng Cú village, Gung Ré commune, Di Linh district. Di Linh district is located in Lâm Đồng province in the Central Highlands of Vietnam with a total area of 1,628 km². Gung Ré commune has an area of 121.5 km² with a population under 9,000 people and a population density of 69 people/km² (Lam Dong Portal, n.d.). Lâm Đồng province is characterized by its varied terrain with mountains and highland terrains in the north and hills and valleys in the south. Elevation in the northern districts of Lâm Đồng is around 1,500 meters, while the southern districts reach elevations of about 800–1,000 m. The elevation change in the Lâm Đồng province naturally separates the growth of various perennial crops based on their climate preferences. The cooler, high elevation climate of the north is ideal for the growth of high-quality Arabica coffee, while the hotter, lowlands in the south are home to the hardier Robusta coffee. Di Linh district is the largest producer of Robusta coffee in Lâm Đồng Province, with about 41,000 hectares of coffee cultivated throughout the region, accounting for 75% of agricultural land in the district. In the last 10 years, more than 50% of coffee plants have been replanted with new varieties. In Lãng Cú village, about 80 out of 330.7 hectares of coffee (~25% of the farmland) have been replanted in recent years.

To conduct a comparative analysis between regenerative shade-grown coffee farming practices and conventional sun-grown coffee farming practices, we collected soil samples, conducted invertebrate counts, and compared the presence of the Roya fungus on three farms: one regenerative shade farm and two conventional sun farms as shown in **Figure 1**. An economic analysis of these farms was also conducted.

The K'Ho Perceptions of Sustainable and Conventional Coffee Cultivation in the Region

Part of this study included a survey of 30 ethnic minority K'Ho farmers (17 were female and 13 were male) who grow Robusta coffee in this village (Jovanovic and Le, 2019; Le et al., 2020). Twenty-two of the 30 farmers migrated over 35 years ago from



FIGURE 1 | Lãng Cú village, Gung Ré commune in Di Linh district of Lâm ồng province. Source: Google Earth, Image @2019 DigitalGlobe.

the mountainous area of Son Ền commune to Lãng Cú village, where the local government initially gave each family 100 coffee trees and between 4,000 and 5,000 m² of land. Some families expanded their land up to 3–4 hectares until the government restricted land expansion around 15 years ago. These farmers first cultivated dry rice on the hillsides, then wet rice in the flatlands, and finally switched to coffee cultivation on the hillsides around 25 years ago. Today, each family has an average of 2–3 hectares of coffee farm and 1 hectare of wet rice field. A coffee-rice segregated system is typically chosen by farmers in the Central Highlands as a form of subsistence for food security because rice is a stable crop (Ho et al., 2017). Each hectare of conventional sun-grown coffee yielded an average of 2.5 tons, earning a net income of 20 mil VND (\$870) per ton, compared to 1.5 tons shade-grown organic coffee with an expected earnings of 67 mil VND (\$2900) per ton (Le et al., 2020).

Currently, the village has 185 households with 764 people, of which the K'Ho accounts for 40.5% (Lam Dong Online, n.d.). The history of chemical use in the village began with the initial migration to the province. The government gave farmers

fertilizers and pesticides for rice cultivation upon arrival to the region. Although the government subsidies of chemicals ended between 6 and 7 years ago, most farmers in the area continue to use chemicals on both their rice and coffee farms. The farmers indicated that the quality of their soil is progressively worsening, decreasing coffee yields; they use chemicals to counteract the infertile land, but also attribute lower soil quality to a history of chemical use.

The average age of the 30 farmers surveyed is 52 years old, the youngest is in the late twenties and the oldest farmer is over 80 years old. The average size of the family is 8. Out of the 30 farmers, only three farmers cultivate sustainable shade-grown organic coffee. The farmers that practice organic cultivation are young, college graduates who have perceived negative impacts of chemical fertilizers and pesticides and want to practice more sustainable soil management. Shade-grown organic coffee is viewed as an experimental farming practice in this village and other farmers are waiting to see how well the organic coffee succeeds environmentally and financially before they consider implementing the technique. Despite a higher projected net

income from organic coffee, only young farmers are considering transitioning their farms because the initial expenses and labor costs of conversion are considerably high for the older farmers. Many farmers are also concerned that without pesticides, their crops will be overrun by pests in the area, particularly the borer beetle and Roya fungus (Le et al., 2020).

Farmers in the village have already perceived impacts of climate change on their coffee production. They have noted that increases in heatwaves, periods of intense rainfall and drier, nutrient-deficient soil have all lead to recent declines in production. Farmers are already grappling with decreasing harvests due to climate change; therefore, despite research indications that switching to more sustainable cultivation methods may mitigate the impacts of climate change, farmers are concerned that removing pesticides and chemical fertilizers will lower their production even further. However, research has shown that regenerative farming practices that focus on restoring soil health actually increase farm productivity (Sherwood and Uphoff, 2000).

Study Area 1: Shade Farm (Regenerative Agriculture)

The first research site was a regenerative shade-grown coffee farm, started by a K'Ho farmer who graduated with a degree in soil management and is a leader in his community in the regenerative farming movement. This farmer learned regenerative farming practices in college and integrated these techniques into his own coffee farm after graduating in 2013. His family owns a total of four hectares of land, of which three hectares are allocated for coffee production and one hectare for wet rice cultivation. The three hectares for coffee production are divided into smaller plots along the hillsides of the village. Currently, the farmer in this study has been implementing functional regenerative agriculture (level 1) and integrative regenerative agriculture (level 2) on his farm. In level 1, the farmer's objective is to regenerate the soil that has been damaged from years of chemical use. To complete level 2, he must improve the health and strength of the whole farm ecosystem through the integration of shade tree species and livestock for optimal biodiversity and carbon capture.

The farm revealed in **Figure 2** is an experimental farm with a total area of 5,000 m². 1,000 m² contain the farmer's main house, a traditional wooden house, animal cages, an area to dry coffee, and a fertilizer storage area. To the southeast, the farm is located next to one hectare of wet rice fields owned by the same farmer. The remaining 4,000 m² (in a triangular shape) comprise the shade coffee farm classified as a commercial polyculture system, consisting of 450 coffee trees and other tree species planted in 2014. Dispersed among the coffee plants, the farmer planted 200 *Senna siamea* trees to shade the coffee plants. He chose *Senna siamea* because this particular plant has a rapid growth rate and attracts birds that eat coffee pests. The farmer explained that there is no need for pesticides to treat the coffee pests. The birds eat the coffee berry borer once migrated to the *Senna siamea* trees. Additional benefits of these trees include the ability to use the leaves as an organic green compost, stabilizing soil properties

of tree roots, and that the roots of the trees provide micro-organisms that keep the soil fertile and provide nutrients to the coffee plants. Third, these trees also contain economic value because after 5 years, they can be harvested for timber.

In developing countries, the diversification of cropping systems does not only depend on cash crops, but also on food crops for household consumption (Scialabba and Müller-Lindenlauf, 2010). Zhang and Li (2003) demonstrated that intercropping utilizes soil nutrients more efficiently, thus increasing productivity. Crop diversification is an important factor on this experimental farm. In addition to *Senna siamea*, tree varieties on the farm include jackfruit, guava and banana. Between 2017 and 2018, the farmer also planted 70 macadamia trees that were provided by the local government as an experiment to see if macadamia can thrive in the elevation and climate of this region as a possible alternative commercial product. On the ground, the farmer also grows different types of vegetables and mushrooms for consumption. All these plant species feed the family and animals, and leftovers can be sold to the local and farmer markets. Animals on the farm include three cows, 12 goats, one black pig (native to this region), and chickens. The farmer recently sold dozens of pigs and used the money to build larger cages for the next pig herd. The cows and goats eat *Pennisetum purpureum* grass and straws from the rice fields. The pigs eat banana leaves and trunks. The livestock on the farm provide multiple benefits to the household and are important assets for the family, as major food sources and as manure sources for organic fertilizer.

The farmer does not use any chemical fertilizers on his farm; rather he makes his own organic fertilizer collected from cow, goat and pig manure. He creates a mix of 80% manure and 20% rice husks and straws; he learned this optimal ratio from a workshop organized for farmers in the community by the Japan International Cooperation Agency (JICA). He combines the mixture with yeasts from a traditional K'Ho wine and stores the mixture under a plastic cover for a fermentation period of 2–3 months. The farmer only applies organic fertilizer and refrains from all chemical pesticide usage on his farm. In contrast, other farmers in the village use chemical fertilizers which they mix with animal manure and store for only 1 month. All of the farmers in the village apply fertilizer to their coffee trees three times between March and June: the first time in March before the rainy season, the second time in May during the rainy season, and the third time in late June after the rainy season.

The sustainable farming system implemented by the farmer on his experimental farm integrated coffee with other crops (*Senna siamea* and fruit trees) and rice has proven to be more efficient than the current conventional systems (sun-grown coffee mono crop and sun-grown coffee and rice crops) practiced by the majority of the farmers in the village. This is consistent with the findings in coffee farming communities reported in Ho et al. (2017). Furthermore, the regenerative farming practices limited the use of external inputs through a system of integrated livestock production to improve productivity and economic performance while preserving the ecological and environmental integrity of the landscape. Regenerative agriculture levels 1 and 2 (Soloviev and Landua, 2016) have demonstrated that these are important



FIGURE 2 | Triangular shape shade-grown coffee farm (regenerative) in 2019 vs. 2013. Source: Google Earth, Image @2013 and @2019 DigitalGlobe.

steps toward climate change adaptation and mitigation for sustainable intensification as described in Campbell et al. (2014).

Study Area 2: Sun Farm A

The second farm site is a conventional sun-grown coffee farm located directly adjacent to the shade farm. This is a typical unshaded monoculture system in the Central Highlands of Vietnam. Under this system coffee trees are exposed to full sun and are highly reliant on chemical inputs and water, which make them financially vulnerable to market fluctuations (Gobbi, 2000). The farmer of the shade farm waters his farm two times per year during flowerings, whereas the sun farms are constantly being watered, especially during the hottest months. The analysis was conducted on a 2,000 m² plot containing about 400 coffee trees sharing a property line with the shade farm. The coffee plants on this farm are over 25 years old and very low in productivity. Chemical fertilizers and pesticides are used on this

farm. Soil erosion and degradation are apparent on this sun farm. The rice fields have been slightly impacted by erosion and soil running down hills into the lowlands; however, there is little impact on the shade farm and the rice fields located right below it.

Figure 3 provides an image of the shade farm and sun farm for comparison. The shade farm on the left is greener and has more biodiversity compared to the sun farm on the right. There were no birds and far fewer ants and other invertebrates on the sun farms. This observation is consistent with a previous study in Latin America coffee plantations (Philpott et al., 2008), which revealed that sun coffee exhibits the highest losses of ant and bird species, and these losses increase with management intensity. Since coffee trees require light to produce and for the cherries to mature, light shade is preferred over thick shade. **Figure 4** provides an image of the coffee-*Senna siamea* intercropping with spreading crown to allow light to filter onto the coffee trees. The



FIGURE 3 | Shade farm and sun farm A. Source: Photo provided by the owner of the shade farm. Shade farm covered with *Senna siamea* trees is on the left. Sun farm A is on the right.

shade farm had a much cooler temperature than the sun farm which was around 27°C on the field research days in March.

Study Area 3: Sun Farm B

The third farm site is a sun farm owned by the family of the same farmer who cultivates the shade farm. Chemical fertilizers and pesticides are used on this farm. This farm is located on a hill across from the shade farm, separated by wet rice fields. The total area of the sun coffee farm is 2,000 m², containing over 200 coffee trees that are over 25 years old and also very low in productivity due to old age. Most of the coffee trees on this farm are infested with *Phytophthora*, a white fungus which harms coffee plant trunks, branches, and bark. The farmers interviewed noted that most of their trees have an apparent presence of this water mold. This water mold decreases the productivity of their coffee trees. In order to combat the mold, some farmers have applied *Trichoderma harzianum*, a natural fungicide that attacks the mold. This is an example of a natural method of farm management that is being applied to minimize the use of chemical pesticides.

METHODS AND RESULTS

Site Designation and Soil Sampling

The USDA's Soil Quality Test Kit Guide and Soil Quality Indicator Sheets were referenced to establishing the soil sampling method used in this study. Due to limited time and resources, one round of soil measurements was collected to compare to

standard soil conditions instead of multiple soil samples taken over an extended period of time. On each of the three farms (shade farm, sun farm A, and sun farm B) five sites labeled A–E were designated on the north, south, east, west, and middle of each farm. This methodology was used instead of random sampling on each farm to ensure that soil near the border of neighboring farms was collected in case neighbor's farms were impacting the soil health of each farm. At each of the five sites, four soil samples were taken using a soil corer drilling 0.5 m below the surface, for a total of 20 samples taken at each farm. The top 0.25 m of topsoil was removed and the bottom 0.25 m of soil was stored in sealed plastic bags. The samples from each farm were transferred to the Da Lat Nuclear Research Institute for analysis. The soil samples were analyzed between one and 2 days after retrieval from the farms. Soil samples weighing 0.5 kg were analyzed according to dry weight at 105°C. Total nitrogen, total phosphorus, total potassium, bulk density, and pH were calculated by the research institute. **Tables 1, 2** present the paired samples *t*-test for comparison of the mean scores of the soil samples on the farms.

A *t*-test was calculated to determine if there was a statistically significant difference between the soil components of the shade and sun grown coffee. The result revealed that there is a significant statistical difference in pH at the 10% level between the shade farm and sun farm A and sun farm B, indicating that the pH of the soil from the shade farm was statistically higher than the pH of the soil in both sun farms. According to a study on land use requirements for Robusta coffee, the optimal pH ranges



FIGURE 4 | Shade farm—Coffee-*Senna Siamea* intercropping. Source: Photo provided by the owner of the shade farm.

TABLE 1 | *T*-test of soil analysis in shade farm vs. sun farm A.

	Shade farm	Std. Dev.	Sun farm A	Std. Dev.	t-stat.
pH (KCl)	4.146	0.510	3.726	0.072	1.946*
Total nitrogen (ppm)	1888.400	327.291	1942.000	211.463	−0.308
Total phosphorus (ppm)	949.400	357.250	1142.000	434.645	−0.765
Total potassium (ppm)	231.800	57.454	143.160	65.013	2.284**
Bulk density (g/cm ³)	1.605	0.015	1.602	0.014	0.257

Sig. 2-tailed. **significant at 5% level; *significant at 10% level; equal variances assumed.

TABLE 2 | T-test of soil analysis in shade farm vs. sun farm B.

	Shade	Std. Dev.	Sun farm B	Std. Dev.	t-stat.
pH (KCl)	4.146	0.510	3.702	0.030	1.944*
Total nitrogen (ppm)	1888.400	327.291	1846.200	317.807	0.207
Total phosphorus (ppm)	949.400	357.250	834.600	242.551	0.594
Total potassium (ppm)	231.800	57.454	142.380	37.702	2.910**
Bulk density (g/cm ³)	1.605	0.015	1.603	0.016	0.141

Sig. 2-tailed. **significant at 5% level; *significant at 10% level; equal variances assumed.

between 5.0 and 6.3 KCl, but possible extremes can range from 4.0 to 8.0 KCl (Haggar and Schepp, 2012). The average pH of the shade farm (4.146 KCl) was closer to the optimal pH range conditions for Robusta coffee than the average pH of the sun farm A (3.726 KCl) and sun farm B (3.702 KCl), respectively.

There is also a statistically significant difference at the 5% level between the soil samples of the shade and sun farms in the total amount of potassium, which is beneficial for fruit development and higher yields. Potassium level at the shade farm was higher on average (231.8 ppm) compared to sun farm A (143.16 ppm) and sun farm B (142.38 ppm), respectively. Higher potassium levels of the shade farm were unexpected when compared to previous studies, which found that many organic systems need to add significant quantities of additional composted organic matter from external sources to meet nutrient demand, and that many organic farmers face lower yields because they are unable to acquire the additional compost (van der Vossen, 2005).

A study in El Salvador found that higher shade tree densities were associated with lower nitrogen and potassium levels possibly due to competition between the shade trees and coffee plants (Méndez et al., 2009). Shade tree densities are typically high in commercial polyculture system compared to very high in traditional polyculture system and medium in shaded monoculture (van Rikxoort et al., 2014). Contrary to this pattern of lower nitrogen levels on shade farms, there is a statistically insignificant difference found between nitrogen levels on the organic and conventional farms in this study. Nitrogen is a key factor impacting vegetative growth and coffee yields, which is usually 20–40% lower on organic farms when compared to conventional farms (van der Vossen, 2005). Previous studies indicated that organic farming systems usually fail to achieve optimal levels of available nitrogen exclusively through organic compost and manure (van der Vossen, 2005); however, the shaded system in this study did manage to supply the same amount of nitrogen as both sun farms that utilized chemical fertilizer despite the fact that *Senna siamea* trees are not nitrogen-fixing trees. The lack of statistical difference between nitrogen levels across organic and conventional farms indicates that the effectivity of organic compost in this study was comparable with that of chemical fertilizer.

Although the amount of phosphorus required in coffee plants is relatively small compared to other nutrients, it is a necessary macronutrient for root growth, fruit development, and cherry maturity. A lack of phosphorus poses a constraint to coffee yields. Coffee's main sources of organic phosphorus are leaves

and pruning remnants (Ling et al., 1990). Additionally, organic or inorganic phosphorus (bone meal or rock phosphate) can be applied to cultivated soils. Another study found that the distribution of organic and inorganic phosphorus pools varied depending on the inherent characteristic of the agroecosystem, i.e., agroforestry vs. full sun (Xavier et al., 2010). In this study, there is no statistically significant difference in the levels of phosphorus between the shade and sun farms. The leaves from the coffee trees and *Senna siamea* trees provide nutritional efficiency in the shade farm without further application of phosphorus.

There is no statistically significant difference in the bulk density levels between the shade and sun farms. This was unexpected because bulk density is generally lower when soils are rich in organic matter and have higher porosity (USDA Natural Resources Conservation Service, 2008). It was anticipated that the regenerative farm would have lower bulk density than the other farms given the state of the soil as looser and richer in organic matter from the use of organic compost and shade cover.

Through visual observation, it was noted that the coffee plants on both sun farms were deficient in calcium, whereas the shaded plants were not. This observation is consistent with a study comparing soil properties of organic and conventional coffee systems that found organic systems contained significantly higher levels of carbon (Velmourougane, 2016).

Invertebrate Biodiversity Sampling

Following the same site designation as the soil sampling method, a 0.5 × 0.5 m quadrat was placed on the ground at each of the five sites A–E. The leaf litter inside the quadrant was sorted through and the number of individuals of each invertebrate taxonomic group was recorded to assess invertebrate abundance and biodiversity. This method was repeated at each of the five locations at each of the three farms. The data are presented in **Table 3**. The shade farm had greater invertebrate abundance and species biodiversity than both sun farms, which is consistent with previous studies (Perfecto et al., 2007; Vandermeer et al., 2010). These results indicate that the cultivation of shade coffee is less damaging to biodiversity than the cultivation of sun coffee.

Assessment of Roya Fungus Presence

Following the same site designation, A–E, one coffee plant was randomly selected at each of the five locations on each farm, and five branches on the chosen trees were randomly selected to inspect the leaves. All the leaves on the selected branches

TABLE 3 | Invertebrate abundance and biodiversity comparison.

	Shade farm	Sun farm A	Sun farm B
Total abundance	47	29	21
Total no. of species	5	4	3

The total number of invertebrates (abundance) and number of different species were counted inside of a 0.5 × 0.5 m quadrat at five locations across each farm.

TABLE 4 | Comparison of Roya fungus presence.

	Shade farm	Sun farm A	Sun farm B
No. of leaves inspected	432	436	370
No. of leaves infected	75	38	48
Percentage of infected leaves	17.36%	8.72%	12.97%

were examined for the presence of Roya fungus, and the total number of infected leaves on each branch was recorded and presented in **Table 4**. The shade farm had a higher percentage of coffee leaves infected with the Roya fungus, with 17.36% of leaves infected on the shade farm compared to 8.72% and 12.97% of leaves infected on the trees of sun farms A and B, respectively. While lower levels of fruit loads on the shaded coffee plants may decrease leaf receptivity to Roya, the higher resilience to rust of the shade plants did not outweigh the negative impact of the shaded microclimate that promotes the germination and spread of the fungus. These results are consistent with established literature on rust, because the shaded area cultivates a more ideal microclimate for the disease to cultivate and spread (López-Bravo et al., 2012).

Economic Analysis of Regenerative vs. Conventional Farming

This section pertains to the economic analysis of regenerative farming and conventional farming practices. A previous study by the U.S. Department of Agriculture (USDA) indicated that farmers who apply soil conservation methods and reduce their dependence on fertilizers and pesticides generally report lower production costs in comparison to conventional farms (Reganold et al., 1990, p. 112). In terms of output, organic agricultural systems in developing countries generate equal or even higher yields compared to conventional practices (Scialabba and Müller-Lindenlauf, 2010). With respect to coffee production, sustainable production using coffee husk compost to supplement cow manure and chemical fertilizers increases coffee yields in Vietnam (Nguyen et al., 2013).

Following the comparative analysis between sustainable and conventional farms described in Reganold et al. (1990), this study compares the costs and returns between the regenerative shade farm (commercial polyculture) and the conventional sun farm (unshaded monoculture) for the coffee harvest season 2018–2019 based on 4,000 m² of land in each farm. The results are shown in **Figure 5**. Despite higher total input costs incurred in the shade farm due to fixed costs, total cash income is significantly higher because of an improvement in the quality of coffee and a higher premium for organic, and additional income from other sources

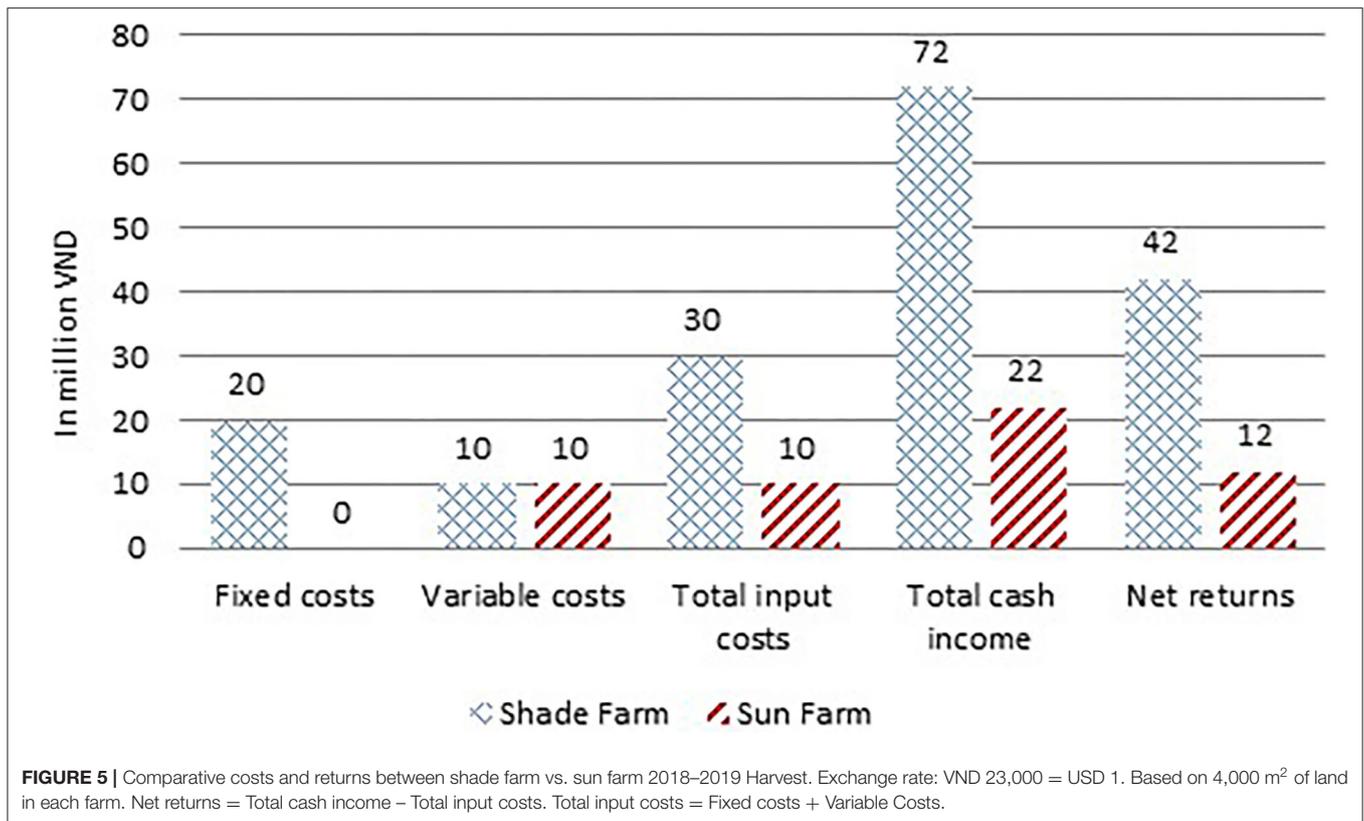
on the farm. Fixed costs include building infrastructure for the regenerative farm (i.e., shade trees, cages and livestock). Over the past 5 years, the farmer of the shade farm has invested about VND 100 mil. in building infrastructure (equivalent to USD 4,350). In 2018–2019 he invested VND 20 mil. in fixed costs. Currently, the variable costs for both farms are the same. However, in the future, it is expected that variable costs of the shade farm will be lower when compared to the sun farm when less purchased inputs are required. Variable costs for the shade farm include water, fuel for water irrigation, maintenance, straws and rice husks, yeasts for mixing with manure to make organic fertilizer, grass to feed the cows and goats, and labor for harvesting cherries. Variable costs for the sun farm include water, fuel for water irrigation, maintenance, chemical fertilizers, pesticides, and labor for harvesting cherries. Overall, the net returns are higher for the shade farm compared to the sun farm, being VND 42 mil (USD 1,826) vs. VND 12 mil (USD 522). The shade farmer expects his farm to generate higher net returns in the future when fixed costs are no longer required (or minimized) once the regenerative infrastructure is self-sustained and variable costs are lower.

The results of this analysis are similar to the findings of Reganold et al. (1990), which concluded that low-input sustainable agriculture reduces reliance on fertilizers, pesticides, and other purchased inputs. As a result, profits for the sustainable farms are higher. In addition, total cash income will also increase with the commercial polyculture system. The shade trees, *Senna siamea*, can be harvested for timber, and macadamia nuts have a high commercial value. To generate additional income, the farmer also sells the pig herd (when they reach 15 kg at 100,000 VND/kg) and the grass-fed goats to local markets. He is planning to commercialize the traditional K'Ho smoked pork for higher value-added. He is also in the process of creating a brand for his coffee with a trademark and will eventually roast the coffee with a purchase of a roaster. This would require an additional capital investment added to the fixed costs, but with high net returns in the long run.

A study in El Salvador reveals that investing in a commercial polyculture farm is profitable but also has the highest risk since coffee yields are lower (Gobbi, 2000). This is due to the farm's devotion to other economic activities, especially the planting of shade trees. Thus, regenerate agriculture must provide the potential for farmers to realize viable livelihood as demonstrated in coffee micro-mills in Costa Rica (Nuñez-Solis et al., 2021). As an experimental farm, the farmer in this study seems to engage in multiple activities without taking the opportunity costs into consideration. In the future, as he plans to replicate and expand the regenerative farming practices to the rest of his family's farm, he has to find an optimal solution for coffee-shade tree-livestock interaction to sustain a biodiverse farm as well as his family livelihood.

CONCLUSION

The results of this study indicate that the soil health of regenerative shade coffee is comparable to or better than that of fertilized sun coffee. With higher and statistically significant



pH and potassium levels on the shade farm, and statistically insignificant differences in the levels of nitrogen, phosphorus, and bulk density between the organic shade soil and inorganic sun soil, our results illustrate that organic compost can be just as effective as chemical fertilizers when supplementing soil health on coffee farms. Limiting the use of chemical fertilizers reduces input costs without compromising soil quality, resulting in higher profits for low-input, sustainably cultivated coffee. The shade farm had significantly higher levels of pH (at the 10% level) and potassium (at the 5% level) in comparison to the sun farms, indicating that the regenerative method resulted in more optimal pH and potassium levels for coffee cultivation. These factors may benefit vegetative growth, fruit development, and yield for coffee plants on shade farms.

Consistent with existing literature on shaded management systems and biodiversity, the shade farm exhibited greater species biodiversity than both sun farms. With greater species biodiversity and invertebrate abundance, our research indicates that the regenerative shade cultivation method is less damaging to biodiversity than the cultivation of sun coffee. The enhanced biodiversity of the shade farm likely benefits coffee production by maintaining the health of the coffee agroecosystem, encouraging natural pest control webs, and promoting a variety of pollinators, which increases coffee yields.

Given the ecological and economic benefits of regenerative shade coffee cultivation, we recommend sustainable, shaded coffee production as a viable adaptation method to mitigate the

harmful effects of climate change in coffee growing regions of the Central Highlands of Vietnam. Higher net returns on shade coffee can improve livelihoods of coffee farmers economically, while ecologically protecting biodiversity and reducing climate change vulnerability. The future success of the experimental farm using regenerative agriculture at levels 1 and 2 is very important as many of the farmers in Lăng Cú village are waiting to see the results before deciding whether to alter their farm management techniques. The systemic regenerative agriculture (Level 3) can be achieved if the whole village begins gradually transitioning from conventional to regenerative farming practices. However, given a limitation of small soil samples collected on three farms in the village, this study can only be considered as a baseline study for further replication and investigation throughout this farm community to draw best practices at different levels of regenerative agriculture, and perhaps if successful, the model should be expanded to other farm communities in the Central Highlands. To make this effort feasible, it would require institutional support from the local government.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

QL and GJ: conceptualization. QL, SC, and GJ: methodology and writing—review and editing. QL, GJ, SC, and D-TL: investigation and data collection. QL: formal analysis, writing—original draft preparation, and supervision. D-TL and QL: visualization. All

authors have read and agreed to the published version of the manuscript.

FUNDING

Project partially funded by Seattle University's Global Grant.

ACKNOWLEDGMENTS

The authors are very grateful for the participation of the K'Ho coffee farmers, community leaders, and the support from local authorities in Lăng Cú village. Responsibility for any errors in this study remains our own.

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