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Original Article

The Effectiveness of Climate-smart Agriculture Practices in Coffee Production at Dlie Ya Commune in Dak Lak Province

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Abstract: This study aimed to quantitatively assess the effectiveness of climate-smart agriculture (CSA) practices in coffee production in Dlie Ya commune, Dak Lak province. A theme-based framework and an indicator-based method with 23 indicators of five components (beneficiaries and yield, enabling environment, natural resources, emission, and benefits and welfare) were used. Semi-structured interviews with 107 local households were conducted. Data were coded, normalized to a 0-1 scale, and assessed, of which 1 refers to the highest effectiveness of CSA practices. Intercropping and soil coverage (mulching) were the two most common CSA practices in the study area. The CSA practices of intercropping and soil cover showed several advantages over not using these practices. These benefits included increased coffee yield, more stable yield variability, and reduced use of natural resources. The effectiveness score for intercropping was 0.66, significantly higher than the score for no intercropping (0.61) ($p < 0.001$). Soil coverage had an effectiveness score of 0.68, which was higher than no soil coverage (0.60) ($p < 0.001$). The results of this study indicate that intercropping and soil cover are good CSA practices and should be promoted for broader adoption among coffee farmers. Despite the results showing higher yields with the introduction of CSA, farmers still need to consider comprehensive measures to make their decisions. Training workshops organized by the local government might be essential to communicate the benefits of CSA practices to local farmers.

Keywords: climate-smart agriculture, coffee, effectiveness, indicator, Vietnam.

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1. Introduction

Coffee is the 2nd most frequently traded commodity globally, after crude oil [1]. The coffee sector supports the livelihoods of 25 million farmers in 60 countries worldwide [2], mostly smallholder farmers. This perennial crop is susceptible to changes in climate systems and weather conditions [3, 4]. Drought, heat, and light stresses affect coffee crops' physiological and agronomic features [3]. Climatic conditions strongly influence coffee yield, especially at immature and productive stages [3]. Increases in temperature, along with relatively long-lasting heat waves, have negatively affected the growth and development of coffee [5]. Prolonged droughts, especially during flowering and fructifying seasons, not only reduce the productivity of coffee but also increase farmers' production costs and lower-income [6]. The ongoing systemic shocks due to synchronous climate hazards are predicted to impact coffee production negatively [7], highlighting an urgent need for sustainable coffee production in the context of climate change.

Climate change is driving innovative adaptation ideas to mitigate the adverse impacts on productivity, yield, taste, aroma, and the size of coffee beans [8]. The concept of climate-smart agriculture (CSA) emerged in the context of increasing arguments around definitions and approaches to sustainable agriculture and food security. In 2009, the Food and Agriculture Organization (FAO) initiated the concept of CSA and then officially presented this new concept in 2010 at the Hague Conference on Agriculture, Food Security and Climate Change [9]. According to FAO [9], CSA is a holistic approach to agricultural production that "achieving triple wins of increasing productivity and incomes, adapting to climate change, and reducing greenhouse gas emissions". Various CSA practices have been adopted worldwide to enhance agricultural productivity and to respond to climate change [10, 11].

Climate change hinders the agricultural sector in Vietnam, which accounts for 18% of the GDP [12], and the government emphasizes strengthening this sector. However, in addition to climate change, the agricultural sector faces challenges such as inefficiency and high risk due to small-scale farming. Therefore, various policies have been issued in Vietnam toward sustainable agriculture in the context of climate change [13-15]. For sustainable agriculture, water management, intercropping, land management, and waste treatment should be addressed [12]. Although these practices should be adopted soon, the agricultural sector in Vietnam has faced numerous challenges, including coffee production.

Vietnam is considered the largest Robusta coffee-producing country globally, contributing 17% of global coffee production [16]. The total coffee production area in Vietnam is more than 700,000 ha, of which 95% is Robusta coffee, primarily grown in five provinces of the Central Highlands (Lam Dong, Dak Lak, Gia Lai, Dak Nong, and Kon Tum). Being one of the countries most affected by climate change, the Vietnamese government has been implementing CSA programs [17], of which coffee farmers are encouraged to adopt best agricultural practices such as soil cover (mulching), intercropping, shading trees, agroforestry, and integrated plant health management. Using mulching (sometimes with soil covered by weeds), farmers can reduce pesticides, and water can be maintained in the soil. Therefore, this measure is also connected to integrated plant health management [18]. Intercropping is planting cash crops such as avocados and durian between coffee trees. It can be shading trees if the tree's height grows higher than the coffee. Besides, planting other crops can help avoid monoculture, maintain a higher biodiversity of microbes in the soil [19], reduce the risk of climate impacts, and provide farmers with multiple income sources [20]. This practice is also considered part of agroforestry. Therefore, intercropping and soil cover can be representative ways for CSA. A better understanding of changes and the benefits of CSA will mitigate the negative impacts of climate change on the coffee industry and promote sustainable coffee production.

However, the effectiveness of CSA practices in coffee production has not been assessed at the household scale.

A variety of research on CSA practices has been conducted, including analysis to clarify the high-priority agricultural technologies [21], development of the integrated tool from the survey to farmers and stakeholders, climate calendar, and data analysis [22], development of consolidated information systems using climate data [23], econometric analysis [24, 25], and indicator-based analysis [26, 27]. Indicator-based analysis is an approach consisting of several categories and components and evaluates the comprehensive conditions of farmers (e.g., economic situation, water accessibility, and crop yield). It can also provide farmers' current challenges and valuable solutions to policymakers by conducting interviews with farmers. However, research on CSA among coffee farmers has a short history [28], and there is no research on CSA effectiveness using an indicator-based approach across coffee cultivation practices in Vietnam. According to Poucet et al., [20], more research is required in this field at the country- and local levels.

The objectives of this study were to assess the effectiveness of CSA practices in coffee production at Dlie Ya commune, Krong Nang district, Dak Lak province and to propose proper solutions for improving the effectiveness of CSA practices in the study area.

2. Materials and Methods

2.1. Indicator-based Assessment Method

In the present study, the indicator-based assessment method is used to quantify the various aspects of the CSA practices. Common indicator frameworks include causal chain, theme-based, capital-based, system dynamics, mixed approaches, and composite indicators, of which theme-based framework is widely used for multi-dimensional assessment [29, 30]. In the current study, a theme-based framework consisting of 5 components (i.e., beneficiaries and yield (B), enabling environment (E), natural resources (N), emission (EM), and benefits and welfare (BW)) [27] was used for effectiveness assessment of CSA practices at the household scale (Table 1). 23 indicators were developed based on their suitability, availability, and accessibility [29, 30]. These indicators were selected based on Bellagio principles [29] and previous related studies [26, 27, 31]. The references used for the indicator selection are listed in Table 1.

Table 1. Indicators for effectiveness assessment of climate-smart agriculture practices in coffee production

Component	Indicator	Code	Description	Calculation equation	References
Beneficiaries and yield (B)	Adoption rate	B1	Adopting CSA practices in coffee farms or not.	(1)	[27, 31]
	Coffee yield	B2	Average coffee yield per hectare.	(1)	[31, 32]
	Yield variability	B3	The trend of coffee yield of coffee in the last 3 years.	(1)	[25, 31]
Enabling environment (E)	Training on climate-smart agriculture (CSA)	E1	Number of trainings on CSA provided and participated in the last 3 years Diversity of training organizations.	(1)	[19, 25]
	Information Communication Technology (ICT) services	E2	Types of ITC used in survey area Percentage of households obtain information on weather and climate, CSA practices, and market (price) through ICT services.	(1)	[19, 31]

Component	Indicator	Code	Description	Calculation equation	References
	Ownership	E3	Households own land titles for their production area.	(1)	[31, 32]
Natural resources (N)	Water source	N1	Types of water sources used.	(1)	[27, 34]
	Accessibility to water	N2	Access of farmers to water (e.g., surface water, groundwater) for coffee production and domestic usage Distance from coffee farm to nearest water source.	(1)	[27, 31]
	Availability of water	N3	Change in availability of all types of water in the last 10 years.	(1)	[33]
	Irrigation system	N4	Using efficient irrigation systems (i.e., dripping or small sprinkler).	(1)	[27, 32]
	Irrigation frequency	N5	Number of times per year irrigating coffee trees.	(1)	[31, 33]
	Soil cover	N6	Number of households applying practices of adding mulching and/or weed to cope with drought.	(1)	[31, 34]
	Fertilizer management	N7	Amount of each type of fertilizer used for a crop year (organic/chemical fertilizers/compost).	(2)	[25, 31]
	Farm diversification	N8	Coffee farm intercropping with other crops, including either cash crops, perennial crops, or both.	(1)	[25, 31]
	Pest and disease management	N9	Integrated pest management/ pesticide usage for pest and disease prevention and control.	(1)	[27, 31]
	Crop and genetic diversity	N10	Adopting drought-resistant varieties.	(1)	[27, 31]
	Climate buffer and adjustment	N11	Change in time or method of coffee production to adapt to climate change.	(1)	[31, 34]
	Extreme climate event	N12	Change in popular extreme climate events.	(2)	
Emission (EM)	Greenhouse gas (GHG) emission intensity	EM1	GHG emission in coffee production crops	(2)	[35]
Benefits and welfare (BW)	Income	BW1	Income from coffee.	(1)	[31, 32]
	Agro-inputs expenses	BW2	Expenses and investment in coffee farm in a crop year (i.e., energy, pesticides, fertilizers, machine, and seedling).	(2)	[31, 36]
	Labor costs	BW3	Total expenses for hired labors in a crop year.	(2)	[31, 36]
	Profit	BW4	Economic profit from coffee production and intercropping crops in the last 3 crop years.	(1)	[31, 37]

2.2. Social Survey

A social survey was conducted in January-March 2024 in the studied commune via semi-structured interviews with coffee farmers. Dlie Ya commune, Krong Nang district, Dak Lak province was selected given its typical characteristics of lowland Central Highlands, impacts of climate change (e.g., rainfall patterns, heatwaves, and water shortages), the proportion of coffee-producing households (one-third), and CSA practices. In addition, the commune has approximately 2,500 hectares of coffee at mature ages. Coffee is recognized as an important crop that generates income for farmers in the studied commune.

107 households were randomly selected for interviews, ensuring a 95% confidence level and a 10% margin of error. Only farmers living in the Krong Nang district and having a coffee farm(s) in the commune were interviewed. Farmers were asked to provide information about their actual production situation, such as productivity, production area, expenses, and profits. They were also invited to provide some data on changes in climate and extreme climate events, based on which reasons for changes were identified in the timing of harvesting time (if any).

Minimal responses were removed from the data obtained. After data cleaning, 14 responses were removed from the final results [18]. As a result, data from 93 households were used for analysis.

2.3. Data Analysis

Since the units and assessment scales of the indicators are different, they need to be normalized to compare variables within the same range. Coded data were normalized using the min-max method based on the OECD guidelines [30]. Equations (1) and (2) were respectively used for the normalization of data that were positively and negatively correlated with the effectiveness of CSA practices [30]:

$$Indicator_{S_d} = \frac{S_d - S_{min}}{S_{max} - S_{min}} \qquad (1)$$

$$Indicator_{S_d} = \frac{S_{max} - S_d}{S_{max} - S_{min}} \qquad (2)$$

where, S is the value of each indicator for household *d*, and max and min are the maximum and minimum values of each indicator.

After normalization, data were in the range of 0-1, in which 0 reflects the lowest effectiveness and 1 demonstrates the highest effectiveness [30]. After calculating the index, the main components and effectiveness of CSA practices were calculated as average.

SPSS 20.0 was used to identify the correlation between groups of indicators and differences in the effectiveness of CSA practices (intercropping and soil cover).

3. Results and Discussion

3.1. Effectiveness of CSA Practices in Coffee Production

3.1.1. Beneficiaries and Yield (B)

Adoption rate (B1): Of the farms surveyed, 44.1% were practising one CSA, and 38.7% were practising two or more. In total, 82.8% of surveyed farmers were practising at least one CSA. Additionally, 71.0% of surveyed farmers adopted the intercropping practice, and 50.5% of them addressed the soil cover practice.

Coffee yield (B2): The result of this study showed that the average coffee area was 1.5 ha/household (0.5-7.3 ha/household; Figure 1). The average coffee yield was 3.14 tons/ha of coffee bean, which was higher than the average Robusta coffee bean yield (2.2 tons/ha) [39] or a range of 1.4-2.8 tons/ha [39] in the Central Highlands. The average yield of intercropping farms was 3.01 tons/ha, slightly lower than that of no intercropping farms (3.45 tons/ha).

Yield variability (B3): The social survey demonstrated that most coffee farms had stable yields in the last three crop years, accounting for 92.5% of the total respondents. The percentage of intercropping farms having stable yields (95.5%) was higher than that of no intercropping farms (85.2%). Approximately 89.4% of farms with soil cover had stable yields, which was lower than those without soil cover (95.7%).

3.1.2. Enabling Environment (E)

Training on CSA (E1): Farmers rarely joined in technical training on coffee production either organized by the local government, extension system or by the private sector, such as fertilizer suppliers and coffee traders. The results of the 93 answers showed that 62 farmers did not participate in any training course, only 15 farmers joined one training/year, eight farmers joined two training courses/year, and five farmers joined three training courses/year.

Information Communication Technology (ICT) services (E2): This indicator measures farmers' accessibility to information on market price, weather, and extreme climate events through information-communication technologies. All farmers could update information via ICT such as Zalo, Facebook, websites, television, and mass media. Most farmers updated information frequently, but only a small number of farmers updated information via ICT.

Ownership (E3): Owning tenure rights may encourage long-term investment in coffee farms, which might positively impact three triple wins of CSA [12]. The survey results demonstrated that 100% of respondents had farmland titles.

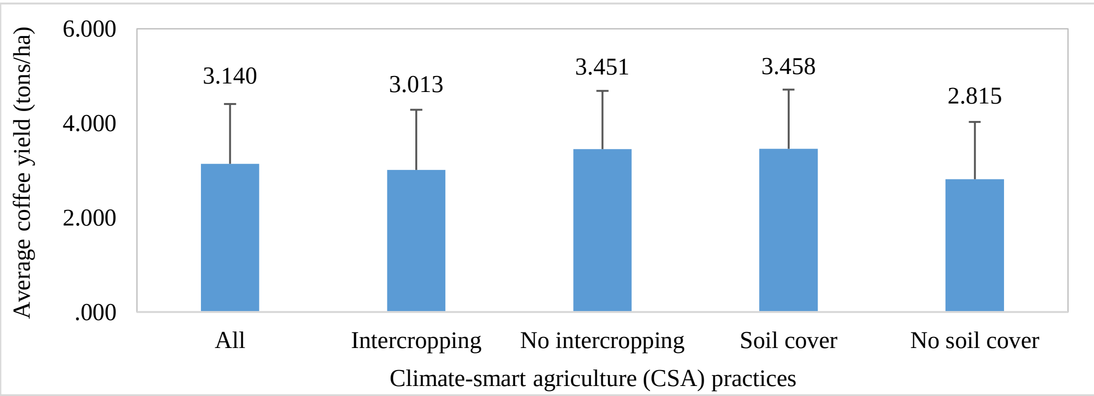

Figure 1. Average coffee yield (tons/ha) in the crop year 2023-2024.

3.1.3. Natural Resources (N)

Water source (N1): The survey results showed that farms in the commune depend on freshwater (e.g., pond and lake) and groundwater to irrigate coffee farms. Approximately 46.2% of respondents used 1 water source, and 53.8% of farmers used both freshwater and groundwater sources.

Accessibility to water (N2): 48.5% of intercropping farms have a distance from coffee farms to the nearest natural freshwater source of less than 500 m, double that of no intercropping farms (22.2%). The percentage of intercropping farms 500m-1km far from coffee farms to the nearest natural freshwater source was 18.2%, lower than that of no intercropping farms (40.7%). The percentages of soil cover and no soil cover farms less than 500 m from the nearest freshwater resource were 48.5% and 32.6%, respectively.

Availability of water (N3): The Central Highlands of Vietnam has been facing water depletion for many years due to climate change, a decrease in the water storage capacity of the soil, overuse of water in agriculture activities, and land use change [40]. The situation is reflected in survey results, which show that 91.4% of respondents recognized a reduction in freshwater levels. In addition, 100% of respondents shared that they witnessed a significant reduction in groundwater, causing many challenges for them in irrigation, particularly during blooming flower time.

Irrigation frequency (N4): Most coffee farms in the study applied a flooded irrigation method, the most conventional method; only 6.5% of coffee farms used a micro-sprinkler irrigation system, and no farm used drip and spray irrigation systems.

Soil cover (N5): Soil cover refers to soil covered by crops, weeds, or mulch; any type of inorganic soil cover is not taken into account in the scope of this research. This layer helps to reduce water evaporation, improve soil fertility, and reduce soil erosion. Of 93 respondents, 49% applied soil cover, and 59.5% did not in their coffee farms.

Fertilizer management (N6): The survey result indicates that most coffee farms in the commune needed to follow the recommendations on the amount of fertilizers used for coffee farms. To be more specific, 69.7% of intercropping farms and 74.1% of no intercropping farms did not follow recommendations. Meanwhile, only 30.3% of intercropping farms follow recommendations, slightly higher than that of no intercropping farms. In addition, 25.5% of farms with soil cover followed the recommendations, which was lower than farms without soil cover practice (32.6%). This fact may result in the overuse of chemicals for coffee production, relatively low-cost efficiency, and environmental issues [41].

Farm diversification (N7): Coffee farmers in the study commune intercropped coffee with other crops on a farm (e.g., durian, macadamia, avocado, and fruit trees). Each farm grew different crops. The survey results demonstrated that 29.0% of respondents did not intercrop coffee with other crops; the percentages of coffee farms intercropped 1, 2, and ≥3 crops were 19.4%, 14.0%, and 37.6%, respectively. The most common intercropped crops in the study area are durian, pepper, avocado, and macadamia. This result reflects Vietnam's transition from monoculture to mixed cropping systems [42].

Pest and disease management (N8): The most common pests and diseases in coffee trees were berry borer, leaf rust, leaf spot, and nematodes. According to the survey result, in the last 12 months, 68.8% of farms were affected by pests and disease.

Crop and genetic diversity (N9): Many coffee trees in the study commune were planted in the 1990s or early 2000s. Thus, the farmers could not remember the names of coffee varieties grown on their farms. However, they could not remember whether the coffee trees in their coffee farms were drought-resistant. Approximately 15.1% of farmers shared that they planted drought-resistant coffee varieties, and 84.9% shared that they planted conventional varieties.

Climate buffer and adjustment (N10): Interviewed farmers shared that in the past, coffee trees were blooming the first round right after the Tet holiday, but recently, some trees bloomed in December or January, and some trees bloomed in October when fresh cherries were not harvested yet. Approximately 87.1% of respondents recognized changes in flowering time, and 88.2% responded that they must harvest fresh cherries earlier.

Extreme climate event (N11): In this study, six extreme climate events (e.g., hoar, heat wave, extremely cold, landslide due to heavy rain, drought, and unusual rain) were investigated for their impacts on coffee production. Out of which, heat waves, drought, and unusual rain substantially impacted coffee production. To be more specific, 96.8% of farmers faced negative impacts of unusual rain followed by heat waves and drought, at 92.5% and 74.2%, respectively. This result is in agreement with previous studies [34, 36, 43]. Byrareddy et al., [31] recorded a 6.5-22% decrease in gross margins in drought years. In the growing season, an increase of 1 °C above 24.1 °C might result in yield declines of ~14% [43]. Dinh et al., [39] found an abnormal variation of coffee yield of ~36% due to weather impact. In addition, 21.5% of farmers faced severe impacts due to drought as they did not have enough water or had to pay more energy to drill and pump water to irrigate coffee trees.

3.1.4. Emissions (EM)

GHG emissions from coffee production were calculated based on USAID, 2021 [35]. USAID

[35] estimated that GHG from coffee production in Krong Nang district was 1.56±0.18 kg CO_2e/kg green beans. Because the study commune is located in Krong Nang district, this value was used to calculate GHG emissions from coffee production. The total GHG emissions were calculated based on the total production area of coffee farms. As a result, the average amount of GHG emissions in the survey sample was 6,778 kg CO_2e/year. The average amount of GHG emissions in intercropping farms was 6,500 kg CO_2e/year, which was comparably lower than that of no intercropping farms (7,459 kg CO_2e/year). Each year, farms with soil cover emitted an average of 6,519 kg CO_2, which was lower than farms without soil cover (7,044 kg CO_2e/year) (Figure 2).

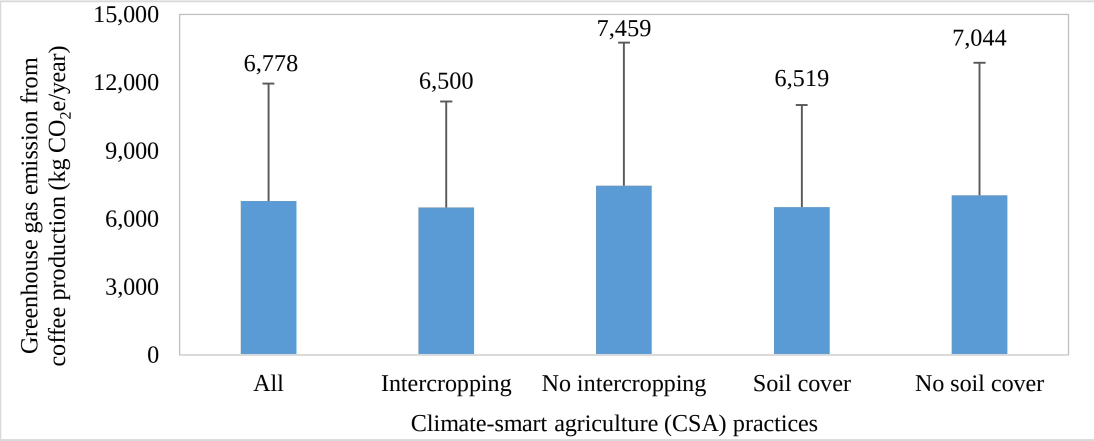

Figure 2. Yearly carbon emissions from coffee farms in the study commune (kg CO_2/year).

3.1.5. Benefits and Welfare (BW)

Income from coffee (BW1): Robusta coffee bean prices slightly increased globally from 2.29 USD/kg to 2.6 USD/kg during 2022-2023 [44]. Nevertheless, in Vietnam, it has rocketed over the past 1 year from approximately 32,000 VND/kg (~1.3 USD/kg) to 75,000 VND/kg (~3.01 USD/kg) for green beans and even posted new historical records at 93,162 VND/kg in March 2024 (~3.70 USD/kg) [45] and at 128,000 VND/kg in late April 2024 (~5.08 USD/kg). During the survey, many farmers still stored coffee, expecting a continuous increase in coffee prices. Therefore, in this study, the price of coffee beans in January 2024, when the survey was conducted (70,000 VND/kg of green bean coffee), was used to calculate coffee income. The results showed that the average coffee production generated 304,161,290 VND/household/year. Income from intercropping farms (291,666,667 VND/household/year) was lower than no intercropping farms (334,703,704 VND/household/year) (Figure 3). Lower income in the former than in the latter was due to the income calculation from coffee production without additional income from other crops in the intercropping farms. This is supported by Clément et al., [42] that intercropping in the Central Highlands showed higher gross margins than monoculture coffee production. In another study in Indonesia, Robusta coffee was intercropped with perennial plants such as avocado, pepper, and dog fruit to increase income [35]. In addition, in the current study, farmers probably did not follow intercropping recommendations, such as too crowded tree density in a production area leading to lower productivity [46] and, thus, lower income from coffee. The farms with soil cover had an average income from coffee of 292,510,638 VND/household/year. Meanwhile, coffee production in no soil cover farms generated 316,065,217 VND/household/year (Figure 3).

Agro-input expenses (BW2): Agro-input expenses include the total costs each household incurs in a year for fertilizers, energy for irrigation, cutting weeds, and pesticides. This excluded investments in machines, seedlings, and land. Farmers invested 86,679,269 VND/household/year for the above costs with the variation of expenses in each CSA practice (Figure 5). The intercropping farms group invested 84,194,697 VND/household/year, which was lower than no intercropping farms (92,752,668 VND/household/year) (Figure 5). Particularly, agro-input expenses of farms with soil cover were significantly lower than those of farms without soil cover, at 72,103,936 and 101,571,457 VND/household/year, respectively (Figure 4).

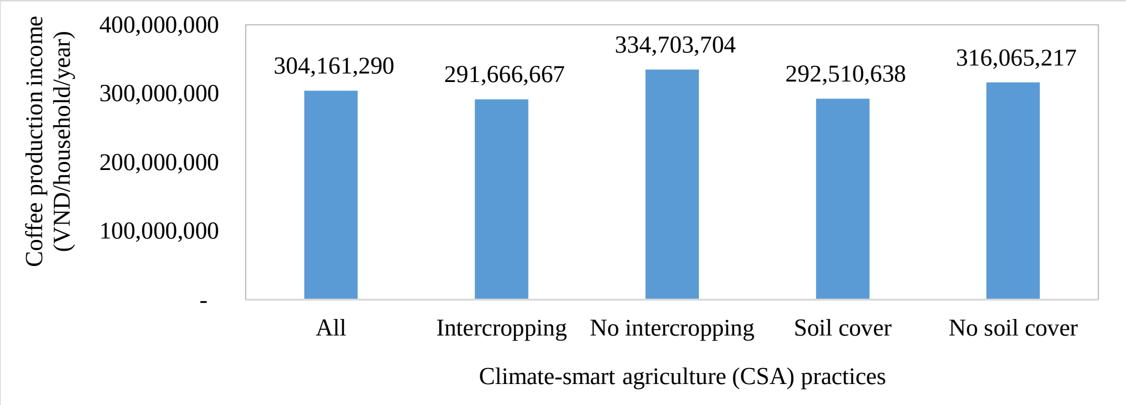

Figure 3. Average total income from coffee production (VND/household/year) (calculation based on unit price in January 2024: 70,000 VND/kg of green bean coffee).

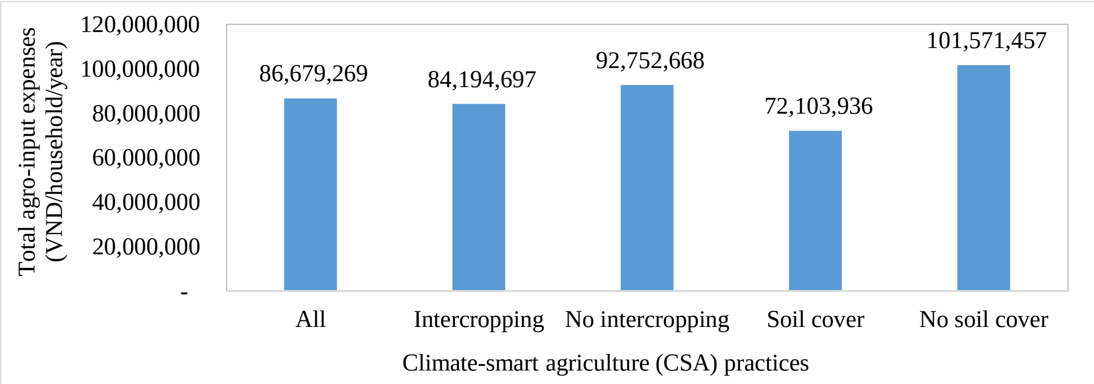

Figure 4. Total agro-inputs expenses for coffee production in a crop year (VND/household/year).

Labor cost (BW3): Another main production cost in coffee production is for hiring labors. Coffee farmers tend to hire seasonal labor for irrigation, pesticide spraying, and, particularly, harvesting fresh cherries. The interview results showed a range of 300,000-500,000 VND/labor/day, depending on workload and capacity. Each year each household paid 52,153,839 VND for hired labor costs. Intercropping and no intercropping farms paid 50,727,273 and 55,644,444 VND/household/year for hired labor costs. Particularly, farms with soil cover only paid 41,500,000 VND/household/year for hiring labor, which was dramatically lower than farms without soil cover (63,041,304 VND/household/year). By covering the soil, farmers can reduce the usage of pesticides because it can be a weed control and able to reduce the cost of these chemicals.

Profit (BW4): This indicator was calculated by subtracting total income from coffee for agro-input expenses and hired labor cost, then dividing the result by the actual production area. The profit per ha was counted based on the unit price of 70,000 VND/kg of green bean coffee. The survey results indicate that, on average, the net profit from coffee was 160,356,350 VND/ha/year (Figure 5). Net profit from the coffee of intercropping farms (151,116,729 VND/ha/year) was lower than that of no intercropping farms (182,942,090 VND/ha/year) due to no calculation of income from other crops in intercropping farms. The net profit of farms with soil cover (180,178,065 VND/ha/year) was sharply higher than that of farms without soil cover (140,103,728 VND/ha/year) (Figure 5). In addition, 51.5% of intercropping farms witnessed an increasing trend in profit from coffee over the last 3 years, 74.1% no intercropping farms had the same situation, 53.2% of farms with soil cover, and 63.0% of farms without soil cover had better profit from coffee. Only a small percentage of coffee farms reported that profit from coffee decreased.

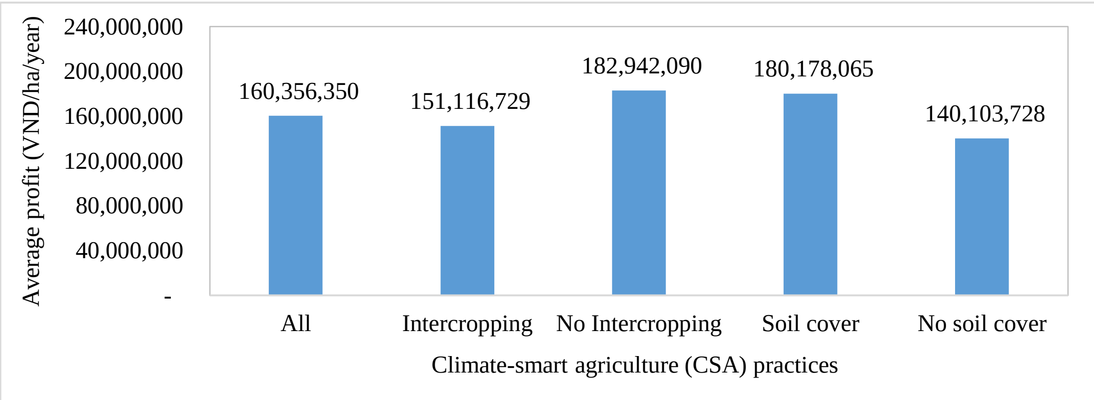

Figure 5. Average profit from coffee production (VND/ha/year) (calculation based on the unit price in January 2024: 70,000 VND/kg of green bean coffee).

3.1.6. Comparison of the Effectiveness of CSA Practices in Coffee Production

The average effectiveness values of beneficiaries and yield (B), enabling environment (E), natural resources (N), emissions (EM), benefit and welfare (BW) of all interviewed households were 0.61, 0.78, 0.40, 0.82, and 0.60 with the average score of 0.64 on the score of 0-1. The five components (B, E, N, EM, and BW) were correlated with CSA (r = 0.25-0.48, $p < 0.001$), indicating the contribution of these components to total CSA effectiveness.

Intercropping and no intercropping: Intercropping farms showed higher effectiveness in beneficiaries and yield (B = 0.65), natural resources (N = 0.42), and emission (EM = 0.82) than the no intercropping (B = 0.49, N = 0.35, and EM = 0.79) (Figure 6). The effectiveness of intercropping in coffee production was significantly higher than that of no intercropping practice ($p < 0.001$). However, the interview results showed that many farmers did not know about intercropping guidelines; they grew coffee trees and other crops on their farms by experience. In many cases, they grew many trees in a production area, leading to lower coffee productivity and, thus, lower income. Furthermore, the possibility of cross-contamination of hazardous chemicals due to farmers' tendency to use pesticides rather than natural enemies has not been assessed. Therefore, if they sprayed pesticides on intercropping trees, coffee trees might also be affected by the pesticides. These issues should be considered and addressed to reduce additional pollution risks in coffee production.

Soil cover and no soil cover: coffee farms with soil cover demonstrated higher effectiveness in beneficiaries and yield (B = 0.73), natural resources (N = 0.45), and benefits and welfare (BW = 0.62) than the no soil cover (B = 0.48, N = 0.35, and BW = 0.59) (Figure 7). Soil cover CSA practice showed significantly higher effectiveness in coffee production than no soil cover ($p < 0.001$). The result of this study implied that soil cover probably promoted CSA, particularly in beneficiaries and yield, natural resources, and benefits and welfare. Regarding emissions, the practice of soil cover was likely to reduce carbon emissions better than no soil cover. The resulting survey indicates that although soil cover had a good implication in coffee production, this practice has not been widespread because it requires more time and proper soil cover layer management. For many years, farmers have preferred using herbicides to control weeds because they believed weeds had no good impact on coffee production. Therefore, farmers should be trained continuously on the advantages of soil cover and encouraged to adopt this practice.

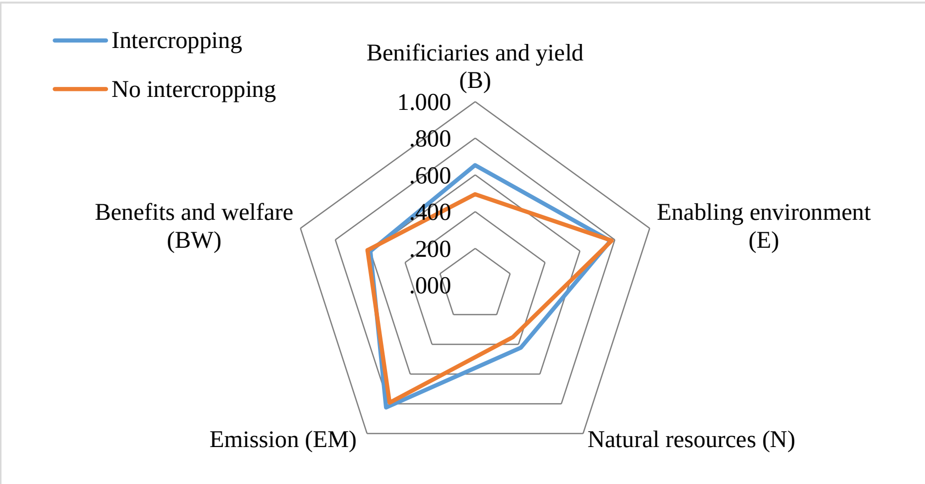

Figure 6. Comparison of the effectiveness of intercropping and no intercropping practice. The assessment scale ranges from 0-1, in which 0 reflects the lowest effectiveness and 1 demonstrates the highest effectiveness.

Consolidated interpretation of CSA: In the present study, the effectiveness of two representative CSA measures on coffee farmers in a commune in Kak Lak province was investigated, and intercropping and soil cover can increase the productivity of coffee and reduce GHS emissions (Figures 6 and 7). These results were consistent with that of Thornton et al., [21], who investigated the effect of CSA on agriculture, including crops. Despite many advantages, CSA practices in general and two selected practices of intercropping and soil cover in this study possess some disadvantages. Maintaining adequate soil cover requires more time and labor to manage and effectively mow weeds and mulch. Meanwhile, for better management of intercropping farms, it is important to identify suitable intercropping crops that will not only compete with nutrients and water for coffee but also provide additional benefits to farmers [47]. Otherwise, the intercropping crops will replace coffee and become the primary crop or will cause a decrease in coffee yield due to their negative impacts on soil health and nutrients [48]. Farms start intercropping coffee with other crops; nevertheless, in order to fully follow guidelines in intercropping, they should develop multi-layer farms with four layers of forest trees, shading trees (e.g., avocado, macadamia, and durian), coffee, and soil cover. The density of trees in one production area should also be considered thoroughly [49]. Doing that will improve soil health, reduce GHG emissions, increase carbon sequestration capacity, and secure farmer income.

Because the current study is based on one-time data only, there might be varieties affecting results, such as coffee price, durian price, and production costs. Therefore, annual or bi-annual surveys should be conducted to develop time series data for better assessment of the effectiveness of CSA practices. Despite these challenges, there have been only a few reports on the practice of coffee production CSA in Vietnam. While there have been reports on the potential introduction of IoT systems [47] and examples of practice in limited areas [48], the present study is the first to demonstrate the outcomes of CSA practices quantitatively. Also, financial problems could be one of the reasons hindering the introduction of CSA in Vietnam [8]; focusing on ethnic minorities and language barriers is also rare. Therefore, the present study provides valuable results.

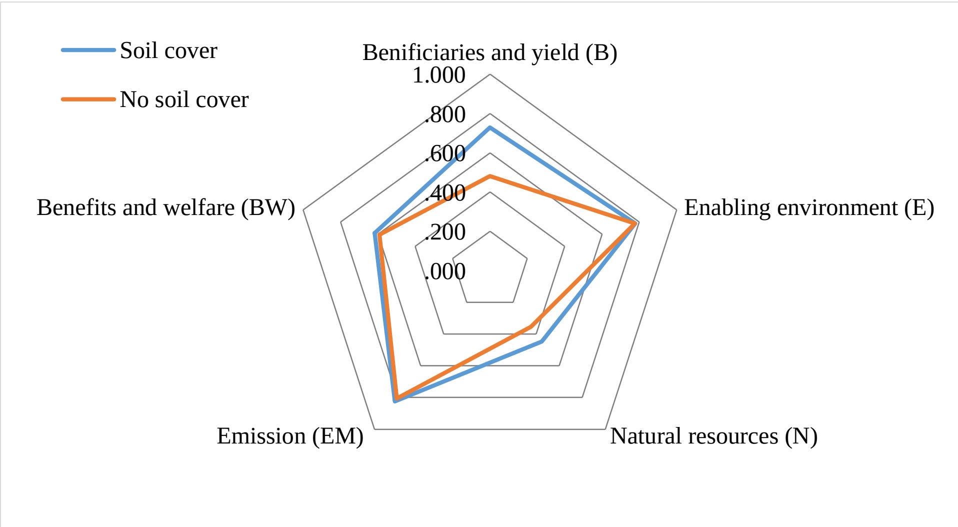

Figure 7. Comparison of effectiveness between soil cover and no soil cover. The assessment scale ranges from 0-1, in which 0 reflects the lowest effectiveness and 1 demonstrates the highest effectiveness.

3.2. Solutions for Effective Implementation of CSA Practices in Coffee Production

The present study showed several challenges for coffee farmers: the need for recognition of CSA, insufficient introduction of CSA technique, management of water, and overuse of chemical fertilizers and pesticides. Plausible solutions are listed below:

Lack of recognition of CSA: Many farmers do not fully understand CSA practices. Local governments should have training for coffee farmers and explain the benefits of CSA. This case was also reported in Ethiopia, where the farmers who introduced intercropping and appropriate soil and water management were 45% on average and 44-49% depending on each region, respectively [24]. Appropriate knowledge should be disseminated not only in Vietnam but also in other coffee-producing countries.

Insufficient introduction of the CSA technique: The number of farmers who have adopted the CSA technique is still low. This lack of adoption and insufficient knowledge could reduce its effectiveness. In order to disseminate the appropriate CSA technique, local government should have actual fields, let farmers understand visually, and boost the introduction of CSA techniques.

Management of water: Dzvene et al., [50] indicated that covering the soil with crops (called living mulch) helps retain rainfall in the soil and enhances water penetration. Additionally, this phenomenon can be boosted by microbes in the soil. Since Central Highland in Vietnam is facing the challenges of lack of water due to climate change [40], this should be implemented appropriately for coffee farmers.

Overuse of chemical fertilizers and pesticides: Integrated Pest Management (IPM) and Integrated Plant Health Management (IPHM) are the important guidelines for weed, pest, and disease management. Farmers are encouraged to apply the practices in these guidelines to reduce the excess usage of hazardous chemicals. It is also connected to increasing farmers' profits and conserving biodiversity. Moreover, by reducing the usage of these chemicals, GHG emissions could be reduced because these hazardous chemicals emit lots of GHGs through the production process [51].

4. Conclusions

The effectiveness of the two most popular CSA practices in a commune in Dak Lak province (intercropping and soil cover-mulching) was quantitatively assessed using an indicator-based method (0-1 scale). Intercropping farms showed higher effectiveness in beneficiaries and yield, natural resources, and emission than no intercropping. Coffee farms with soil cover demonstrated higher effectiveness in beneficiaries and yield, natural resources, and benefits and welfare than those with no soil cover. The effectiveness values of intercropping (0.66) and soil cover (0.68) were significantly higher than those of no intercropping (0.61) and no soil cover (0.60). Since the income of intercropping crops (e.g., durian and avocado) was not included in the present study, further research is needed to clarify the total benefit of this technique. The present study showed that CSA can boost the productivity of coffee and reduce GHG emissions; meanwhile, farmers were not aware of the benefits of CSA and have not been introduced to the appropriate measures. Therefore, local government should provide sufficient training and guidance to farmers and promote the appropriate introduction of CSA in the future.

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