Climate-smart agriculture implementation facing climate variability and uncertainty in the coffee farming system

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Abstract. Climate risk in agriculture indicates the potential of climate-related hazards to impact coffee production and quality negatively. Coffee production has decreased due to changes in temperature, more extended droughts, and increased pests’ invasion. Coffee agribusiness is demanded to respond to the increasing need for Climate-Smart Agriculture (CSA). As a CSA model, coffee cattle integration offers farmers risk management strategies and options to adapt to climate change. However, the effectiveness of its implementation is still low due to technical and institutional constraints. The study’s objectives are to analyze constraints to implement coffee cattle integration as a CSA model and formulate strategies to implement it. The analysis method used Interpretive Structural Modelling. CSA implementation constraints include input, labor, knowledge, technology, capital, and farmer institutions in crop and livestock production. Strategies for implementing coffee cattle integration, as CSA practice, is carried out in a hierarchical stage. It starts with developing a support system to improve agricultural support policies, promote public-private partnerships, and support community assistance and facilitation center, followed by the increasing availability of capital through credit farm.

1. Introduction

Coffee is an agricultural commodity that contributes significantly to the global economy. Global coffee consumption tends to increase. Over the last five years, an average annual growth rate of global coffee consumption was 2.7%. Coffee consumption in the South and East Asian markets has grown higher than other regions, wherein the last 25 years, it has increased by 6% while other areas have only 2% [1]. The world coffee consumption is influenced by consumers’ attributes such as naturalness, sustainability, health, nutrition, and multisensory experiences [2].

Coffee crops require specific temperature, light, and humidity levels. Drought and inappropriate temperature determine the level of quantity and quality of coffee production [3]. On the other hand, climate change is a serious threat affecting the agricultural sector and people’s lives. Changes in weather in the form of higher temperatures, changing rainfall patterns, rising sea levels, and more frequent extreme weather events can pose risks to agricultural activities [4]. During the 21st century, if greenhouse emissions are not prevented from increasing, it can be predicted that the global average temperature will continue to rise [5].

Coffee agribusiness is demanded to construct a competitive advantage to supply expanding global consumption through increasing productivity, implementing technology, using natural resources efficiently, and responding to the increasing need for climate-smart agriculture. Implementing climate mitigation and adaptation that is carried out incrementally and transformationally is expected to reduce
climate change risk [6]. Climate-Smart Agriculture (CSA) is defined as agricultural practices that can increase agricultural systems’ productivity and resilience in a sustainable manner [4]. This approach provides farmers with more strategies and options for managing risks to deal with climate change and disruption.

As a CSA model, coffee cattle integration provides more options for managing risks to adapt to climate change. However, its implementation in smallholder coffee plantations has not been running optimally. On the other hand, the dramatically increasing impact of climate change dramatically affects livelihoods, food security, and farmers’ welfare. The study’s objectives are to analyze constraints to implement coffee cattle integration as a CSA model and formulate strategies to implement it.

2. Research method
The study was carried out in Kertasari District (2019) and Pangalengan District (2020), Bandung Regency, a coffee production development. The unit of analysis of this research is coffee smallholder. Data were collected through field observations and in-depth interviews. The survey was conducted involving 26 respondents.

The analytical method used is Interpretive Structural Modeling (ISM), a methodology that can analyze the relationship between factors to obtain a more systematic description of the problem or an issue [7]. The steps in ISM are divided into (1) identifying the elements, (2) establishing a contextual relationship between elements by using scoring method V if $e_{ij} = 1$ and $e_{ji} = 0$; X if $e_{ij} = 1$ and $e_{ji} = 1$ A if $e_{ij} = 0$ and $e_{ji} = 1$; O if $e_{ij} = 0$ and $e_{ji} = 0$ [8], (3) developing a Structural Self-Interaction Matrix (SSIM), (4) compiling the affordability matrix from SSIM, (5) dividing into several levels of the affordability matrix, (6) converting the affordability matrix into a cone shape, (7) drawing a digraph based on the existing relationships in the affordability matrix and removing the transitive link, and (8) changing the resultant digraph becomes an ISM-based model, and (9) analyzes conceptual inconsistencies and makes necessary modifications [9].

3. Results and discussion
Global coffee production in 2018/2019 increased by 4.6% or reached 170.22 million bags, where Arabica and Robusta coffee production was 100.32 and 69.91 million bags, respectively. However, world coffee production in 2019/20 decreased by 1.6% to 168.55 million bags, where Arabica production declined by 5.1% to 95.73 million bags, and Robusta production increased by 3.2% to 72.82 million bags [10]. Coffee production in Asia and Oceania increased by 4.1% with a value of 50.07 million bags, while Africa tended to be stable, reaching 18.86 million bags. Coffee production in South America has decreased by 4.6%, with a value of 78.87 million bags. The same condition happened in Central America and Mexico, where there was a decline in production of 4.5% to 20.76 million bags. Estimated world coffee production for 2020/21 will increase by 9.1 million bags, higher than the previous year [11].

The development of Indonesian coffee production in 1980-2019 increased with an average growth rate of 2.5% per year. Coffee production based on the farming category is dominated by smallholder plantations, which production of 502.30 thousand tons or 94.6% of the total national production. Indonesian coffee production is dominated by Arabica coffee, where production in 2017 was 686.44 thousand tons or 95.6% of Indonesia’s total coffee production. South Sumatra Province is the province with the highest contribution to Robusta coffee production, followed by Lampung, Bengkulu. Arabica coffee production in 2017 amounted to 189.74 thousand tons or 26.4% of total national production, with the main production areas are Aceh and North Sumatra [12].

Since 1990, the contribution of Indonesian coffee production has tended to stagnate. In 1990/91, production reached 7,441 thousand bags or contributed 6.3%. However, in 2018/19, it amounted to 9,418 thousand bags or contributed 5.5%. The opposite happened to Vietnam. In 1990/91, the production was only 1,310 thousand bags or contributed 6.3%, then in 2018/19 it was 31,174 thousand bags or contributed 18.2%. The average growth contribution of Indonesia is 6.8%, while Vietnam is 11.3% per year.
In 2024, the global coffee market is estimated to reach 134.25 billion US$, with a 5.3% CAGR growth in the 2020-2024 period. Coffee consumption will grow over the next 30 years, leading to expanding plantations in both Arabica and Robusta’s production area. Several factors drive consumption, such as rapid urbanization, increased income, shifting consumer tastes, development of the e-commerce market, increased preferences for instant coffee, increased demand for specialty coffee, and increased green coffee consumption. However, climate change will significantly impact the coffee supply chain over the next forty years [13]. Without adequate management of climate change risks, coffee production is expected to decline due to changes in temperature, drought, and increased pest infestation.

3.1. Impacts of climate change on coffee crops

Coffee plant growth requires specific requirements to grow optimally, namely a cool to warm tropical climate, fertile soil, and few pests or diseases. Coffee producers spread along the equator with high climate suitability, such as North America, Central America, South America, the Caribbean, Africa, the Middle East, and Asia. The largest coffee producing country in the world is Brazil.

Climate changes that can affect coffee plantations’ performance include temperature increases, seasons changes, changes in rainfall, and extreme weather events such as droughts, heavy rains, or storms. Temperature and rainfall conditions are considered the main factors are determining potential coffee yields [14]. These factors interfere with plant phenotype and, consequently, affect the productivity and quality of the coffee. Apart from air temperature and rainfall, groundwater availability during various coffee plant growth stages also significantly affects coffee production [14]. Meanwhile, although they affect coffee trees’ physiological processes, solar radiation and relative humidity generally do not affect them substantially [15].

The proportion of Arabica coffee is 70% of world coffee production. In the flowering fruit-set and development, temperature changes will have a significant impact. The optimal temperature range for Arabica coffee is 18-21 °C, and it can still tolerate average annual temperatures of up to approximately 24 °C. Above that moderate temperature, fruit development and ripening accelerate. Faster ripening will significantly affect the quality of the coffee beans. Besides, continuous exposure to temperature can be very damaging to coffee plants, characterized by stunted growth, yellowing of leaves, and even spawning stem tumors.

Arabica and Robusta coffee’s productivity and quality are highly dependent on climate suitability, especially rainfall and air temperature. These caused the direct and indirect impacts resulting from climate change. Indirectly, climate change can also affect fertilizer absorption and pest attacks [16]. In terms of coffee quality, changes in temperature, relative humidity, and green coffee beans’ water content during transportation can impact coffee quality [17].

3.2. Model of climate-smart agriculture on coffee agribusiness

CSA is an approach that guides action to adapt and transform agricultural systems into forms or practices that are more appropriate to climate change to achieve sustainable farming systems and achieve food security. In its application, CSA will be related to economic, social, and environmental aspects. CSA will combine not only technical aspects but also institutional, policy, and investment aspects. CSA is a locally based agricultural practice that considers local elements, so it is not a universal approach.

Implementing CSA practices includes integrated water, soil, and ecosystems management at a landscape scale [7]. Cultivation techniques can act as a preventive or mitigation measure in facing climate variability or global warming in coffee crops [14]. CSA practice is related to elements (1) agricultural management for adaptation and mitigation, (2) ecosystem and landscape management to conserve ecosystems, (3) support services for farmers for climate risk management and mitigation, and (4) transformation in food systems [4].

One form of agricultural, crop, and livestock management for adaptation and mitigation is Integrated Crop Livestock System (ICLS). The integration of crops and livestock can occur through livestock grazing on plantations, plantation waste, planting grass on plantation land, and livestock rotation
systems [18]. At the macro level, implementation of ICLS is expected to reduce pollution and environmental damage and increase yields [19].

The coffee cattle integration is a CSA model that implements an ICLS as an agricultural management system. This system’s characteristic is that the outputs from one land use are used as inputs to other services. The practice of ICLS affects crop production by affecting soil properties and affect livestock performance by affecting nutrient availability, net recovery, and grazing provision. The application of integrated livestock coffee provides benefits such as increased coffee plant productivity, increased livestock weight, decreased fertilizer costs, reduced livestock management costs, increased soil fertility, and improved land structure to prevent land erosion [20]. The addition of nutrients from the compost and urine can increase coffee productivity significantly, where organic fertilizer can help plants prepare better conditions for produce [21].

3.3. Implementation of climate-smart agriculture on coffee plantation in Bandung Regency

Under the morphology of Bandung Regency, a mountainous or hilly area, coffee is one of the main plantations besides tea, tobacco, and cloves. In a regional scope, the development of coffee plantations aims to improve and restore ecosystem conditions around the upstream Citarum watershed, which have been degraded due to the application of farming systems that are not environmentally-oriented [20]. At the farmer level, the coffee plantation is expected to generate household income in a sustainable agriculture approach.

Bandung Regency is indicated to be vulnerable to El-Niño Southern Oscillation (ENSO) events, and if this happens, it can cause drought and flooding, which will ultimately affect crop production [22]. Farmers’ perception analysis on climate change occurrences showed that 46% of respondents noticed rising temperature, and only 19% of respondents noticed changing rainfall, but 80% of respondents noticed drought. Half the number of respondents detected extreme weather.

CSA is an approach that provides opportunities for improving agricultural systems under the effects of climate change. It is related to soil management, water management, cropping system, or integrated farming system. Issues about GAP, soil management, water management, and ecological objectives can be addressed well in ICLS. Data showed that around 80% of respondents are interested in Mix Crops System and 91.3% in ICLS.

CSA builds on existing efforts to achieve sustainable agriculture, such as the implementation of GAP. However, there are still several farmers who have not implemented the GAP (20.6%). Adoption of acceptable practices for pruning and integrated pest management was low. Around 84% of farmers know organic fertilizer, but most of them implemented in horticulture plants. Only 39.1% of farmers know organic pesticide and enforce in a low frequency.

| Aspect          | Crop production                           | Livestock production                        |
|-----------------|-------------------------------------------|---------------------------------------------|
| Input           | Non-availability of planting material      | Non-availability of improved breeds of livestock |
|                 | The high cost of inputs                   | Lack of green fodder                        |
| Knowledge       | Scarcity of farm labor                    | Scarcity of skilled labor                   |
|                 | Lack of knowledge about Organic Fertilizer | Lack of knowledge about livestock management |
|                 | Lack of knowledge about Organic Pesticide  | Lack of knowledge about complete feed        |
| Technology      | Limited access to technology              | The problem of infertility in cattle         |
| Capital         | Inadequate and or non-availability of farm credit | Inadequate and or non-availability of farm credit |
| Farmer Institution | Limited role of farmer group            | Limited role of farmer group                |

The evaluation showed that the implementation of livestock coffee integration is still limited. 55% of farmers who own sheep, with average ownership, are 2-3 cattle per household. On average, they have three years of ICLS experience. Livestock management is carried out individually with a cage built
around the house. The benefits of integration were not optimal. Manure was not used for organic fertilizer, and the coffee pulp was not used for animal feed. In ICLS, the farmers’ constraints have been categorized into two major categories, i.e., crop production constraints and livestock management constraints [11]. The implementation is affected by farmer constraints related to input, labor, knowledge, technology, capital, and farmer institutions in crop and livestock production (Table 1).

Non-availability of planting material, high cost of inputs, scarcity of farm labor, lack of knowledge about organic fertilizer and organic pesticide, limited access to technology are the constraints faced related to coffee production. From the cattle production, the constraints included non-availability of improved breeds of livestock, lack of green fodder, scarcity of skilled labor, lack of knowledge about livestock management and complete feed, the problem of infertility in cattle. Related to capital and farmers’ institutions, both faced inadequate and or non-availability of farm credit and farmer groups’ limited role.

3.4. Strategies to implement climate-smart agriculture model for coffee smallholder
CSA implementation’s readiness includes four significant types of action: developing the evidence base, supporting enabling policy frameworks, strengthening national and local institutions, and increasing financing options [4]. Based on the constraints faced, some strategies are formulated. It is related to technical and technology aspects: capital, technology, input production, and institutional aspects: knowledge transfer, organizational development (Table 2).

Table 2. Strategies to implement coffee cattle integration as a climate smart agriculture model

| Aspect                      | Strategies                                                                 |
|-----------------------------|-----------------------------------------------------------------------------|
| Capital                     | Increase in the availability of capital through credit farm (E1)             |
| Technology                  | Increase in the availability of technology (E2)                            |
|                             | Increase in the competitiveness of coffee agroindustry (E3)                |
| Input Production            | Increase in labor availability and productivity (E4)                       |
|                             | Improve the quality and availability of input supply (E5)                   |
|                             | Increase in the availability of planting materials (E6)                     |
|                             | Increase in the availability of breeds of livestock (E7)                    |
| Knowledge Transfer          | Implementing field school for farmers (E8)                                 |
|                             | Expanding extension activities beyond production to include market accessibility (E9) |
| Organizational Development  | Empowering farmer group (E10)                                              |
|                             | Empowering farmers as a rural entrepreneur (E11)                           |
|                             | Improvement of agricultural support policies (E12)                         |
|                             | Promote public-private partnership (E13)                                   |
|                             | Initiate a community assistance facilitation center (E14)                  |

![Figure 1. Matrix graph of strategies to implement coffee cattle integration](image-url)
The factors of E12, E13, E14, and E1 are independent factors, which have strong drive power but weak dependence power. These factors are the essential factor in accelerating coffee cattle integration as a CSA model with an extreme drive power. Improvement of agricultural support policies, promoting public-private partnerships, and initiating a community assistance facilitation center are the main strategies that will be a first step to build the support system for implementation of ICLS as a CSA model (Figure 2). Another strategy is increasing the availability of capital through credit farm.

Figure 2. Matrix hierarchy of strategies to implement coffee cattle integration

Agricultural policy is one of the instruments in agricultural development, which is expected to achieve self-sufficiency, income transfer between economic actors, food security, and competitiveness through competitive prices [23]. Agricultural support policies are expected to be related to local economic development. The policies formulated will encourage the development of a vertical and horizontal integration system of coffee livestock. The private sector is needed in product marketing. Purchasing contracts will be an incentive for farmers to increase production and product quality.

Developing a community assistance facilitation center is a way to provide assistance and facilitation services for farmers in both coffee production and cattle production. Technology is expected to be appropriately transferred and applied through the development of participatory knowledge management. Women contribute a significant role in the coffee farming system. About 80% of coffee farmworkers in North Sumatra, Indonesia, and about 50% in Lam Dong Vietnam, play a significant role in carrying out coffee cultivation, processing, and marketing activities. However, their involvement in training and development opportunities is still relatively low [24]. The community assistance facilitation center ideally will be constructed by involving women.

The coffee cattle integration implementation needs more capital working. However, the availability of credit farm is limited. Another issue, the coffee farmer’s purpose to take credit was not for coffee business production, but household consumption [25]. Business development is influenced by the availability of capital, which will affect the benefits achieved. Increasing access and provision of farm credit will optimize the effectiveness of integration system implementation related to the economies of scale and scope economies.
4. Conclusion
Coffee crops are susceptible to climate change. Coffee agribusiness is demanded to respond to the increasing need for Climate-Smart Agriculture (CSA). As a CSA model, coffee cattle integration offers farmers risk management strategies and options to adapt to climate change. Issues about GAP, soil management, water management, and ecological objectives can be addressed well in Integrated Crop Livestock Systems. Constraints in adopting coffee cattle integration as CSA practices are related to production input, labor, knowledge, technology, capital, and farmer institution. Strategies for implementing coffee cattle integration as a CSA practice is carried out in a hierarchical stage. It starts with developing a support system to improve agricultural support policies, promote public-private partnerships, and support community assistance and facilitation center, followed by the increasing availability of capital through credit farm.

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