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Research Paper

The Role of Food Crops for Communities with Agroforestry Farming in the Highlands of North Sumatra, Indonesia

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ABSTRACT: *This study aims to determine the type and pattern of agroforestry systems practiced in the North Sumatra Highlands in terms of functional and commercialization levels. Furthermore, the contribution of tree crops as a group or per type of plant and food crop farming to the income of farmer households and the role of food crops in the agroforestry system developed will be analyzed. The results of the study revealed that (i) the agroforestry system developed in the North Sumatra Highlands is classified as agrisilviculture with a variation of "multi-purpose tree" type, but the combination of woody plants is cultivated in the form of mixed gardens separated from food crop farming (paddy rice), (ii) based on the level of commercialization, the agroforestry system practiced is classified as "commercial agroforestry" where the production of tree / woody plants that contribute more than 90% of household income is entirely for sale in the market (not for self-consumption), (iii) both mixed garden farming and rice farming are financially very efficient with high R/C values (above 3), and (iv) although the contribution to household income is less than 10%, farmers rate the role of food crop farming (rice) very high (scores above 80 in the range of 0 - 100) as food security and to be stored until the next harvest season, to be sold in the crisis time or if farmers need cash unexpectedly.*

KEYWORDS: *Typology and classification of agroforestry, commercial agroforestry, agroforestry and food security, food crop in an agroforestry system, Highland of North Sumatra*

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I. INTRODUCTION

Growing trees and crops in intimate combination with each other is an ancient practice that has been applied all over the world [1], which is one form of sustainable land use system [2]. Furthermore, [1] points out that traditional land use practices involving the combined production of trees and agricultural crop species on the same land are diverse in different parts of the world and are now known as agroforestry. Trees are an integral part of these farming systems; they are deliberately retained on the farm to support agriculture but the ultimate goal of the practice is not tree/wood production but food production.

Nowadays there are various ways to classify agroforestry systems either based on function, for example as a windbreak, or based on the diversification component of the farming branches managed such as the combination of crops with pastures for livestock and trees (agrosilvopastoral) [1-3]. However, research results conclude that all agroforestry systems practiced provide benefits from ecological and socio-economic aspects. Ecological benefits include improving the quality of agricultural resources such as microclimate regulation, water retention, increasing soil fertility, and suppressing pests and plant diseases. At the same time, the socio-economic benefits of agroforestry consist of increasing farmers' income, improving food security, encouraging gender equality, and stimulating cultural activities in rural areas [2-5].

Climate change, a major global challenge today, has brought agroforestry into the limelight. Agroforestry systems attract attention because the forest component of these systems can contribute to carbon sequestration and therefore reduce the concentration of greenhouse gases in the atmosphere, thereby mitigating global warming as a trigger of climate change [6-8].

The North Sumatra highlands are located at the top of the Bukit Barisan Mountains with an altitude of more than 900 m above sea level, hilly topography and are dominated by dryland farming systems (included in the rainfed farming system according to the classification of [9]). Agroforestry systems are a common practice in this region. Similar to other regions in Indonesia, agroforestry systems in the highlands of North Sumatra can be based on forestry crops such as kemenyan (benzoin) and aren palm [10-11], or based on plantation crops such as Cocoa [12], Rubber [13] and Coffee [14], or based on fruits such as Durian, Mango, Avocado and other tropical fruits [14]. Likewise, agroforestry-based farmers of various crops generally cultivate food crops such as rice, corn, and cassava as one branch of farming. Therefore, the problem formulation in this study is to find out what type of agroforestry system developed in the North Sumatra Highlands, what is the role of food crop farming in agroforestry-based farming communities in terms of farm income structure and what are the main reasons for farmers to cultivate food crops as part of agroforestry practices.

II. LITERATURE REVIEW

2.1. DEFINITION, TYPOLOGY AND CLASSIFICATION OF AGROFORESTRY

Many types of agroforestry are location-specific as a form of farmer adaptation to local agroecological and agroclimatic conditions, which have been practiced for generations to make the best use of agriculture and forestry. Therefore, the definition of agroforestry is also very diverse ([15], [16], [1]). A more general definition is provided by [15] as follows: “Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboo, etc.) are deliberately used on the same land management unit as crops and/or animals, either on the same form of spatial arrangement or temporal sequence. In agroforestry systems, there are both ecological and economic interactions between the different components”. This definition outlines the broad boundaries of agroforestry and the distinctive characteristics of such systems which universally include: (i) agroforestry usually involves two or more species of plants (or plants and animals), at least one of which is woody, (ii) agroforestry systems always produce two or more outputs, (iii) the cycle of agroforestry systems is always more than one year, and (iv) even the simplest agroforestry systems are more complex than monoculture systems, both ecologically (structure and function) and economically.

Agroforestry systems can be categorized on four criteria, although these categories are not strictly separate but interrelated, namely [1]: (i) Structurally: refers to the components, including the spatial arrangement of the woody components, the vertical stratification of all components, and the temporal arrangement/planting time of different components, (ii) Functionally: refers to the main function or role of the system, usually complemented by the woody component (can be as a natural barrier, e.g. windbreak, shelter belt and soil conservation), (iii) Socio-economically: refers to the level of management inputs (low input, high input) or the intensity or scale of management and commercial objectives (subsistence, commercial, medium), and (iv) Ecologically: refers to ecological environmental conditions which assume that certain types of systems may be more suitable for certain agroecological conditions, i.e. there may be separate agroforestry systems for arid and semi-arid lands, tropical highlands, humid tropical lowlands and so on. Functional and structural aspects often relate to the biological properties of the woody components of the system, while socioeconomic and ecological stratification refers more to the organization of the system according to local conditions (socioeconomic or ecological).

Nair [1] inventoried 18 types of agroforestry commonly practiced in various parts of the world along with their main characteristics including descriptions of component arrangements, major component groups, and agroecological adaptability. These 18 types were then grouped into three major systems, namely: (i) Agrisilviculture: crops, including shrubs, vines and trees, (ii) Silvopastoral: trees + pasture and/or livestock, and (iii) Agrosilvopastoral: trees + crops + pasture and/or livestock. Some of these systems based on their functions are described as follows:

(i) Silvopastoral system: Trees are intentionally integrated with pastures or forage areas. The benefits of this system include improved livestock nutrition, shelter for animals, and reduced soil erosion. An example is the planting of fodder trees in pastures.

(ii) Alley cropping: This practice involves planting rows of trees or shrubs alongside food crops. These aisles provide shade, windbreak, and organic matter when mowed. Common tree species used are nitrogen-fixing legumes or fast-growing trees.

(iii) Windbreaks and Protective Belts. Trees are strategically planted to protect crops, livestock, and buildings from wind in extreme weather. Linear planting reduces soil erosion, improves microclimate, and creates wildlife habitat.

(iv) Home gardens. Small-scale agroforestry systems around a home or village. Home gardens contribute to household resilience and nutrition through the planting of trees, shrubs, and food crops in an intercropping pattern, to provide diverse food, medicine, and firewood.

(v) Forest gardens. Mimic natural ecosystems by incorporating different layers of vegetation (trees, shrubs, perennials, and ground cover). Forest gardens produce fruits, nuts, vegetables and other products. It provides benefits for enhancing biodiversity and soil health.
(vi) Agroforestry for soil improvement. For this purpose, trees are planted to improve soil fertility, prevent erosion, and enhance water retention. The types of crops used are nitrogen-fixing trees in fallows or contour planting on slopes.
(vii) Agroforestry for livelihoods. This system focuses on increasing income by planting timber plantations, orchards, and non-timber forest products.

2.2. BENEFITS OF AGROFORESTRY SYSTEMS

2.2.1 AGROECOLOGICAL BENEFITS

Agroforestry systems offer a harmonious blend of agriculture and forestry that provides a range of agroecological, global environmental (particularly climate change mitigation), and socio-economic benefits. Agroecological benefits include improved soil fertility, water retention, microclimate regulation, increased biodiversity, and reduced pest pressure [2-3]. Tree planting in agroforestry systems improves soil fertility by increasing organic matter, enhancing microbiological activity, mineralizing nutrients into more plant-available forms, cycling nutrients from deep to shallow soil layers, fixating nitrogen (for leguminous trees), and preventing nutrient loss due to leaching. Trees significantly increase soil organic matter in cropping systems through pruning, littering, root decay, and root exfoliation. This additional organic matter serves as food for microbes, which in turn increases soil microbiological activity. Increased microbiological activity leads to increased mineralization and decomposition of nutrients so that nutrients in the soil become more easily absorbed by plants, resulting in higher nutrient uptake. Increased soil organic matter added by trees to agricultural land also results in higher cation exchange capacity in the soil, which allows the soil to better retain applied nutrients to resist nutrient leaching ([2], [17-19]).

Agroforestry plays an important role in water management by improving water availability and quality. The presence of trees in agroforestry systems helps capture rainfall and reduces water runoff. This reduces soil erosion and prevents water pollution, thereby improving overall water quality. Trees in agroforestry systems have extensive root systems that penetrate deeper into the soil. These roots help absorb water from the lower soil layers, preventing excessive runoff and improving water retention. In addition, the addition of organic matter and root activity improves soil structure. This results in increased water-holding capacity, allowing the soil to hold more water for plant use. On the other hand, shade from trees in agroforestry systems slows down the evaporation of water from the soil [20].

Agroforestry practices intentionally manipulate microclimates to improve crop performance, conserve resources, and promote sustainable agriculture [21-22]. Tree canopies modify sunlight exposure. By regulating the density and placement of trees, agroforestry systems can create shaded areas for crops. Trees act as natural temperature regulators. Trees absorb solar radiation during the day and release it slowly at night. In cold climates, windbreaks minimize heat loss from cultivated areas, preventing frost damage and in hot climates, tree canopies provide shade, lowering soil and air temperatures. Trees contribute to evapotranspiration, increasing humidity in the surrounding area. Soil moisture levels are influenced by tree roots, which impact local climatic conditions. Tree roots also affect soil temperature and moisture. Agroforestry systems also increase biodiversity [3].

Agroforestry systems integrate trees, shrubs and other vegetation alongside food crops. This habitat composition provides shelter, food and breeding grounds for a variety of species. The diverse structure of agroforests supports different habitats, allowing a wide variety of organisms to coexist. Birds, insects, mammals, and soil-dwelling organisms all benefit from this habitat diversity. Agroforestry diversifies the types of crops grown. In a multi-strata system, farmers cultivate different layers (e.g. canopy trees, shrubs, ground cover). This biodiversity benefits both humans and wildlife. By combining different types of plants, agroforestry systems increase species richness. Trees, food crops, and understory plants create a complex ecosystem. In short, agroforestry practices promote biodiversity by creating diverse habitats, supporting wildlife and increasing ecological resilience.

Agroforestry systems not only increase biodiversity and improve soil health but also play an important role in reducing pest infestations on crops. By implementing a balanced ecosystem, agroforestry systems can reduce reliance on chemical pesticides, promoting a healthier environment and more resilient agricultural practices [23]. By integrating a variety of plant species, agroforestry creates a more complex habitat that supports more organisms, including beneficial predators and parasitoids of common agricultural pests. This diversity can disrupt pest population dynamics, making it more difficult for pests to thrive and spread. Predatory insects, birds, and other organisms that prey on pests will be more numerous and effective in diversifying the ecosystem. By providing a continuous variety of habitats and food sources, agroforestry systems can sustain these natural enemies, which in turn helps keep pest populations in check.

The degree of soil cover by different crops in agroforestry systems can have different effects on soil pathogens, which can be one of the IPM (integrated pest management) tools in sustainable agriculture. Weed control by cover crops is due to direct competition with weeds, use of crop residues as mulch, and in some cases allelopathy; thus eliminating, or reducing the rate, number of applications, or type of herbicides required. In allelopathy, biochemical production under vertical agroforestry systems has deleterious effects on the growth and survival of other crops. The use of complex cover crop mixtures can utilize allelopathic suppressive weeds [24].

2.2.2 GLOBAL ENVIRONMENTAL BENEFITS: CLIMATE CHANGE MITIGATION

Climate change is widely recognized as one of the most important global challenges today ([6-8], [4]). This is particularly important for the following reasons: (i) Climate change is disrupting ecosystems, affecting biodiversity, weather patterns, and natural habitats. Rising sea levels, extreme weather events, and temperature changes threaten the balance of our planet, (ii) Climate change exacerbates health risks. Heat waves, air pollution, and the spread of disease are linked to changing climatic conditions, and (iii) The economic impacts of climate change are enormous. Damage to infrastructure, agricultural losses, and increased healthcare costs strain the economy globally [25]. Climate change occurs due to a combination of natural processes and human activities. The increase in greenhouse gases from human activities, especially the burning of fossil fuels, increases the greenhouse effect. This leads to global warming, which is a rise in the average temperature of the Earth's surface. Global warming is one aspect of climate change, which refers to long-term changes in temperature, precipitation, wind patterns, and other aspects of the Earth's climate.

Agroforestry can contribute to climate change mitigation in two ways: sequestering carbon in biomass and soil and reducing greenhouse gas emissions. Agroforestry systems provide sustainable land use practices that increase agricultural productivity, maintain ecosystem services, and significantly contribute to climate change mitigation by sequestering carbon in biomass and soils. The tree and shrub components of agroforestry practices contribute to carbon sequestration by using carbon dioxide for photosynthesis and storing carbon above ground in tree trunks and branches, and below ground in roots and soil. This carbon can remain in the tree or soil for a long time. If trees are harvested for timber, this carbon will be stored for the lifetime of the products produced, such as in buildings or furniture [26]. Through plant biomass, indirect carbon sequestration also takes place. The lignin, hemicellulose and cellulose content of plant biomass fertilizes soil microbes. These microbes bind carbon from dead plant material into stable soil carbon stocks. This indirect sequestration of soil carbon contributes to overall carbon storage in agroforestry systems ([18], [27]).

Agroforestry systems can significantly reduce greenhouse gas emissions other than carbon dioxide. Agroforestry practices can reduce greenhouse gas emissions, such as nitrogen dioxide, for example, because trees can absorb excess nutrients, reducing the need for synthetic fertilizers, which are associated with high greenhouse gas emissions. By incorporating trees into agricultural systems, agroforestry can reduce the need for fossil fuels and energy use on farms. This is achieved by providing a natural windbreak, which can reduce the need for mechanical cooling or heating.

2.2.3 SOCIO-ECONOMIC BENEFITS

Agroforestry systems provide benefits generated by agricultural diversification (multiple cropping) in the form of: (i) increased income, (ii) risk reduction, (iii) increased food security, (iv) utilization of family labor throughout the year and (v) increased land productivity. In addition, there are social benefits in the form of (i) job creation, (ii) gender equality in rural areas, (iii) health by traditional medicine derived from trees or shrubs, and (iv) social culture. The agroforestry principle of cultivating two or more crops and/or livestock allows farmers to diversify their income (multiple sources of income). For example, combining crop cultivation with livestock or agroforestry can generate higher overall income and involve different labor requirements ([3], [28]). [3] further explains, that the difference of agroforestry compared to other land use systems lies in the inclusion of woody plants in the system. From an economic perspective, the adoption of tree-based agriculture can improve economic resilience through product diversification. The utilization of multipurpose trees, in particular, can increase the profitability of agroforestry as they can serve as fodder or food (e.g. edible fruits) during lean times among rural communities. In addition, some timber species that have a higher economic value can provide additional income to the community apart from the income generated from annual crops.

By diversifying activities, farmers reduce dependence on one type of crop or product. This helps reduce the impact of market fluctuations, climate variability, and other risks. For example, if one crop fails, income from other diversified activities can compensate for the loss ([24], [2-3]). Diversified farming practices in agroforestry systems also contribute to food security. By growing a variety of crops, farmers can meet local food needs and reduce dependence on external food sources. This is especially important in areas where food availability is a concern [3]. From various studies, [4] concluded that agroforestry can play a role in improving food security among forest communities, and increasing the absorption of micronutrients among children. There is a correlation between the presence of agroforestry and increased consumption of legumes, as well as increased consumption of fruits and leafy vegetables rich in vitamin A. In addition, agroforestry systems are also associated with higher meat consumption, especially from communities that adopt silvopastoral practices. Various studies have shown that business diversification (multiple cropping) which characterizes agroforestry systems will increase the efficiency of using limited land resources as measured by an increase in cropping index and land equivalent ratio (LER) which leads to an increase in relative total yield (RYT) and further results in an increase in the income equivalent ratio (IER) ([24], [29-30]). A high cropping index with year-round distribution of activities between one branch of farming and another will provide work equally for family labor and rural labor in general. Thus, seasonal fluctuations with labor-intensive seasons (therefore increasing labor demand and pushing wages up) and lean seasons (low-work activities ahead of harvest so wages are very low) will no longer occur. Whereas fluctuations in labor allocation will also affect household income and liquidity [31].

In addition to economic benefits and more efficient management of natural resources for agriculture, agroforestry systems offer opportunities to improve gender equality and increase utilization of family labor [32]. The implementation of agroforestry can also open up new employment opportunities in rural areas for off-farm activities such as drying crops and other post-harvest handling, logging, furniture making, and others. Increased employment opportunities can also benefit women as they can be directly involved in production activities, which can improve gender equality in rural areas. In addition, the absorption of labor in rural areas can prevent the exodus to other regions [3].

Rural communities rely more on traditional treatment or health care by utilizing the leaves, stems, fruits, and roots of plants that have medicinal properties or prevent various diseases that grow or are cultivated in agroforestry systems. [2] reported, that there are about 52 species of medicinal plants identified in Ethiopia, which shows the benefits of trees or shrubs for traditional medicine.

In terms of socio-culture, [3] stated that agroforestry promotes socio-cultural activities among adopters of this system. This is mainly because tree-based agroforestry land use practices provide shade services. People gather under shade trees for social and religious purposes [2]. The socio-economic benefits of agroforestry systems are summarized in Table 1.

Table 1: Socio-economic Benefits of Agroforestry System

Benefits	Description
Economic Benefits	• Increase farmers' income with diversified sources of income • Overcoming risk, falling prices, or poor harvests in one crop can be covered by other crops • Improve food security directly from the production of food crops, fruits, and vegetables and indirectly from the sale of high-value cash crops used to purchase foodstuffs • Relatively more equal allocation of family labor throughout the year to various farm businesses with different seasons and labor demands • Improved efficiency of agricultural natural resource use in the forms of increased cropping index and land equivalent ratio (LER)
Social Benefits	• Creating new rural jobs • Improving gender equality in rural areas • Producing biopharmaceuticals to treat and prevent diseases in rural areas • Encouraging cultural activities that utilize the shade of trees for activities

2.2.4 AGROFORESTRY IN INDONESIA

In Indonesia, the three major classes of agroforestry systems proposed by [1] are practiced, namely Agrisilviculture, Silvopastoral, and Agrosilvopastoral. Although farmers understand the agroecological benefits of agroforestry practices, the decision to convert agroforestry into monoculture crops depends on [33]: (i) the suitability of the crops to be planted, i.e. combining the types of plants that can grow in the land plot they have. Especially combinations with types that can be quickly harvested, for example, every day or every two weeks, (ii) pest and disease control. When the level of pests and diseases suffered by trees is getting higher, then farmers will change the land use system to the same system but with different commodities or to another system also with different commodities, and (iii) price stability of commodities produced in the form of knowledge and access to markets, especially those related to the price received by farmers for certain agroforestry commodities. Farmers will usually immediately plant crops that are known to be of economic value.

A review by [4] of publications on agroforestry in Indonesia since 2000 has revealed that the composition of crops in smallholder agroforestry systems is influenced by several factors, such as area, location, and economic background, culture, and beliefs of farmers. The most commonly cultivated agroforestry crops are (i) timber species, such as teak, sengon (*Falcataria falcata* synonyms: *Albizia falcata*, *Falcataria moluccana*, and *Paraserianthes falcataria*), and mahogany (*Swietenia spp*.), (ii) multipurpose species, such as mango, durian, coconut, and aren palm; (iii) food crops, such as upland rice, maize, cassava, taro, and sweet potato; (iv) high-value commodity crops, such as cacao, cloves, nutmeg, and coffee; (v) spices and medicinal plants, such as chili, ginger, turmeric, and galangal; and (vi) fodder crops, such as *Leucaena leucocephala*, *Gliricidia sp*., and *Erythrina sp*.

Furthermore, [4] classified agroforestry systems in smallholder communities in Indonesia based on the level of commercialization into three categories as follows:

1. Subsistence Agroforestry: 'Subsistence-scale' agroforestry means that most products are consumed directly to meet domestic household needs, and only a small portion, if any, is sold to the market. 'Subsistence-scale management' means cultivating a variety of crops with less intensive maintenance in yards or fields around the farmer's home. This is similar to complex agroforestry types, home gardens dominated by trees, or plantations that rural households have cultivated for short-, medium-, and long-term income generation.
2. Semi-Commercial Agroforestry: 'Semi-commercial' agroforestry is a transition from subsistence to commercial: it is a mix of crops for subsistence needs and commodities for local-scale commercial sale. It usually involves several crops, and each serves both subsistence and commercial functions. Thus, the combination of crops results in multifunctional (semi-commercial) agroforestry. Examples of semi-commercial agroforestry include cocoa and coffee-based agroforestry in Central Sulawesi, rubber and fruit-based agroforestry in Jambi, fallow agroforestry systems in East Kalimantan, coffee-based agroforestry in Lampung and South Kalimantan, community forest agroforestry in Bogor, West Java, traditional huma agroforestry in West Java, traditional tembawang agroforestry in West Kalimantan, mixed gardens in South Sumatra, agarwood intercropping in Flores, shifting cultivation and home garden agroforestry in West Papua and mixed gardens in Bali.
3. Commercial Agroforestry: Commercial agroforestry tends to be simple with two or three crop combinations, one of which is the main commodity that is developed more intensively. These agroforestry practices have multiple commodities, and each commodity has a commercial function. While these systems are often a combination of several commodities, they usually focus on only two or three species for commercialization. Thus, the diversity of commercial commodities is much less than in semi-commercial agroforestry or subsistence agroforestry. These systems cannot contribute directly to domestic needs (food) but earn income, which increases consumption power to purchase food. Commercial agroforestry will increase income but decrease biodiversity. For example, commercial vegetable agroforestry is found in home-garden agroforestry systems in West Java, dragon blood fruit agroforestry in South Sumatra, repong damar agroforestry in Lampung, palm oil agroforestry in Jambi and cardamom agroforestry in community forests of Central Java.

The subsistence, semi-commercial and commercial categories are not always reliable predictors of landowners' income and welfare prospects. Many factors lead landowners to choose a particular agroforestry model. These factors include land size, which affects the productivity prospects of the land; the need for crops and the financial condition of the landowner; the investment capacity of the landowner; the type and quality of commodities that can be cultivated; and market conditions (which are often influenced by access and transportation, which in turn affect the demand and selling price of commodities). The ability of the land to generate economic value can also vary from region to region, depending on the tenacity of the farmer, land security, commodity type, capital capacity of the farmer, market access, crop quality, and seasonal suitability. All of these factors are interrelated and shape agroforestry patterns in Indonesia today.

So far, research on agroforestry in the North Sumatra Highlands has been dominated by commercial agroforestry with forestry crops such as frankincense, candlenut and aren palm or plantation crops such as coffee, rubber and cocoa as the main crops. Studies on the role of fruit and/or food crops as the basis of agroforestry systems are still very rare.

This study aims to investigate (i) the types and patterns of agroforestry systems developed in the North Sumatra Highlands in terms of functional and commercialization levels, (ii) the level of income and efficiency of agroforestry as a unit and per type of plant, (iv) the level of income and efficiency of food crop farming (paddy cultivation), (v) the contribution of tree crop business results as a group and per type of plant as well as food crop farming to farmer household income and, (vi) the role of food crops in the agroforestry system developed.

III. METHODOLOGY

This study is descriptive, using primary data obtained through interviews based on a prepared questionnaire to 20 farmers who cultivate woody crops, especially fruits, and rainfed paddy as one of the combination commodities. The function of trees in the agroforestry system was observed.

Farming analysis was carried out to compute the income of the food crop subsystem and tree crop subsystem by comparing revenue (financial earnings obtained from the sale of production, which is the result of multiplying production by the selling price) with production costs (in the form of expenditures for land rent, inputs - seeds, fertilizers and pesticides and labor wages). Production efficiency is obtained from the comparison of the value of revenue and costs in each farming subsystem. Finally, the contribution of each farming business as a source of farm household income is calculated from the income of the farming business divided by the total farm income.

The role of food crops is obtained from the farmers' assessment of the rice farming they manage, including the reasons for cultivating paddy (easy cultivation techniques, availability of household labor, and guaranteed production) and commercial reasons (stable production prices because the government guarantees) as well as the role of rice yields (to meet subsistence consumption needs and/or in case of difficult times). To explore information on the role of food crops to respondent farmers, statements were submitted that had to be answered with five categories of answers using a Likert scale. The total number of respondents used as informants was 20 farmers who implemented agroforestry with rice as one of its components.

The study was located in Lumban Garaga Village, Pahae Julu Sub-district, North Tapanuli District, North Sumatra Province. Data collection took place in July 2023.

IV. RESULTS AND DISCUSSION

Respondent households are balanced between men as heads of households and women. Rice fields are mostly rented (75%) and only 25% cultivate paddy on their land. The size of paddy fields is relatively small with an average of 0.51 ha. An overview of the characteristics of respondents is depicted in Table 2.

Table 2: Respondent Characteristics

Description	Unit	Mean	Range
Age	year	50.75	30 – 68
Education	year	10.20	6 – 12
Household Size	people	4	1 – 7
Farming Experiences	year	24	8 – 40
Paddy Field Area	hectare	0.51	0.20 – 1

In addition to paddy, farmers cultivate forestry crops: Frankincense (*Styrax spp*.) is cultivated by 55% of respondents. Plantation crops: Cocoa (*Theobroma cacao* L.), Areca nut (*Areca catechu*) and Rubber (*Hevea brasiliensis*) were cultivated by 85, 80 and 75% of respondents respectively and fruit crops: Durian (*Durio zibethinus* Murr) was cultivated by all farmers while Jengkol (*Pithecellobium jiringa*) and Petai (*Parkia speciosa* Hassk) were cultivated by 35 and 30% of respondents respectively.

From the records of seven woody plant species, farmers combined at least three species in agroforestry practices. Likewise, only 5% of farmers cultivate a combination of seven types of plants, the most common combination is five types (by 40% of farmers) and 30% of farmers combine four types of plants, while those who combine three and six types are 15 and 10% respectively. The combination of crops cultivated shows the diversification of income sources and harvest periods. All crops are cultivated for non-timber production in the form of cash crops whose products are sold in the market rather than for self-consumption. The harvest period allows farmers to sell every 10 days (rubber), every two weeks (cocoa) and every month (areca nut). Meanwhile, fruit crops due to their seasonal nature can only be harvested twice a year (jengkol and petai) or even only once a year (durian). Whereas rainfed rice fields, which rely on rain, can only be cultivated once a year and the results can be used for self-consumption, sold at the market or stored until the next harvest season to anticipate a potential crisis.

Paddy is cultivated on flat land surrounded by woody plants in the form of mixed farms according to Nair's typology [1]. The farm location is 700 meters to 2 km from the farmer's settlement. Thus, the type of agroforestry practiced is not a home garden. A visual representation of the spatial layout of agroforestry with rice crops is presented in Figure 1.

Figure 1: Spatial Arrangement of Agroforestry Farming with Food Crops in the North Sumatra Highlands

In contrast to rice farming, where farmers remember exactly the frequency of fertilization and crop protection along with the type and quantity of fertilizers and pesticides used, the maintenance of woody plants is only done sporadically. Therefore, farmers cannot describe costs per crop type but can remember the amount and type of fertilizer purchased for farming other than paddy in a year. Explicit costs for agroforestry only concern fertilizer and equipment because labor for maintenance and harvesting uses family labor. The composition of revenues and costs that form the basis for calculating farm income from woody crops (mixed gardens) is shown in Table 3.

Table 3: Farming Analysis of Mixed Farming (Agroforestry)

Type of Crop Cultivated	*n*	Total Trees	Production Value (IDR)
Frankincense (*Styrax spp*.)	11	139	14 727 273
Areca nut (*Areca catechu*)	16	110	6 225 000
Cocoa (*Theobroma cacao* L.)	15	242	13 305 882
Rubber (*Hevea brasiliensis*)	17	173	11 120 000
Durian (*Durio zibethinus* Murr)	20	17	23 650 000
Petai (*Parkia speciosa* Hassk)	7	12	2 464 286
Jengkol (*Pithecellobium jiringa*)	6	5	600 000
Total Revenue			72 091 441
Total Costs			2 870 000
Average of annual income (gross margin)			54 582 500

Note: The numbers in the table are the average values of the respondents who cultivate each type of crop (*n*).

Paddy farming with rainfed irrigation systems can only be cultivated once a year. The achievable productivity of 3.314 tons/ha is far below the average productivity of North Sumatra of 5.2 tons/ha. Likewise, almost all costs of rice farming are explicit. The nature of rice cultivation, which requires collective action and therefore must be carried out simultaneously in one community/rice field, requires work to be done quickly. In response to such working conditions, farmers hire tractors for tillage and threshers for harvesting and use hired labor for planting. Table 4 presents the analysis of rice farming.

Table 4: Analysis of Rice Farming (Rainfed) in the North Sumatra Highlands (Average Area 0.51 ha).

Description	Value (IDR)
Costs:	
Seeds	70 000
Fertilizer	1 015 000
Pesticide	175 000
Depreciation of capital (equipment)	110 000
Machinery rental and wages	885 000
Land rent	225 000
Revenue: 1 690 kg x IDR 5 000	8 480 000
Gross margin of paddy farming	5 978 000

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Tables 3 and 4 show that both rice farming and agroforestry practices are profitable with high economic efficiency measured by the R/C ratio values of 3.41 for paddy and 25.19 for mixed agroforestry, respectively.

Farmers' income streams by crop (commodity) and by group (mixed farming and rice) are shown in Table 5. Since only durian and paddy are cultivated by all respondents, the income contribution of other commodities refers to the average value of all respondents who cultivate them (*n*).

Table 5: Farmers' Income Sources and Contributions by Crop Type and by Group (Mixed Agroforestry and Rice) in the Highlands of North Sumatra

Description	*n*	Income (IDR)	Contribution (%)
Total Income	20	60 560 500	100
Paddy Farming	20	5 978 000	9.87
Agroforestry	20	54 582 500	90.13
Frankincense (*Styrax spp*.)	11	14 727 273	24.32
Areca nut (*Areca catechu*)	16	6 225 000	10.28
Cocoa (*Theobroma cacao* L.)	15	13 305 882	21.97
Rubber (*Hevea brasiliensis*)	17	11 120 000	18.36
Durian (*Durio zibethinus* Murr)	20	23 650 000	39.05
Petai (*Parkia speciosa* Hassk)	7	2 464 286	4.07
Jengkol (*Pithecellobium jiringa*)	6	600 000	0.99

The analysis shows that the agroforestry system in the North Sumatra Highlands is categorized as "commercial agroforestry" according to the classification of [4]. More than 90% of farmers' household income is obtained from woody plants (mixed gardens) in the form of fruit crops, plantation crops, and forestry crops whose overall production is for sale (not for self-consumption). Per crop type (per commodity), the five main commodities that farmers rely on as a source of income are durian, frankincense, cocoa, rubber, and areca nut, respectively.

Financially, the contribution of paddy as a source of income for farmers is only less than 10%. However, farmers highly value the role of rice farming (score > 80 on a scale of 0 - 100), as its production can guarantee food security and is the last stronghold in the face of crisis (failure of mixed crops), as rice can be stored until the next harvest season and can be sold at any time if cash is urgently needed. Rice in Indonesia is one of the commodities controlled by the government, so its price remains stable.

The role of farming for food security and precautionary purposes is much higher than other reasons for farmers to cultivate paddy. Aspects related to technical cultivation as a reason for cultivating paddy got a score of 70 to 80 on a score range of 0 - 100), such as rice farming does not require a lot of labor or availability of production inputs so that the yield is guaranteed (Figure 2).

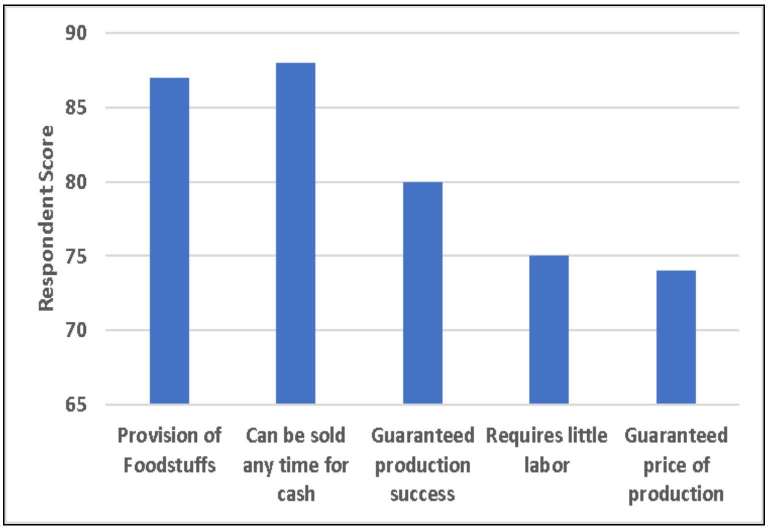

Figure 2: The Role and Reasons of Cultivation of Paddy in Agroforestry-Based Farming Communities in the Highlands of North Sumatra

V. CONCLUSION

Based on the research results, the following conclusions can be drawn:

1. The classification of agroforestry that developed in the North Sumatra Highlands is Agrisilviculture in the form of a combination of forestry plants, plantation crops, fruit crops, and food crops, where woody plants are cultivated in the form of mixed gardens on a separate field of land from paddy cultivation as a food crop.
2. Based on the objectives of production, agroforestry practiced in the North Sumatra Highlands is categorized as "commercial agroforestry" where the production of woody plants that make up more than 90% of the total income of farmer households is entirely for sale in the market (not for self-consumption).
3. Crop types with highly varied harvest periods ensure farmers can sell agricultural products at least every 10 days.
4. Financially, the production of agroforestry systems is highly efficient as measured by the R/C ratio of 25.19 for mixed agroforestry farming and 3.14 for paddy cultivation, respectively.
5. Although the contribution of rice farming yields to farmers' income is less than 10%, farmers consider the role of food crops very high as a provider of food security and stock that can be sold if farmers need unexpected cash.

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