Agricultural Innovation System Development to Support Environmental Management Implementation in Coffee Smallholder Plantation

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Abstract. Climate change significantly impacts coffee production and quality. On the other side, the coffee plantation is dominated by smallholder plantations with limited capabilities. Farmers have implemented Climate-Smart Agriculture by improving the cultivation system. However, the level of technology adoption at the farmer level is not optimal due to the capacity and resources of farmers and the technology dissemination support system. This study aims to analyze the environmental management implementation in coffee smallholder plantations and design an Agricultural Innovation System to accelerate its implementation. The study was carried out in the Robusta coffee development area in Rejang Lebong Regency, Bengkulu Province. The analysis was performed using descriptive statistics. Environmental management in coffee smallholder plantations is related to water management, soil management, and integrated pest diseases management. The application of CSA practices is limited to a few farmers. Smallholder plantations have limited resources, weak risk management, limited access to finance and technology. Farmer organizations, networks, and social capital management have not been developed optimally. Hence the Agricultural Innovation System for supporting environmental management implementation on coffee plantations becomes strategic. The system consists of research and education, agribusiness, bridging system, and innovation ecosystem as a supporting environment.

1. Introduction
Coffee in Indonesia, both Robusta (Coffea canephora) and Arabica (Coffea arabica L.), has an important role as an export commodity that generates foreign exchange and sources of farmers’ income generating. Arabica coffee is only 350 thousand hectares managed by 640 thousand farmers, while Robusta coffee reaches 860 thousand hectares managed by 1.2 million farmers [1]. Although it has been cultivated for hundreds of years, coffee productivity in Indonesia is still relatively below its optimum potential. The average national productivity is only around 800 kg/ha [2], while the production potential of high-yielding varieties that have been released reaches 1.8 tons/ha.

One of the issues in the development of coffee plantations is sustainability, related to the cultivation practices and resource management application. Coffee products that are certified as environmentally friendly are a concern in the global market. Agricultural products are not only measured by quality but also by method of production.

Environmental management is part of the sustainable coffee production system, which refers to sustainable agriculture. Improving coffee quality by carrying out sustainable and environmentally...
friendly cultivation practices is a strategic step to achieve sustainable coffee production [3]. The dimensions of sustainable coffee production include environmental, economic, and social dimensions. A sustainable coffee production system is built without reducing environmental quality (environmentally sustainable), providing economic benefits (economically profitable) and being accepted by the community (socially feasible) [4]. From the consumer side, sustainable coffee production is a demand that is stated in various international coffee trading and certification systems such as Fairtrade, Organic Coffee, UTZ, Common Code for Coffee Community (C4), and geographical indications [5] [6]. These systems promote the coffee production system that produces a high quality product and provide traceability to achieve sustainability.

Coffee plantations in Indonesia are dominated by smallholder plantations (96%) [3]. The implementation of sustainable coffee production through environmental management is faced with various obstacles related to the characteristics of smallholder coffee plantations [7]. Most coffee farmers have not entirely used seeds from superior varieties due to limited access to information or economic limitations. Some farmers who have used high-yielding variety seeds have understood GAP. However, others have not applied the principles of good cultivation accordingly [8].

The level of technology adoption at the farmer level is still low related to farmers’ limited capacity and resources. In addition, the technology dissemination support system has not been running well. Therefore, studying sustainable coffee production through environmental management and support systems that encourage technology adoption at the farmer level is necessary. This study aims to analyze environmental management implementation in coffee smallholder plantation and Agricultural Innovation System to promote its implementation.

2. Research Method
The research was conducted in 2020 in Rejang Lebong Regency, Bengkulu. Coffee is the main plantation commodity in Rejang Lebong Regency. Production of coffee beans produced by smallholder’s plantations in Rejang Lebong 2020 reached 18,604.69 tons [1]. Data was collected through a survey using a questionnaire. Data were obtained through interviews with 49 coffee farmer respondents, where the selection used purposive sampling. Data analysis was performed using descriptive statistics as a method related to collecting and presenting a group of data to provide useful information. Data processing is completed by using SPSS.

3. Result and Discussion

3.1 Environmental issues in the coffee farming system
The physical environment will be related to environmental management and sustainable production. Sustainable landscape management means land use by controlling inputs to sustain high productivity, improve land quality, and improve ecological characteristics. Thus, the negative impact on the environment can be reduced to a minimum or a tolerable limit.

The components of sustainable land management can be applied by implementing nutrient management, erosion control, residue management, crop management, and water management. Specifically, sustainable coffee management refers to the coffee GAP. Increased production is influenced by cultivation requirements, including plant aspects and environmental carrying capacity. The crop aspect is related to the genetic quality of the seeds planted. Environmental elements influence the climate in which plants grow (altitude, temperature, humidity, rainfall, wind) and cultivation management (fertilization, weeding, irrigation, drainage, pest control, pruning, plant shade), as well as harvest and post-harvest management.

In climate change conditions, El Nina or La Nina, farmers with limited access are challenging to manage their crops and decrease crop production [9]. Climate change can increase pest and diseases invention and disrupt flowering processes [10]. Sustainable environmental management is a cycle of planning, implementing, re-evaluating, and improving phase to improve the ecological performance in continuous improvement [11]. It is related to managing agricultural resources, including prevention, maintenance, and improvement. Sustainable environmental management can be applied by selecting the right technology for each agroecosystem based on its specific conditions. The driving factors for the
The sustainability of coffee farming can be analyzed from several factors: altitude, land slope, type of shade, superior varieties, plant age, use of fertilizers, pest and disease attacks, soil management, availability of clean water sources, replanting, making roarak, use of shade plants, weed control techniques, pruning, pest diseases management, and harvesting [12].

3.2 Environmental management application in coffee smallholder plantation

The average age of the respondents was 42.7 years (Table 1). The coffee plantation business began to attract young people to be involved. The age of the youngest respondent is 25 years. Based on the experience, the average respondent has 13.4 years. Respondents who have just started coffee farming have two years of experience, while respondents with the most excellent experience are 39 years. This age and experience range is relatively large, so transferring information, knowledge, and technology needs a specific approach.

Table 1. Characteristic of respondents

| Characteristic          | Minimum | Maximum | Mean  | Std. Deviation |
|------------------------|---------|---------|-------|----------------|
| Age (yr)               | 25.00   | 64.00   | 42.7200 | 8.78087        |
| Experiences (yr)       | 2.00    | 39.00   | 13.3673 | 9.10058        |

Coffee plantation is the respondent’s main economic activity. The average area of coffee plantations was 2.19 hectares, where the smallest area was 1 hectare, and the widest was 7.5 hectares (Table 2). All respondents cultivated Robusta coffee. The land is at 725-1140 m asl, with a slope of 5-60%.

Table 2. Characteristic of coffee plantations

| Characteristic          | Minimum | Maximum | Mean    | Std. Deviation |
|------------------------|---------|---------|---------|----------------|
| Land (ha)              | 1.00    | 7.50    | 2.1888  | 1.36314        |
| Altitude (m asl)       | 725.00  | 1140.00 | 963.8367 | 122.40785      |
| Slope (%)              | 5.00    | 60.00   | 23.4694 | 12.12797       |

Fertilizers used in coffee farming are generally the same as fertilizers used by other agricultural commodities. Respondents who use fertilizers include urea and NPK. Some respondents use other fertilizers such as manure and organic. Farmers who apply fertilizers are dominated by chemical fertilizers (Figure 1).

Figure 1. Fertilization and pest management methods applied at farmer level.
Major Pests on coffee plants are Coffee Leaf Miner, Coffee Berry Borer, and Coffee Stem Borers. Major diseases are Coffee Leaf Rust, Coffee Berry Disease, and Coffee Wilt Disease. Pests and disease management aim to suppress the development of pest and pathogen populations so that they are not economically detrimental and increase plant resistance. Most farmers do not control (89.8%), while pests and disease management generally depends on synthetic chemical pesticides.

Environmental management for coffee plantation has been developed to overcome the problem in acid soil, which includes (1) conservation, (2) improvement of cultivation techniques through rejuvenation with superior clones supported by entre gardens, (3) post-harvest handling to improve the quality of coffee beans, and (4) strengthening farmer institutions by increasing conservation concerned [15]. Environmental management in coffee smallholder plantations is related to water management, soil management, pruning, shading plant use, rorak development, and cover crop application (Figure 2). Most of the farmers have never applied water management (55.1%), soil management (46.9%), rorak development (62%), and cover crop application (84%). Most farmers implemented environmental management in pruning (14.3% for very high frequency and 46.9% for high frequency) and shading plant used (4% for very high frequency and 62% for high frequency).

![Figure 2. Environmental management practises applied at the farmer level.](image)

Nutrient and water management in coffee plantations can be managed by using shade plants, biomass, agricultural by-products as fertilizer supplements, legume cover, and planting materials that are tolerant of marginal land, also conserving nutrients and water. Rorak is a dead-end channel or a holding hole in the field if the terrace traps or captures the surface flow and eroded soil [16]. In dry climates, rorak serves as an effective rainwater harvesting site for conserving groundwater and meeting the water needs of coffee plants.

Knowledge of farmers related to climate change and how to deal with it is one of the keys to anticipating a decline in yields resulting from climate change [13]. A study conducted in Pakistan regarding farmers’ concerns about the impacts of climate change shows that farmers’ responses to climate change are strongly influenced by age, education level, farming experience, land ownership status, ease of accessing information [14].

### 3.3 Agricultural Innovation System development

The development of sustainable coffee plantations faces climate change and declining economic conditions that can affect global demand, consumer demands for higher quality coffee, increasingly fierce competition, and requests for optimal utilization of agricultural resources [17]. On the other hand, smallholder plantations have limited resources, weak risk management, low finance access, and limited technology adoption [13].

Based on organization aspect, the farmer organizations have not run optimally, networking is limited, and social capital management is still low. Therefore, it is necessary to build an Agricultural Innovation
System that aims to accelerate environmental management implementation in coffee smallholder plantations by strengthening the capacity of individual farmers and farmer organizations.

Agricultural Innovation System is a network of both organizations and individuals and supporting institutions and policies in the form of new products or processes or organizations that can be utilized socio-economically and have an impact on productivity and welfare [19]. The components of the Agricultural Innovation System include (1) research and education involving research institutions, universities, and vocational training centres; (2) agribusiness including various value chain actors, producers, and consumers; (3) bridging system, which includes stakeholder platforms, contractual arrangements, various rural empowerment, and advocacy services; (4) Innovation Ecosystem as an enabling environment that includes government programs and policies. In coffee smallholder plantations, the Agricultural Innovation System to support environmental management is shown in Figure 3.

The factors of the Agricultural Innovation System consist of the government, researchers, businesses, farmers, bridging institutions, NGOs, and markets and consumers. The government develops programs, builds agricultural infrastructure and technology, and encourages innovation through incentives and financial support. The government also implements policies and regulations that regulate a conducive environment for innovation, such as investment support, tax policies, and rural agricultural policies. Research institutes create or produce innovations. Bridging institutions help spread innovation to farmers. Donors and NGOs play a role in funding innovation and providing information and advocacy. Markets and Consumers provide feedback on technology-based products produced. In Agricultural Innovation Systems, actors are involved in creating and disseminating information and knowledge.

One of the strategies to increase smallholder coffee productivity is through trade certification, farmer training related to technology that involves women, and focusing more on active farmers [8]. Research shows that experience and technical capacity are closely related to adaptive capacity, although smallholders do not offer serious concern, and their expectations for external support are very low. The complexity of implementation increases with the severity of climate change [18]. In most smallholders, performance is often affected by lack of knowledge, supportive organization, and financial condition. Community landscape management and sustainable certification are strategic steps to increase community capacity. In addition, extension and mentoring activities can increase the capacity of
individuals and organizations, as well as increase access to technology, capital, and other agricultural resources.

4. Conclusion
In the context of sustainable agricultural development, aspects of environmental management will determine sustainable coffee production. CSA is applied in several cultivation practices that will be related to processing and marketing activities. However, CSA practices are applied in various ways to smallholder plantations, which is influenced by farmers’ limited ability both individually and in organizations. An integrated innovation approach is needed to improve its performance in the form of an Agricultural Innovation System. The Agricultural Innovation System for implementing environmental management in coffee plantations consists of research and education components, agribusiness, bridging system, and an innovation ecosystem as a supportive environment.

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