



Optimizing Soil Fertility To Achieve Food Security In Krueng Raya, Aceh Besar District

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ABSTRACT

Agroforestry optimizes soil fertility by adding organic matter from tree litter, enhancing nutrient cycling, improving soil structure and water-holding capacity—all of which contribute to increased and stable crop yields, thereby supporting food security. Soil fertility optimization is the process of improving soil quality to make it more productive and support plant growth, including which can be achieved through soil and water management techniques in agroforestry systems, beginning with periodic soil analysis to help determine plant nutrient needs and assist in establishing appropriate fertilization strategies. Soil fertility in agroforestry lands is crucial for supporting food security. Agroforestry, which involves the integration of trees with agricultural crops, can significantly enhance soil fertility through various mechanisms. The objective of this study is to analyze the soil in agroforestry lands regarding its physical and chemical properties, as well as to develop agroforestry-based land optimization strategies. The results indicate that the soil texture in Mon Village is loamy. Its chemical properties include slightly acidic soil (pH), low organic carbon (C-Organic), low total nitrogen (N-total), very low available phosphorus (P-available), and high soluble potassium (K-dd). The key factors determining the success of land optimization include: (a) Ecological aspects, such as the types of trees planted and soil fertility (i.e., soil physical and chemical properties), (b) economic aspects, including farmers' knowledge of economic value, and (3) socio-cultural aspects, including community perception and participation, understanding of agroforestry systems, and the local wisdom of communities surrounding the forest.

INTRODUCTION

Land resources are vital to human life and environmental sustainability. Land use must be carried out responsibly and sustainably, taking into account potential geological hazards, environmental conservation, and community needs. Soil is a vital natural resource that is non-renewable in the short term, as soil damage takes a long time to recover. Soil serves as the primary medium for plant growth, including both forestry and agricultural crops (Purba et al., 2023).

Challenges to soil resource sustainability include land degradation, which is the process of declining soil quality due to various factors, such as erosion, pollution, and unsustainable land use. Land degradation can reduce forestry and agricultural productivity and damage ecosystems. Another challenge is land fragmentation—the division of land into small parcels—which can reduce efficiency in the forestry and agricultural sectors and increase the risk of degradation, often caused by changes in land-use planning and social pressures (Tutuarima et al., 2021).

Soil fertility optimization is the process of improving soil quality to make it more productive and support plant growth; this can be achieved through soil and water management techniques in agroforestry systems, beginning with periodic soil analysis to help determine plant nutrient needs and assist in establishing appropriate fertilization strategies. Soil fertility in agroforestry systems is crucial for supporting food security. Agroforestry, which involves integrating trees with agricultural crops, can significantly enhance soil fertility through various mechanisms (Dono et al., 2023).

Agroforestry systems can improve soil quality in various ways, such as adding organic matter, improving soil structure, reducing erosion rates, enhancing soil microbial activity, and increasing water availability. Trees in agroforestry systems provide fallen leaves, enrich the soil with nutrients, and enhance soil fertility. Tree roots also help improve soil structure, making it better for water and air absorption. Tree canopy cover also reduces erosion rates (Fitri et al., 2020).

Agroforestry systems, which combine woody plants with food crops and livestock, are highly effective in improving soil fertility and supporting food security in Mon Krueng Raya Village, which is dominated by relatively infertile Ultisol soils. By leveraging the positive interactions between trees and other plants, agroforestry can increase soil organic matter content, reduce erosion rates, and provide nutrients for crops. This helps maintain ecosystem balance and sustainably enhance forestry and agricultural productivity (Amanullah et al., 2025).





MATERIAL

The following table will present the materials in this study:

Table 1. Research Material

Materials	Description
1. Map of Mon Krueng Raya Village, scale 1:10,000	showing the location and position of the research site
2. Aquades	Pure water (H ₂ O), distilled to remove dissolved substances
3. Bottles	0.1 N HCl and 10% H ₂ O ₂ solutions. K ₂ Cr ₂ O ₇ , NH ₄ OAc, NaOH, phosphate reagent solution, and other chemicals for chemical property analysis in the laboratory
Tool	
1. GPS (<i>Global Positioning System</i>)	Determining the location and point of soil sampling.
2. Drill	Digging holes to view the soil layers
3. pH meter	Measuring acidity
4. Digital camera	Documenting.
5. Hoe, shovel, machete	Collecting soil samples
6. Plastic bags, rubber bands, paper, and other supporting tools.	For soil samples to be analyzed in the laboratory

METHOD

The steps in this research are: (1) Preparation of materials, tools and data collection (2) Field survey of open land and agroforestry land and taking soil samples, (3) Analysis of soil chemical properties in the laboratory, and (4) Data analysis referring to the criteria for assessing soil chemical properties, discussion, conclusions and suggestions. The Research Flowchart is shown in Figure 1.

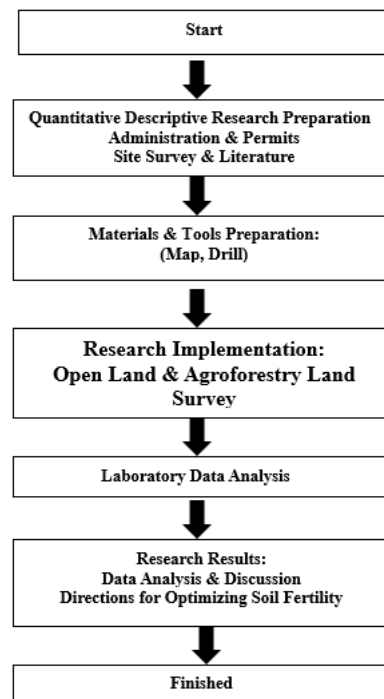


Figure 1. Research Flow Chart

RESULT

Results of Soil Property Analysis

Several soil property parameters analyzed in open fields and agroforestry systems in Mon Krueng Raya Village, Aceh Besar Regency, include: (1) Soil physical properties, namely soil texture, and (2) Soil chemical properties, namely: soil pH, organic C (%), total N (%), available P (mg kg⁻¹), and exchangeable K (cmol kg⁻¹). The results of the analysis of several soil property parameters in Mon Krueng Raya Village, Aceh Besar Regency, are shown in Table 1.





Table 2.. Results of Soil Texture, Soil pH, Organic Carbon, Total Nitrogen, Available Phosphorus, and Exchangeable Potassium Analysis in Mon Krueng Raya Village, Aceh Besar Regency.

No.	Soil Property Parameter	Unit	Soil Sample Collection Location			Average	Criteria
			T ₁	T ₂	T ₃		
I.	Physical Properties of Soil						
1.	Soil Texture	%	H ₁	H ₂	H ₃		Silty Clay
II.	Chemical Properties of Soil						
1.	Soil pH (pH H ₂ O)	-	6.01	5.24	5.40	5.55	Slightly Sour
2.	C-organic	%	1.11	0.95	1.28	1.11	Low
3.	Total N	%	0.14	0.15	0.16	0.15	Low
4.	Available P	mg kg ⁻¹	12.75	3.95	0.30	5.67	Very Low
5.	K-exchangeable (K-ex)	cmol kg ⁻¹	1.45	0.29	0.53	0.76	Height

Notes: T₁ = Open land, T₂ = Agroforestry land, T₃ = Agroforestry land with, and turmeric plants; H = Silty loam

DISCUSSION

Soil pH

Soil pH values at the study site showed no significant differences across the soil samples. The soil pH criteria for open land (T₁), slightly acidic, agroforestry land (T₂), acidic, and agroforestry land with turmeric plants (T₃), acidic. The average soil pH value was 5.55, classified as slightly acidic, as the values ranged from 5.6 to 6.5 (Soil Research Center, 1995).

The decrease in soil pH in plots T₂ and T₃ compared to plot T₁ is due to the presence of ash residues from combustion, which are basic cations consisting of calcium (Ca), magnesium (Mg), potassium (K), and phosphate (P). Thus, the decrease in soil pH is a result of the decrease in the amount of basic combustion residue (charcoal) (Choiruddin et al., 2018).

The insignificant difference in soil pH values is due to the study location, which, based on the USDA soil taxonomy system (Soil Survey Staff, 2014), is dominated by Ultisol soils—old and relatively infertile soils. Generally, Ultisol soils have low to moderately low acidity potential (Agricultural Research and Development Agency, 2017).

Organic Carbon

Organic carbon values at the study site showed no significant differences across soil samples. The organic carbon criteria for open land (T₁), low, agroforestry land (T₂), very low, and agroforestry land with turmeric (T₃), low. The average organic carbon value was 1.11, classified as low, as it fell within the range of 1.00–2.00% (Soil Research Center, 1995).

The decrease in organic carbon content in T₁ land compared to T₃ land is due to the vegetation on the surface—which is dominated by frequently burned grass—allowing rainwater to fall directly onto the soil surface. This results in more intensive nutrient leaching during rainfall. Organic carbon experiences a significant decline immediately after a fire but begins to increase several months after the fire (Choiruddin et al., 2018). In frequently burned areas, organic carbon levels decrease. The greater the amount of organic carbon burned, the faster the decline in soil organic carbon (Murtinah et al., 2017).

Total N

Total nitrogen (N-total) values at the study site showed significant differences across each soil sampling point. The total nitrogen (N-total) values were low in open land (T₁), agroforestry land (T₂), and agroforestry land with turmeric (T₃). The average total N value was 0.11, classified as low, as the values ranged from 0.10–0.20% (Soil Research Center, 1995).

The total N values of T₁, T₂, and T₃ increase as the concentrations of ammonium (NH₄⁺) and nitrate (NO₃⁻) rise. NH₄⁺ and NO₃⁻ are the most common forms of inorganic nitrogen available and easily absorbed by organisms, and an increase in their concentrations directly increases the total nitrogen content (Hanifah et al., 2023). This is supported by Choiruddin et al. (2018), who noted that the more litter that falls, the more organic matter and nitrogen enter the soil, thereby potentially increasing the total nitrogen content in the soil through the decomposition process.

Available P

Available P values at the study site showed significant differences across each soil sampling point. The available P values were classified as low in open land (T₁), very low in agroforestry land (T₂), and very low in agroforestry land with turmeric (T₃). The average available P value was 5.67 mg kg⁻¹, classified as very low, as values fell below 10 mg kg⁻¹ (Soil Research Center, 1995).

Available P values from T₁, T₂ to T₃ decrease due to fixation by Al and Fe, particularly under low soil pH conditions. Soil P can be defined as soil P that can be extracted with water and nitric acid (HNO₃), while P loss can





occur through leaching (Hanifah et al., 2023). According to research by Choiruddin et al. (2018), soil P content decreases at depths of 0–20 cm due to leaching into deeper layers caused by water movement, uptake by plant roots, and the decomposition of organic matter, which is the primary source of P.

Exchangeable potassium (K-dd)

The K-dd values at the study site showed significant differences across each soil sample collection. The K-dd criteria for open land (T1, high), agroforestry land (T2, moderate), and agroforestry land with turmeric (T3, moderate). The average K-dd value was 0.76 cmol kg⁻¹, classified as high, as the values ranged from 0.60 to 1.00 cmol kg⁻¹ (Soil Research Center, 1995).

The decrease in K-dd values in plots T2 and T3 compared to plot T1, which is frequently burned, is due to the fact that basic cations (K) in the ash increase the amount of K-dd. Ash residue from land fires containing alkali cations is believed to be easily washed away by water or carried by wind currents. After a fire, the base cations (K) in the post-fire ash result in an exceptionally large increase in exchangeable base (K). The increase in K content following a fire is due to the supply of K from post-fire ash that seeps into the soil. This K supply originates from the fuel residues present on the soil surface (Murtinah et al., 2017).

**Guidelines for Optimizing Soil Fertility in Agroforestry Systems to Achieve Food Security
Structural and Non-Structural Soil Fertility Optimization**

Optimizing soil fertility in agroforestry systems to achieve food security in Mon Village, Krueng Raya Subdistrict, through structural and non-structural approaches. Optimizing soil fertility using vegetative methods includes: (1) Selecting appropriate tree and crop species, and proper spacing, which is crucial for ensuring adequate sunlight for intercrops, (2) Planting various tree and crop species that interact synergistically, adding organic matter from fallen leaves and tree roots, managing the root system to prevent nutrient loss, and considering the planting of nitrogen-fixing crops such as legumes, (3) Implementing crop diversification and rotation, and (4) Using biological agents.

Optimizing soil fertility through civil engineering methods includes: (1) Improving water retention, (2) Post-harvest soil management, (3) Efficient irrigation systems, (4) Reducing erosion rates, and (5) Increasing organic matter and reducing synthetic pesticides. Meanwhile, optimizing soil fertility through non-structural methods involves outreach on: (1) Ministry of Environment and Forestry Regulation No. 9/2021: Social Forestry Management, (2) Outreach on Ministry of Environment and Forestry Regulation No. 7/2021: Agroforestry and Food Estates, (3) Government Regulation No. 17/2015: Food Security and Nutrition, (4) Capacity building for Forest Farmers’ Groups (KTH), and (5) Training and capacity building in agroforestry. Alternative guidelines for optimizing soil fertility in the agroforestry system to achieve food security in Mon Krueng Raya Village, Aceh Besar Regency, are listed in Table 2.

Table 3. Alternative Guidelines for Optimizing Soil Fertility in the Agroforestry System to Achieve Food Security in Mon Krueng Raya Village.

Guidelines for Optimizing Soil Fertility in Agroforestry Systems			
No.	Technical (Structural) Methods	Non-Technical Methods (Non-Structural)	
	Vegetative Methods	Civil Engineering Methods	
1.	Selecting the right types of trees and plants	Improving water retention	Outreach on Ministry of Environment and Forestry Regulation No. 9/2021: Management of Social Forestry
2.	Selecting trees and plants that can increase organic matter	Post-harvest soil management	Outreach on Ministry of Environment and Forestry Regulation No. 7/2021: Agroforestry and Food Estates
3.	Crop diversification	Efficient irrigation systems	Outreach on Government Regulation No. 17/2015: Food Security and Nutrition
4.	Implementing crop rotation	Reducing the rate of erosion	Capacity building for Forest Farmers’ Groups (KTH)
5.	Use of Biological Agents	Adding organic matter and reducing synthetic pesticides	Agroforestry Training and Capacity Building

**Structural Optimization of Soil Fertility
Vegetative Methods**

Selecting the right types of trees and plants is one of the technical methods for optimizing soil fertility in agroforestry systems. Choose trees with a relatively compact canopy or adjust the planting distance, and ensure they align with the sunlight requirements of the intercrops. Consider planting shade-tolerant crops, such as turmeric, taro, or spices, under the tree canopy. Furthermore, selecting appropriate tree and plant species in an agroforestry system can increase farmers’ income and strengthen food security (Achmad & Diniyati, 2021).





Planting various tree species to ensure abundant leaf litter that decomposes helps add organic matter, improving soil structure and nutrient content. The roots of fallen trees serve as a source of organic matter. Integrating leguminous plants as nitrogen fixers from the air enhances the supply of nitrogen available to other plants. The organic matter produced through leaf decomposition serves as nutrition for soil microorganisms, thereby creating a productive environment for plant growth (Bawamenewi & Lase, 2025).

Implementing crop diversification by planting various types of mutually beneficial crops reduces the risk of crop failure and maintains nutrient diversity in the soil. Practicing crop rotation by alternating the types of crops planted on the same land to prevent pests and diseases and maintain soil nutrient balance. This aligns with the research by Mucharam et al. (2025), which indicates that the combination of crop diversification and rotation is a strategy for building a productive and climate-resilient sustainable agricultural system.

The use of soil microorganisms in agroforestry systems, such as beneficial microorganisms and rhizobia, can promote plant growth and protect against pathogens. The use of biological agents is beneficial for controlling plant pests and diseases in an environmentally friendly manner, improving soil fertility and productivity, and reducing dependence on chemical inputs, thereby reducing pollution and the persistence of pests and diseases (Lestari et al., 2023).

Technical Civil Engineering Methods

Planting trees in an agroforestry system enhances the soil's ability to store water, maintain soil moisture, and support plant growth. Implementing post-harvest soil management by properly preparing the soil after harvest helps maintain its fertility and prepares it for the next growing season. Water conservation and post-harvest soil management in agroforestry systems improve the soil's water-holding capacity, enhance soil structure, and reduce erosion and surface runoff (Pakaya et al., 2025).

Implementing an efficient irrigation system, ensuring the right amount of water is available for crops, to maintain soil fertility and land productivity. Reducing erosion, as tree root structures and vegetation cover can hold soil particles and maintain soil fertility in agroforestry systems. This aligns with the research by Waruwu & Lase (2024), which recommends creating terraces with the planting of groundcover plants to manage water flow and strengthen soil structure in agroforestry systems.

Adding organic matter to agroforestry systems—such as compost, green manure, or livestock manure—can improve soil structure, enhance water-holding capacity, and provide nutrients for plants. The use of organic pesticides can further enhance soil fertility. The addition of organic fertilizers and pesticides can improve soil fertility and physical properties, strengthen plant resistance to diseases and pests, enhance product quality and nutritional value, and maintain ecosystem balance while reducing erosion risks (Andriyani & Patricia, 2024).

Non-Structural Optimization of Soil Fertility

The primary Ministry of Environment and Forestry (LHK) regulation related to social forestry is Ministry of Environment and Forestry Regulation No. 9 of 2021, which serves as the foundation for sustainable forest management in collaboration with local communities to improve welfare and food security. This policy supports the formation of Social Forestry Business Groups (KUPS) to develop high-value economic commodities, such as Non-Timber Forest Products (NTFPs) and Timber Forest Products (TFP), which contribute to food security and the local economy.

The agroforestry system through Social Forestry holds great potential for enhancing food security. This system integrates agricultural crops with trees, either simultaneously or in rotation, on the same land, creating a more sustainable and productive environment. Social Forestry provides legal access for communities to manage forests, which can then be implemented through agroforestry systems to increase agricultural yields and community income (Wiwidiati et al., 2024).

Ministry of Environment and Forestry Regulation No. 7 of 2021 is closely related to forestry planning, changes in forest area designations and forest area functions, as well as the “ ” of forest areas. This regulation provides detailed provisions regarding these activities in the environment and forestry sectors. This regulation also relates to the provision of forest areas for agroforestry and food estate programs, including the potential utilization of protected forests whose functions have diminished.

Government Regulation No. 17 of 2015 on food security and nutrition. This Government Regulation is more recent and relevant to the current context. This regulation specifically addresses food security and nutrition. It defines food security as the condition where food needs are met for the nation down to the individual level, encompassing quantity, quality, safety, diversity, and availability of food that does not conflict with religion and culture.

Institutional strengthening and access to information, including: (1) Capacity building for Forest Farmers' Groups (KTH). Strengthening Forest Farmers' Groups to enhance their capabilities in planning, technology application, and information sharing to address agricultural challenges. (2) Improving access to information by providing training and guidance to farmers so they can receive and apply new information and technologies to increase productivity within the agroforestry system (Ruhimat, 2021).





CONCLUSION

1. The C-organic and Total-N values in agroforestry plots with turmeric plants were higher than those in agroforestry plots and open fields, which had low values in their respective criteria.
2. Soil pH and available phosphorus values in agroforestry plots with turmeric (H3) were lower than those in agroforestry plots and open fields, with the respective criteria being slightly acidic and very low.
3. The K-dd value for agroforestry land with turmeric plants is higher than that of other agroforestry land and lower than that of open land with high criteria.
4. Optimizing soil fertility in agroforestry systems using structural (vegetative) methods, namely: (a) Selecting appropriate tree and plant species, (b) Selecting trees and plants that can increase soil organic matter, (c) Implementing crop diversification, (d) Implementing crop rotation, and (e) Using biological agent.
5. Optimizing soil fertility in agroforestry systems using structural (civil engineering) methods, namely: (a) Improving water retention, (b) Post-harvest soil management, (c) Efficient irrigation systems, (d) Reducing erosion rates, and (e) Increasing organic matter and reducing synthetic pesticides.

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