Journal of Smart Agriculture and Environmental Technology
e-ISSN:3021-8802
Vol. 2, No. 1, April 2024
https://josaet.com | https://doi.org/10.60105/josaet.2024.2.1.1-8

Research Paper

Linking Women Farmer Perceptions and Knowledge of Soil Health to Climate-Smart Coffee Cropping Management

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Article History: Received: July 21. 2023, Accepted: February 20, 2024

Abstract

Coffee cropping is very sensitive to global warming, thus affecting coffee growers, particularly women farmers and their economies. As unpredictable weather continues to limit the suitability of the majority of traditional coffee-growing regions, women farmers are applying climate-smart agriculture (CSA) practices as a means of climate change mitigation and adaptation through healthy soil identification. Healthy soil is an important indicator that determines the sustainability of coffee cropping under CSA practices. This study determined women farmers' knowledge of soil health indicators and perspectives on CSA practices in the coffee cropping region of Sumatra, Indonesia. The qualitative analysis based on the interviews and focus group discussions from 90 women farmers revealed that the most common soil health indicators were soil color and soil organic matter, while the least common was soil ecology. The best climate-smart coffee cropping practices were from the agroforestry system and the least were observed in the long-term conventional tillage system. Over 80% of women farmers express a strong belief in the effectiveness of soil health indicators for implementing successful climate-smart farming methods. The majority of the women recognized the importance of the use of cover crops and strategies to prevent soil erosion. Knowledge about the benefits of soil amendments and intercropping was limited. Women farmers need to have more opportunities for training on various aspects in soil management as a mechanism for climate change adaptation as well as to improve their land for the sustainability of coffee production and their resilience in coffee farming. In order for the farm communities to make the full transition to CSA practices, the success factors and benefits of this management must be demonstrated to the coffee farmers.

Keywords

climate-smart agriculture, coffee, healthy soil, woman farmers

1. INTRODUCTION

Coffee is one of the most traded agricultural commodities in the world and considered a crop sensitive to climate change (DaMatta et al., 2019). Global warming is causing substantial issues in coffee farms, resulting in a decrease in production and quality (Ebisa, 2017). Coffee production is mostly reliant on certain and regular rainfall and temperature (Rahman et al., 2022), nevertheless, an increase in severity and frequency of both of them has a negative impact on coffee production (DaMatta and Cochicho Ramalho, 2006). The main climate challenges for coffee production are drought and high temperatures (DaMatta and Cochicho Ramalho, 2006). Limited soil water holding capacity at different stages of coffee growth significantly lower coffee production (Camargo, 2010). Changing rainfall patterns and increasing temperatures cause low yield and quality of coffee and enhance the incidence of pests and diseases (Sujatmiko and Ihsaniyati, 2018). Changes in temperatures controls the climatic suitability for coffee plants which can increase the cost of coffee production. To address climate change, climate-smart agriculture (CSA) is proposed with the goals of increasing crop productivity by reducing greenhouse gas emissions using agricultural technologies and improving methods for better carbon sequestration (FAO, 2012). CSA technologies have more than 1700 unique production systems depending on crop commodities. For example, the type of CSA practices in coffee production is implemented as entry points for climate change adaptation and mitigation, such as management of soil, water, soil amendments and farm diversification (Taylor, 2018).

Integrating CSA in coffee cropping systems significantly affects coffee production and contributes to carbon sequestration on a global scale (Sujatmiko and Ihsaniyati, 2018). CSA provides agricultural production practices that benefit farmers through increased productivity and profitability and reduced vulnerability to climate change (Taylor, 2018). Although CSA provides numerous benefits and technological innovation is highlighted as playing an important role, it is not always adopted (Long et al., 2016). This phenomenon also happens among coffee farmers who pay less attention to technologies to increase productivity (Sarirahayu and Aprianingsih, 2018). Coffee farmers are dominated by smallholder plantations reaching 95.45% (Directorate General of Estate Crops, 2021). Adoption of CSA practices at the smallholder level faces obstacles related to the character and gender of farmer and farming system, such as shortage of productive land, land tenure issues, limited knowledge of CSA, slow return on investment, and inadequate policy and implementation schemes (Zerssa et al., 2021). CSA adoption is also related to technological characteristics and external factors, such as market access and traditional culture (Kongsager, 2017). The lack of research on the impact of climate change on coffee production among women farmers presents a challenge for implementing CSA (Nyang'au et al., 2021).

A basic assumption underlying the concept of CSA practices is the knowledge of soil, particularly soil health because it is the foundation of sustainable land management (Kongsager, 2017). Farmer knowledge is a valuable resource that can contribute to the scientific finding of soil health indicators. Farmer assessments of soil health are useful for understanding a holistic concept of soils as the foundation of cropping. Ethno-pedologists have identified strong relationships between indigenous soil classification systems and soil properties (Queiroz and Norton, 1992). In fact, indigenous soil classification systems distinguish soil characteristics that guide local land management (Krasilnikov and Tabor, 2003). The term "soil health" describes the concept of soil fitness to perform important soil functions (Larson et al., 1994). It is also an ecological term that describes the extent to which a soil fulfils key criteria of biological integrity. Thus, soil health is the appropriate term when discussing farmer perceptions of soil performance in agricultural production system using CSA practices. Farmer's observations and judgments of soil health could serve as the foundation for soil health indicators (Harris et al., 1994).

Given the relative importance of coffee in the livelihoods of women smallholders, it is imperative to evaluate their knowledge for soil health and perspectives for different CSA practices and to discuss the barriers related to certain practices. Climate change and related rising temperatures are changing the viability of women's farms, resulting in less suitable environments for coffee cultivation and threatening the economies and livelihoods dependent on it (Bejan et al., 2018; Bunn et al., 2015). The women farmers who rely solely on coffee for their livelihoods suffer the most from climate change (Le et al., 2020; Gillison et al., 2004). 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 to and mitigation of climate change.

The objective of this study is to examine the knowledge of soil health and perspectives on CSA practices in coffee cultivation in a small community of women farmers in Sumatra, Indonesia. By emphasizing the relationships between soil health indicators mentioned by women farmers and the CSA practices based on valuable experiential knowledge, this study also tries to elucidate traditional ecological knowledge, with a particular focus on the unique information held by women. This knowledge is essential for the conservation and promotion of sustainable agricultural methods. Consequently, this information will accelerate the implementation of conventional CSA and build a foundation for implementing cutting-edge practices through local knowledge in coffee cultivation.

2. EXPERIMENTAL SECTION

2.1 Materials and Methods

The research was conducted in the farming communities in Bengkulu Province, Sumatra, Indonesia. The women farmers were selected randomly and by referral from three villages, Tapos, Donok and Pal located near Kerinci Seblat National Park (TNKS). Tapos is the closest distance of 20 km from TNKS, while Donok and Pal have distances of 50 km and 80 km, respectively. The agricultural land in the region is nearly all hilly and sloping with annual rainfall between 2800 to 3000 mm. The Robusta coffee plant or Coffea canephora is the dominant variety grown using intercropping and monoculture (no shade-trees) as well as paddy rice with partial irrigation.

Information about the perspectives of soil health indicators and the knowledge of climate-smart cropping systems (CSCS) from 90 women farmers (30 from each village) was collected through semi-structural interviews in the interviewee's house and field. At the end of the research, focus group discussion was performed to confirm and re-check the information. Conversation was translated by an interpreter then guided toward selected topics while remaining flexible enough to include other related topics of interest to the coffee growers.

Topics covered included soil health and its indicators, CSCS focusing on coffee land management practices and criteria that are commonly used to determine healthy and unhealthy soils for growing coffee such as soil color and moisture. The interview and discussion revolved around the respondents' knowledge of healthy soil and its indicators, their knowledge in farming management, their understanding of the correlation between unpredictable weather patterns and global warming, their farm productivity, and their familiarity with carbon farming.

3. RESULT AND DISCUSSION

3.1 Respondent Characteristics

In general, respondents from Tapos and Pal had more land area to grow coffee than respondents from Donok. Better education, financial status, soil color and soil organic matter content (Handayani and Prawito, 2008) were the main controlling factors. Most women farmers in both villages (Tapos and Pal) studied until middle school or high school, while the ones from Donok only learned until elementary school. More than 85% of coffee growers apply agroforestry systems in their farms which provide better food security because the cash was not always available to purchase food. In all areas, land management practices for coffee are relatively similar, except the use of various crops for agroforestry, the intensity of tillage and the kind and amount of soil amendments. Coffee farms were generally tilled minimally or maximally to reduce soil compaction and kill pests. Vegetables and spice trees are commonly intercropped with coffee. The common plants that are combined with coffee include cacao (*Theobroma cacao*), banana (*Musa acuminate*), mangostene (*Garcinia mangostana*), chempedak (*Artocarpus integer*), rambutan (*Nephelium lappaceurn*), kapok tree (*Ceiba pentandra*), Indonesian mahagony (*Toona sureni*), sugar palm (*Arenga pinnata*), calliandra (*Calliandra thyrsifolia*), jengkol (*Archidendron pauciflorum*), jackfruit (*Artocarpus heterophyllis*), and river tamarind (*Leuceuna leucophala*). Additionally, most farmers applied manure from livestock to darken the soil color and add organic matter.

3.2 Perceptions of Soil Health Indicators and Climate-Smart Coffee Cropping Practices

Soil health indicators discussed by women farmers during interviews were summarized based on the percentage of farmers who mentioned each indicator (Table 1).

Soil color and soil organic matter (SOM) were the indicators of SH mentioned by the most farmers (89%). SOM is the most universally accepted indicator of SH. These indicators are considered sensitive (Granatstein and Bezdicek, 1992). Crop performance, yield and soil erosion were the next most frequently mentioned SH indicators (88% and 87%, respectively). Farmers tend to pay less attention to their soil than their crops because it is harder to observe the quality of soil than crops. SOM and crop performance are the SH indicators most often mentioned by farmers from Wisconsin, USA. Soil moisture related to soil hydrologic function was mentioned by 86% of farmers. The rest of the women farmers considered soil water holding capacity to be the most distinguishing characteristic between healthy and unhealthy soils. Evidence of soil acidity and soil fertility were mentioned by 83% and 75% of farmers. Most of the farmers using minimum tillage and agroforestry systems to improve soil moisture and reduce soil erosion enhanced soil fertility status. Farmers said that intensive tillage caused light soil color, less SOM and high erosion. The fact that a majority of farmers (75%) did not mention soil fertility as a SH indicator suggests most farmers think their soil productivity is not limited by soil nutrients. The relatively large fraction (84%) of farmers that mentioned tilth is related to most (80%) of the participating farmers disliking the presence of Imperata cylindrica as a weed causing blocky soil structure and soil compaction. Soil biological indicators, such as the presence of earthworms and mushrooms on the soil surface were mentioned relatively frequently (70%) by farmers. This indicates a need for identification of practical biological indicators of SH and training programs for farmers related to the contribution of soil biology in mediating soil functions. The percentages of farmers that described a relationship between SH and crop yield should not be interpreted as a direct measure of farmer evaluation of crop yield as SH indicators (Romig et al., 1995). This interview showed a simpler and less inferential technique for quantifying the responses. Direct insights on farmer perspectives about SH indicators can be drawn from the individual farmer comments. The most important indicators described by individual farmers included SOM, soil color, crop performance, crop yield, soil erosion, soil tilth and soil pH.

Women farmer perspectives on the impact of climate-smart coffee farming practices are summarized in Table 2. SH benefits from agroforestry, shade trees and conservation tillage were described by more than 83% by farmers. Most farmers (> 65%) have eliminated conventional tillage practices for almost 2 years. They understand the benefits of undisturbed soil surface to promote the humus content (SOM) and improve soil color. SH benefits from including cover crops, liming and fertilizers were described by more than 80% of the farmers. Pruning, long-term conventional tillage and carbon farming are practices described by less than 66% of the farmers. This indicated that farmers need more training regarding the benefits of these practices for soil indicators. Farmers generally understand the positive impacts of climate-smart coffee farming practices, but have limited knowledge on the benefits of each practice for SH improvement. About 40% farmers learned the negative impacts of long-term continuous tillage practices, excessive field traffic or any traffic over wet soils, particularly on soil color, erosion, and compaction. They also believed that soil acidity due to limited liming and pesticide application decreased the number of earthworms in soil. This data suggests that efforts to improve SH using climate-smart coffee farming practices should focus on monitoring and improvement in SM content, soil erosion and soil hydrology.

3.3 Knowledge on Climate-Smart Coffee Cropping Practices

Farmers commonly intercrop coffee with different trees, but there is limited knowledge on the interaction between different trees and coffee (Table 3). These agroforestry practices resulted in competition with the main crop (coffee)

Table 1. Soil health indicators, climate-smart coffee cropping practices and the percentage of women farmers that mention each

Soil Health Indicators (SHI)	Farmers	Climate-Smart Coffee Cropping Practices (CSCC)	Farmers
Soil Color	89	Shade Trees	87
Humus/Soil Organic Matter	89	Agroforestry	87
Crop Performance and Yield	88	Conservation Tillage	84
Soil Erosion	87	The Use of Organic Fertilizers	83
Soil Moisture	86	Cover Crops	80
Tilth	84	Liming	80
Soil pH	83	The Use of Chemical Fertilizer	80
The Presence of *Imperata cylindrica*	80	Pruning	65
Soil Compaction	76	Carbon Farming	65
Soil Fertility	75	Long-term Conventional Tillage	60
The Presence of Weeds	75		
Soil Biology	70		

Table 2. Knowledge of the benefits of soil amendments (lime, manure, biofertilizers, biopesticides

Statement	SA	A	D	DA
I would like to use soil amendment to improve soil fertility and compaction level	6	5	60	29
Using lime or chicken manure to improve soil moisture and compaction is not very encouraging because it is not efficient in term of the cost	6	6	70	18
I am not interested in using soil amendment to replace chemical fertilizer	4	7	64	25
I do not have motivation to find different type of soil amendments for my coffee farm	3	9	57	31

Note: SA=Strongly Agree, A=Agree, D=Disagree, SD=Strongly Disagree; Values in percentages

which could reduce the coffee yield. The interview showed there is limited knowledge of the value of the complementary effects of the shade trees on the ecosystem. Most farmers use agroforestry systems to improve food security, because monoculture coffee farming will not provide food sustainability. Some farmers still do monocropping to focus on coffee production, but because of soil erosion and low SOM, they tried to use agroforestry practices.

Agroforestry practices are considered as a measure of adapting to the lower coffee prices and productivity as well as to climate change. However, the intercropping mix is not optimal because of the competitiveness among the crops. Crop vulnerability or resilience depends on the adjustment capacity to unpredictable weather conditions (Solorzano and Cardenes, 2019). Adaptive capacity of agroforestry coffee is important to maintain and to enhance the annual yield (Daze and Dekens, 2016). Landscape design in cropping is crucial for sustainable agriculture and sequestering carbon, which eventually maintains ecosystem services related to hydrologic function and reduces land degradation during crop production processes (FAO, 2012). Integrating legumes into coffee cropping will help to reduce the need of N fertilizers and improve the number of beneficial microbes and earthworms in soil (Clark et al., 2019).

There is limited knowledge of the benefits of using soil amendments to coffee production (Table 3). Many farmers do not know that various soil amendments such as, lime, manure, biofertilizers and biopesticides can be used to improve soil nutrient status. Training on this topic is important because farmers do not have good experiences using various soil amendments.

Most farmers have adequate knowledge of the impact of soil erosion and how to conserve the soil in order to keep the topsoil (Table 4). They understand the important contribution of cover crops, particularly legumes to prevent soil erosion. Legumes also can be used to add nitrogen, thus increasing coffee yield.

The important goals of soil management practices are to reduce erosion and improve the fertility status. Adding soil amendments and incorporating cover crops in coffee cropping are mandatory to help with agronomic and ecological services (Sastre et al., 2018). Selection of species that combine different functional traits while having compatibility with the main crops makes the overall performance of

Table 3. Knowledge of shade-coffee or agroforestry.

Statement	SA	A	D	DA
I do not like to have trees covering my coffee	19	3	21	57
I would like to have my coffee farm mixing with other crops or trees	4	4	8	84
I would like to have a half of my coffee farm is under the shade with trees	3	5	13	79

Note: SA=Strongly Agree, A=Agree, D=Disagree, SD=Strongly Disagree; Values in percentages

Table 4. Knowledge about erosion and soil conservation practices.

Statement	SA	A	D	DA
I do not know the strategies to prevent or reduce soil erosion	10	16	50	24
I know that we have to protect our topsoil to make our soil more fertile	59	39	60	1
I have a hard time selecting cover crop to prevent soil erosion	2	5	75	18
I am not interested in covering my topsoil using any cover crop.	5	10	55	40
I would like to have bare soil surface	10	55	35	40

Note: SA=Strongly Agree, A=Agree, D=Disagree, SD=Strongly Disagree; Values in percentages

the selected crop important Holmes et al. (2017). Soils under coffee production in high slope are sensitive to erosion (García-Ruiz, 2010), while continuous cropping decreased organic matter content (Salomé et al., 2016). The use of both cover crops and soil amendments provided benefits to soil through improvement in soil organic matter and biota diversity, controlling erosion and reducing in soil compaction. In term of climate-smart agriculture, soils rich in organic matter are usually related to the development of mycorrhizal fungi which are associated with drought resistance of the host plants due to improvement of plant water relations (Garg and Chandel, 2010). The benefits of cover crops were increasing soil organic matter up to 9%, microbial biomass up to 40% and lowering the weed incidence up to 27% (Gorm et al., 2019). Other positive impacts of cover crops were the increase of yield by about 16%, the reduction of nitrate leaching by 53% and soil moisture improvement by 13%.

Farmers' knowledge about the impact of global warming on coffee production is considered limited (Table 5). Challenges are faced by farmers due to lack of extension service involvement to guide them on the adaptation strategies to climate change. Increasing weather variability has resulted in decreased capacity for most farmers to produce high coffee quantity and quality. There was low adoption of strategies to enhance soil water holding capacity during dry season.

The knowledge about climate change among women farmers was influenced by access to extension services or external reliable communication affecting the adaptation actions on climate-smart cropping practices (Opiyo et al., 2016). In general, the adaptation planning is influenced by the community's knowledge and perspective of the impact of climate change on crop production (Fasih et al., 2019).

Farmers showed high interests (> 80%) to have training on how to improve coffee yield and soil nutrients. This implied the need of guidance from agricultural extension services (Table 6). They would like to know more about carbon farming and strategies to adopt climate-smart coffee farming practices and how to use soil health indicators as a measure of climate-smart cropping practices.

This data suggests that a collaborative governance in coffee production is needed to solve the challenges associated with the limited involvement of extension service providers and stakeholder engagement for the collective decision policy for adopting the climate-smart cropping practices.

Weeding has been the major challenges to farming families with 100% indicating the intensity, particularly those who engage in manual weeding. The data from Table 7 illustrated the farmers' perception of the effectiveness of weeding practices across the variables. Weeds in coffee farms have been associated with loss in yield; they create competition for space, light, moisture, and nutrients, with others releasing their natural substances, which have the capacity to inhibit growth of other crops (allelopathy), with binding weeds physically smothering the growing crop (Fasih et al., 2019). Most farmers in this study are older than 35 years old and used to manual weeding and the application of herbicides, while the use of cover crop is still limited, due to their perception on the high cost (Table 7).

The use of legume cover crops in the coffee farming systems decrease the intensity of weeding thus improving soil moisture and reducing overall weed competitiveness (Tadesse et al., 2020). Reducing weed competitiveness while improving the crop growth requires the choice of vigor-

Table 5. Knowledge of global warming and its relation to productivity.

Statement	SA	A	D	DA
Rising air temperature can cause low yield	10	16	50	24
Changes in rainfall pattern cause lower yield and invite more pests & diseases	59	39	60	1
I use various strategies to the farm in order to conserve soil moisture during dry condition	2	5	75	18
Shading from trees helps to save soil moisture	5	10	55	40
Bare soil around the coffee plants lower the coffee production	89	9	0	2

Note: SA=Strongly Agree, A=Agree, D=Disagree, SD=Strongly Disagree; Values in percentages.

Table 6. Knowledge of the need for training on soil health and carbon farming.

Statement	SA	A	D	DA
My lower coffee production is due to limited amount of chemical fertilizer applications	96	4	0	0
Managing coffee farm without improving soil organic matter is useless	75	10	10	0
Soil color is an important indicator to show if the soil can provide good yield	80	10	5	5
I would like to have training about carbon farming and soil health to improve the coffee farm and to get incentives from government or non-government organizations	80	10	5	5

Note: SA=Strongly Agree, A=Agree, D=Disagree, SD=Strongly Disagree; Values in percentages.

Table 7. Knowledge of the efficacy of methods in eradicating weeds.

Variable	Manual Weeding	Herbicide	Cover Crop
Soil erosion	low	low	high
Soil fertility benefits	low	low	high
Soil structure benefits	medium	low	high
Soil color benefits	medium	low	high
Weed competition	low	high	high
Cost implications	low	high	high
Time requirement	high	low	medium
Crop safety	low	high	high
Yield impact	medium	medium	high
Sustainability	medium	low	high

ously growing locally adopted legume cover crop varieties, which have the ability to smoother weeds but also maintain healthy soil and enhance nutrient cycling, particularly nitrogen fixation (Vitousek et al., 2013). Farmers' knowledge related to climate-smart coffee farming practices by using cover crops is still very low. The adoption of cover crops, particularly legumes, should be promoted to improve the soil as well as to enhance farmers' resilience to climate change.

4. CONCLUSION

The most common soil health indicators described by women farmers were soil color and soil organic matter with the percentage of 89%, while the least was soil biology or soil microbes. Additionally, the most climate-smart coffee cropping practices conducted by the women farmers were agroforestry system (87%) and the least were long-term conventional tillage (60%). In general, the women farmer perspectives about soil health indicators as a means of climate-smart cropping practices are considered high with more than 80% mentioning the topic.

The knowledge about climate-smart agriculture components and practices are relatively dynamic as indicated by the inconsistency in responses. Despite being aware that manual weeding and herbicide application were believed to have a minimal effect on weed eradication, they nonetheless relied on these procedures as their primary practices. Furthermore, the majority of the women recognized the importance of the use of cover crops and the strategies to prevent soil erosion while their knowledge about the benefits of soil amendments and intercropping is limited. Therefore, women farmers need to have more opportunities to have training on various aspects in soil management as a mechanism for climate change adaptation as well as to improve their land for the sustainability of coffee production and their resilience in coffee farming.

ACKNOWLEDGEMENT

Special thanks are given to the farmer communities in Tapos, Talang Donok and Pal Villages for sharing their knowledge on coffee cropping systems. The assistance of local government, non-government organizations (Lembaga Swadaya Masyarakat) and field research team from the University of Bengkulu is gratefully acknowledged. Research funding was provided by the Biodiversity Foundation of Indonesia (Yayasan KEHATI). We thank to two anonymous referees for the valuable comments on the manuscript.

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