The patterns of agroforestry: the implementation and its impact on local community income and carbon stock in Sesaot Forest, Lombok, Indonesia

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The patterns of agroforestry: the implementation and its impact on local community income and carbon stock in Sesaot Forest, Lombok, Indonesia

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Abstract. This article aims to explore the implementation of agroforestry patterns in the Sesaot forest area and the impacts on the local community income and the carbon stocks. It is written based on descriptive research, data are collected through observation, interviews, and FGDs to 42 respondents, and measuring carbon stocks in 18 locations. The analysis in this study is divided into three: 1) clustering based on plant dominance to identify existing agroforestry patterns, 2) allometric equations to measure the amount of carbon stock, and 3) using scoring to analyze the identified agroforestry patterns to find out the most optimal. This study finds that there are four agroforestry patterns in this area: candlenut dominant, mahogany dominant, mixed agroforestry, and simple agroforestry. From these patterns, mixed agroforestry seems to be the best practice in this area since it has complied with the principles of sustainable forest management both from the perspective of economic and the environment.

1. Introduction

Sesaot is a forest in Lombok Island that covers a protected forest area of 3,042 hectares. However, between 2000 and 2010, the coverage of the area changed dramatically due to illegal logging (1). This is in parallel with the results of Landsat 5 TM imagery where, from 1995 to 2010, there has been a 22 percent decline in primary forest cover (2,3). These changes are related to forest management practices by local communities, especially through the implementation of agroforestry systems (4). Nevertheless, it does not mean that agroforestry practices always have bad ramifications, but in many cases, these practices play an important role in supporting forests (5). Agroforestry is regarded to have a beneficial effect on lowering the rate of surface runoff and preserving biodiversity and carbon stocks (6,7).

Agroforestry system used in Sesaot forests, with plant densities above 900 plants per hectare, has positive effects, including maintaining a species diversity index of 2.4, surface runoff of 6%, and carbon stocks of 170 tons per hectare (8). These numbers demonstrate the critical importance of agroforestry systems in preserving environmental quality. Additionally, the agroforestry system helps the community's economic well-being by generating between USD 125.73 - 146.69 per hectare each month, depending on the variety of crops handled by the farmers.

The carbon stock value is one of the instruments to measure the condition of a forest; the higher existence of carbon stock indicates the vegetation cover is getting denser and the plant biomass is getting bigger, thus indicating better forest conditions (9). Accordingly, this measurement is often used by credible institutions such as the Ministry of Forestry, ICRAF, CIFOR, IPCC, and the World Bank to evaluate forest conditions at regional, national, and global levels (10). Local communities manage forests using agroforestry systems in a variety of ways, which are characterized by variation in vegetation kinds, plant structures, recognized vegetation species, and plant density. Indeed, the variety of agroforestry patterns will affect community incomes and carbon stock values.

High generate measurements in both revenue and carbon stock are desired outcomes of a well-implemented agroforestry system (11). Within Sesaot Forests, the varied patterns used by the local population will provide a range of revenues and carbon stocks for the area. However, there are obstacles at the community level in determining which patterns or practices are most acceptable and optimum in terms of economic and environmental advantages, hence achieving sustainable forest management. More precisely, this article aims to analyze the implementation of existing agroforestry patterns in the case of the Sesaot Forest Area, West Nusa Tenggara, from the economic and environmental aspects.

2. Method

This study is written descriptively. The descriptive method is research that is used to examine phenomena in detail or to distinguish one phenomenon from other phenomena (12). Data are collected through observation, interview, and measurement techniques at the plot level. In a field study conducted in July 2020, the authors observed not only the location and block of forest areas where the farmers applied agroforestry practices but also the diameter of the farmers' plants. The number of carbon stock measurement locations at the plot level is 18 locations. The plot sizes are 20 m x 20 m for trees, 10 m x 10 m for poles, and 5 m x 5 m for stakes. In addition, the respondents in this study are farmers who are included in the social forestry scheme, with a total of 42 people who have been determined through the solving approach (10% margin of error). All of the respondents interviewed are members of *Wahana Tani Lestari* (a farmers' organization) who own land in the Sesaot forest area.

There are several variables analyzed in this study. First, identifying the diversity of agroforestry patterns with the variables studied including the name of plant species, the number of plants, a grouping of plants based on wood and non-timber types, and compiling agroforestry patterns based on the dominance of the main stand plant species. Second, analyzing farmer's income through aspects including production input costs, total production of all types of plants, production prices of all types of crops, and production value (13). Third, analyzing the amount of carbon stock by measuring all types of plants that have a diameter (DBH=diameter at breast height) above 5 cm, and grouping based on the size of the stake (DBH 5-10 cm), poles (DBH >10-20 cm) and trees. (> 20 cm). Finally, analyzing the performance of agroforestry patterns where the variables studied are the income value for each agroforestry pattern and the amount of carbon stock for each agroforestry pattern.

Agroforestry patterns are determined based on descriptive analysis through the categorization of the combination of cropping patterns and the dominant variety of Multi-Purpose Trees Species (MPTS); Meanwhile, the income aspect of farmers is calculated from the results of forest management specifically for non-timber forest products. Since the forest area in Sesaot functions as a protected forest, the analysis of the estimated amount of carbon stock uses the allometric equation (Table 1). For the Analysis of the performance of agroforestry patterns, it is measured using a scoring technique by considering the amount of income and the amount of carbon stock (Table 2). Furthermore, the range of values in the table below is obtained from the two components of scores for income and estimated carbon stocks (Table 3).

Table 1. Allometric Equation for tree carbon calculations.

Plants	Tree biomass estimation (Kg/plants)	Sources
Tree	$BK = 0{,}11\ \rho\ D^{2{,}62}$	Katterings, 2001
Tree without branches	$BK = \pi\ \rho\ H\ D^{2{,}08}$	Hairiah et al, 1999
Palm	$B = \exp(-2.134+2.530 \times \ln(D))$	Brown, 1997
Coffe	$B = 0.281D^{2.06}$	Arifin,2001;Van Noordwijk,2002
Cacao	$B = 0.1208D^{1.98}$	Yuliasmara et al., 2009

Source: (14)

Note: B = Dry Weight ($kg/tree^{-1}$)
ρ = Density ($Mg\ M^{-3}$, $kgdm^{-3}$ or $gr\ cm^{-3}$),
D= Diameter (cm) at chest height (1.3 m),
Total biomass = $BK_1 + BK_2 + BK_3 + ... BK_n$

Table 2. Optimal level/feasibility of agroforestry patterns.

Value range	Criteria	Information
20 – 70	Not optimal	Appropriate agroforestry practices have a balance between the income aspect and the amount of carbon stock in the forest area
> 70 - 120	Enough	
> 120 - 170	Good	
> 170 – 200	Very good	

Table 3. Measurement for income.

No	Income Range (USD/year/hectare)	Criteria	Description Score
1	< 377.19	Bad	10
2	> 377.19 – 1131.57	Enough	30
3	> 1131.57 – 1885.95	Good	60
4	> 1885.95	Very good	100
	Carbon stock range (Mg/ha)		
1	< 30	Bad	10
2	> 30 - 70	Enough	30
3	> 70 – 110	Good	60
4	> 110	Very good	100

Note: The approach uses carbon stock values for agroforestry in several locations in Indonesia (Hairiah et al, 2011).

3. Result and discussion

3.1. Overview of respondents

The area of land cultivated by farmers in the forest is approximately 0.4 hectares, and it is in line with the data from West Lombok Regent's Decree on Community Forest Utilization Business Permits (2005). The division of land prioritizes the lower class of society, including landless people, poor widows, and poor people who heavily depend on forest resources. Most of the respondents consist of the age interval of 32-47 years. Land management rights in forest areas are not only cultivated by farmers who receive permits but also those who have previously been involved as the labor by farmers' families (either their children or their relative's in-laws) as well. Respondent's educational backgrounds are mostly from elementary (40%) and junior high school (26%). The level of education is related to the knowledge, skills, cognitive. In the field, two college graduates are involved in community forest management since those two are quite successful in managing their land. Additionally, since all respondent jobs are forest farmers, they rely on forest products for revenue, particularly non-timber forest products (NTFPs). Nonetheless, since farmers have side businesses (such as forest farmers, breeders, and traders) as well, their income is not entirely drawn from the forest.

3.2. Identification of agroforestry patterns

Agroforestry patterns that are generally used are mixed with a random system. Through this pattern, crops are managed randomly by farmers without adjusting the spacing or specific paths between plants (Markum, et al., 2004).

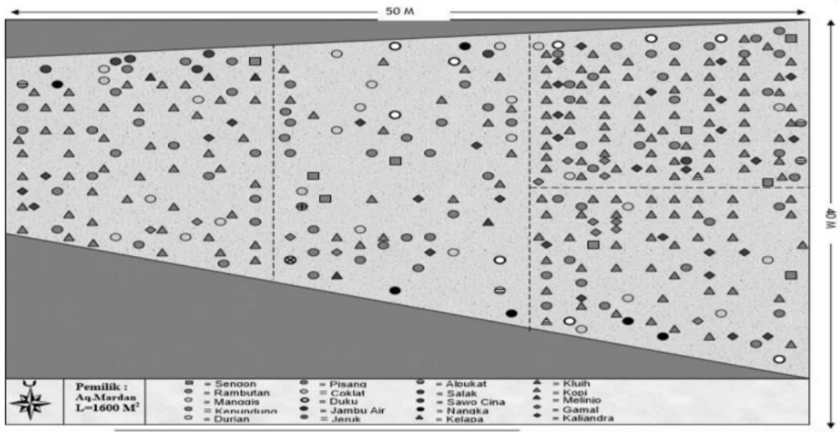

Figure1. The random pattern of agroforestry systems.

Farmers maximize the available space for planting with various types of crops which are carried out in a gradual process. As a result, variety exists not only in terms of plant types but also in terms of plant age. Figure 1 illustrates the random pattern of agroforestry. Meanwhile, Table 4 summarizes the prevalent varieties and quantities of plants in Sesaot with tree diameters more than 5 cm.

Table 4. Types and numbers of plants on farmer's land.

Plants	Latin Name	Average Number of Plants (Plant/ha)
MPTS Plant		
1. Durian	*Durio zibethinus*	20
2. Sugar Palm	*Arenga pinnata*	8
3. Mangosteen	*Garcinia mangostana*	41
4. Rambutan	*Nephelium lappaceum*	24
5. Cocoa	*Theobroma cacao*	67
6. Coffe	*Coffea canefora var robusta*	48
7. Pecan	*Aleurites moluccana*	23
8. Jackfruit	*Artocarpus integra*	5
9. Avocado	*Persea americana*	6
10. Melinjo	*Gnetum gnemon*	8
Tree		
1. Mahogany	*Swietenia macrophylla*	33
2. Sengon	*Paraserianthes falcataria*	5
3. Dadap	*Erytrina sp.*	7
4. Suren	*Toona sureni*	3
Others		
1. Pisang	*Musa paradisiaca*	48
2. Pepaya	*Carica Papaya*	37
		382

The sesaot forest area has a plant density of 382 plants per hectare. The density is lower than the value reported by Markum et al. (2013), which is around 600 plants/ha. Reduced plant density is caused by an increased proportion of MPTS plants which eliminates opportunities for plants to grow in the shade. The categorization of agroforestry patterns is determined based on the dominance of plant species, of which at least four are identified: (1) candlenut dominant, (2) mixed agroforestry, (3) mahogany dominant, and (4) simple agroforestry. These patterns are specifically elaborated in Table 5.

Table 5. The description of agroforestry patterns.

Patterns	Details	Total respondents	Percentage (%)
1. Candlenut Dominant	Candlenut is shown to be more prevalent at a density of 25-30 trees/ha. Along with candlenut trees, there are various other plant species, including durian, coffee, cocoa, jackfruit, and avocado. Banana plants are discovered growing underneath the candlenut stands.	5	12
2. Mixed Agroforestry	Most of the farmers apply this pattern. Types of plants vary with a balanced amount. This pattern is characterized by the number of fruit plants over the age of five years. Farmers choose this pattern because it gives a double benefit, which means they can harvest certain commodities in rotation for most of the year.	27	64
3. Mahogany Dominant	This pattern is rarely used because the mahogany tree is the original stand of the forest area. Farmers do not grow mahogany; rather, they grow plants that thrive in its shade, such as coffee plants. This pattern is the least desirable because the mahogany cover can be very tight, leaving little sunlight for the plant underneath.	3	7
4. Simple Agroforestry	This pattern is characterized by at least tree plantations (below 100 plants/ha) but dominated by banana, papaya, and red bean (lebui) plants. Few farmers follow this strategy, since the outcomes of some goods, such as bananas and papayas, are viable for them. However, currently, the lands have begun to be intercropped with several types of MPTS, so that within the next 5 years it will be predicted that MPTS will overplant bananas and papayas.	7	17
Total		42	100

The first pattern is dominated by the candlenut plant. This pattern is characterized by the prominence of several plants that grow under it such as cocoa, mangosteen, coffee, and fruit. According to the farmers, the advantage of the candlenut plant is that it has sufficient light space for these plants to grow, despite having a wide canopy. The second is a mixed agroforestry pattern. This pattern is overgrown by several types of plants such as cocoa, coffee, mangosteen, durian, rambutan, and sugar palm. These plants not only have a high density but also have a tree diameter of about 10 cm – 30 cm. The total density of the various plants mentioned above is 308 tan/ha for the candlenut dominant agroforestry pattern, while 402 tan/ha for the mixed agroforestry pattern. Meanwhile, striking differences occur in the third and fourth patterns, namely mahogany dominant agroforestry, and simple agroforestry. In mahogany dominant agroforestry, other plants are relatively few. Plants that can grow under mahogany are coffee, cocoa, mangosteen, and rambutan. However, due to the dense shade, it causes the growth of

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various types of plants is not optimal. The plant density in this mahogany dominant pattern is 255 tan/ha (see Figure 2).

The simple agroforestry pattern has a total density of 181 tons/hectare, consisting of a variety of plants such as coffee, cocoa, rambutan, and mangosteen. Some other plants that can be found include dadap, sengon which also function as a shade for coffee, and cocoa plants. In addition, other crops that are quite prominent in simple agroforestry patterns are bananas and papayas. These plants are favored by farmers especially at the beginning of managing Forest land. There are 2 reasons: first, bananas and papayas can grow productively at the beginning of land clearing; Second, the two crops contribute to increasing household economic income, given that apart from these crops being harvested every month, there is also a high market demand for both (Figure 3).

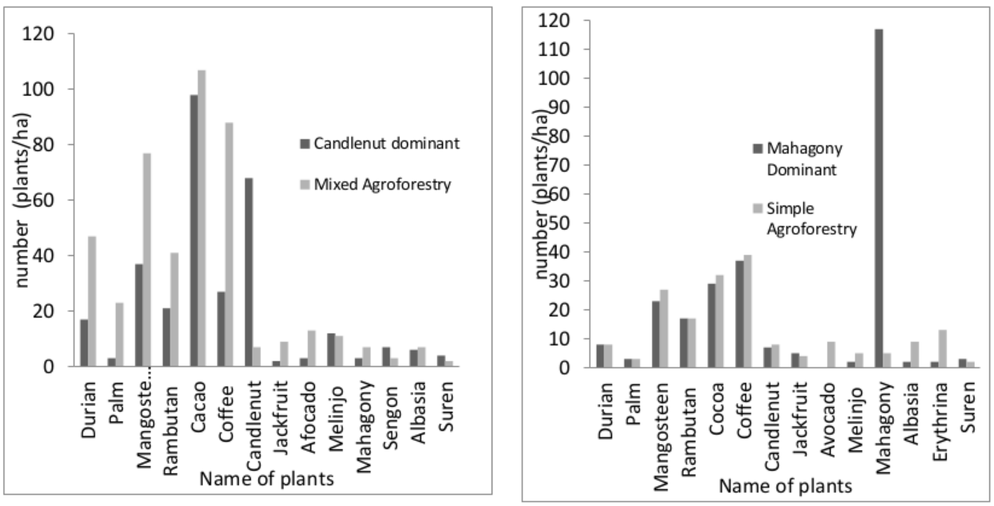

Figure 2. Variety and number of plants in agroforestry patterns.

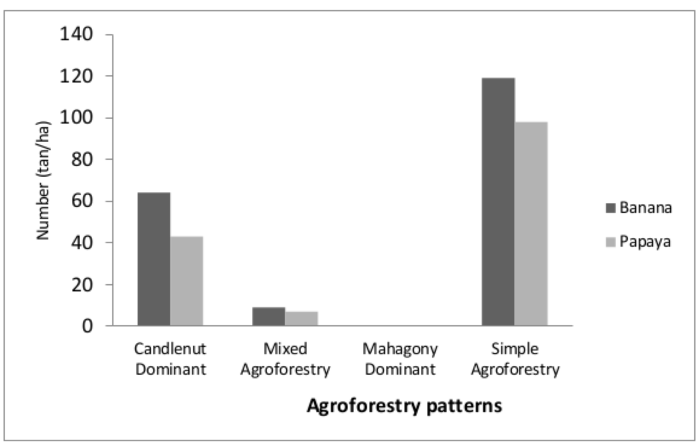

Figure 3. Number of banana and papaya crops in agroforestry patterns.

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3.3. Analysis of income

Plants cultivated using agroforestry methods are critical to the economic well-being of the people surrounding the Forest. Farmers may harvest these plants daily, weekly, monthly, or seasonally because each species of plant has a distinct production phase. It must be notified that NTFPs, particularly fruits, have a high potential economic value. As a result, it is noteworthy that agroforestry methods contribute to these farmers' food security and economic viability.

Table 6. Average production of each plant and cost.

Plants	Average Number of Plants/ha	Average production (/tan/year)	Units	Production cost (USD/unit)
NTFP plants				
1. Durian	20	28	Buah	1.40
2. Sugar Palm	8	179	Butir	0.70
3. Mangosteen	41	7,5	Kg	0.87
4. Rambutan	24	30	Kg	0.42
5. Cocoa	67	13,6	Kg	1.12
6. Coffe	48	4.5	Kg	1.54
7. Pecan	23	50	Kg	0.70
8. Jackfruit	5	17	buah	0.56
9. Avocado	6	47	Kg	0.28
10. Melinjo	8	12	Kg	1.05
Trees				
1. Mahogany	33	-	-	-
2. Sengon	5	-	-	-
3. Dadap	7	-	-	-
4. Suren	3	-	=	-
Others				
1. Banana	48	1	Tandan	2.03
2. Papaya	37	17	buah	0.21
	382			

The above table describes revenue estimates for multiple products per hectare and for one year that are achievable. Based on the production time interval, farmers who have high plant diversity tend to harvest more frequently. From the analysis, it can be concluded that the mixed agroforestry pattern obtained the highest production value, while the lowest is the mahogany dominant agroforestry pattern. These expenditures include seeding, maintenance, and harvesting. Spending costs for garden maintenance are carried out during *ngasor* activities (hoeing/turning the soil) at the beginning of the rainy season. Farmers often do *ngasor* with family members, while only a few hires someone else (approximately USD 4.19/day) to handle this activity. The latter is necessary if the farmer is unable to work or get assistance from family members. Figure 4 below illustrates the production values, costs, and revenues associated with different agroforestry patterns.

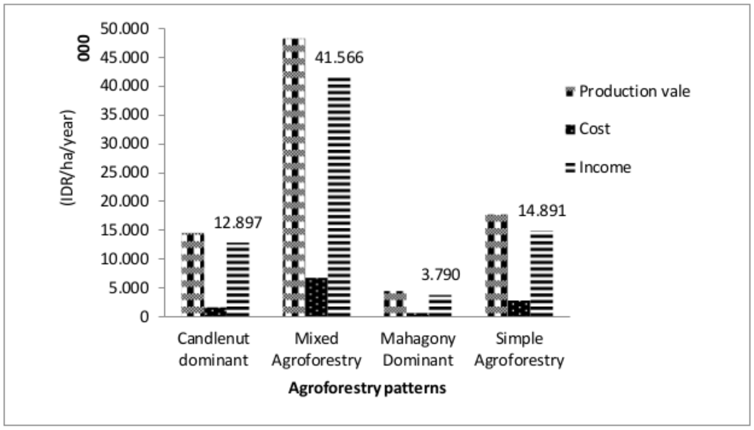

Figure 4. Production values, costs, and revenues in agroforestry patterns.

3.4. Carbon stock estimation

The dominant mahogany agroforestry pattern has the maximum carbon stock, at around 136 tons/ha, whereas mixed agroforestry has the lowest. The diameter of the tree and the specific gravity of the wood are the parameters that influence the outcomes. The diameter of the plants in the dominant agroforestry pattern of candlenut, mixed agroforestry, and dominant mahogany, which mostly consist of plants with a diameter of more than 20 cm (trees). On the other hand, simple agroforestry is dominated by pole diameter plants. In all agroforestry patterns, the amount of carbon stock mostly comes from tree diameter. On average, 75% of carbon stock is contributed by tree diameter, while the smallest is from saplings (6%) (see Figure 5).

The composition of the number of trees is more than that of pole and sapling because the practice of Social Forestry in Sesaot started in 2000, and plant enrichment began in 2005. Accordingly, these plants are between 15-20 years old and have a diameter of up to 20 meters. This finding is in line with the results of the study by Markum et al where most of the carbon stock comes from trees (2). In a nutshell, the application of agroforestry systems contributes to large carbon stocks at the landscape level, as is the case in several other places (6,11).

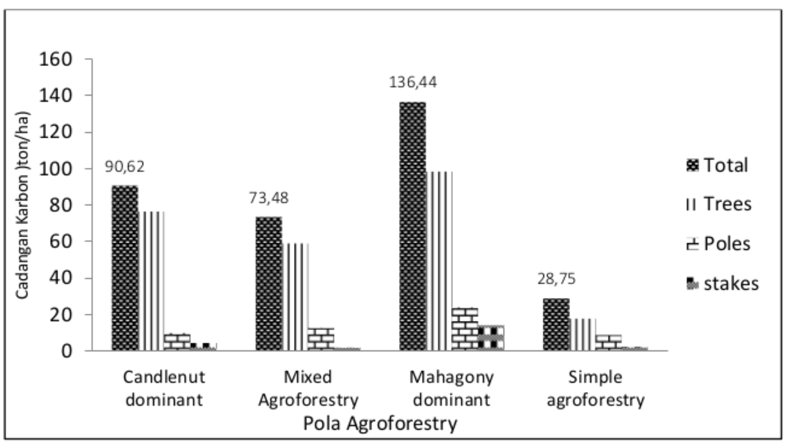

Figure 5. Carbon stocks in various agroforestry patterns.

3.5. The implementation of agroforestry patterns: the analysis

The purpose of the performance analysis is to understand which agroforestry pattern is most suitable by taking the components of income and the amount of carbon stock into consideration. These components represent two aspects of forest area management: economic and environmental concerns. The income aspect describes household economic indicators obtained from non-timber forest products. Meanwhile, carbon stocks provide information on environmental aspects. Carbon stock measurements provide insight into forest conditions, particularly the quantity of plant biomass, forest cover, Base Area (LBD), and plant density (7,15). In terms of income, the highest score is mixed agroforestry (very good category) with an income of USD 2903.39 /hectare/year, where it is assumed that each family earns USD 2.02 per capita/day. This income indicates that the family that earns this amount of income is above the poverty line. Table 7 summarizes the revenue estimates for several agroforestry patterns.

Table 7. Income scores across various agroforestry patterns.

Agroforestry Pattern	Income (USD/ha/year)	Score	Criteria
1. Candlenut Dominant	900.88	30	Enough
2. Mixed Agroforestry	2903.39	100	Very Good
3. Mahogany Dominant	264.76	10	Bad
4. Simple Agroforestry	1040.10	30	Enough

Table 8. Total carbon stock scores in agroforestry patterns.

Agroforestry Pattern	Carbon Stock (ton/ha)	Score	Criteria
1. Candlenut Dominant	90,62	60	Good
2. Mixed Agroforestry	73,48	60	Good
3. Mahogany Dominant	136,44	100	Very Good
4. Simple Agroforestry	28,75	10	Bad

Meanwhile, the mahogany pattern is categorized as bad because the agroforestry pattern has failed to fulfill the minimum poverty standard for 1 person (USD 1.05/person/day) or a minimum of USD 377.19/year. However, on the other hand, this pattern receives the greatest score for the carbon stock component when compared to other patterns (see Table 8). These findings indicate that there is a discrepancy between the economic and environmental components at the implementation level, in agroforestry practices, thus it is required to emphasize this further reconcile the two components.

Table 9. Performance assessment of various agroforestry practices.

Agroforestry Patterns	Income (USD/ha/year)	Carbon Stock (ton/ha)	Score	Criteria
1. Candlenut Dominant	30	60	90	Enough
2. Mixed Agroforestry	100	60	160	Good
3. Mahogany Dominant	10	100	110	Enough
4. Simple Agroforestry	30	10	40	Bad

Based on the analysis above, the mixed agroforestry pattern obtain the best performance among the others. This pattern has met the requirements to support household income as well as forest conservation. Although the carbon stock value is not as large as that of mahogany, this pattern has a high plant density and diversity, which can maintain soil stability in terms of microeconomics, reduce surface runoff, and as a buffer for plant species diversity. In a nutshell, good agroforestry practices may minimize surface runoff by up to 17 percent and are close to surface runoff in primary forests (16).

4. Conclusion

In conclusion, the implementation of agroforestry in the Sesaot Forest is classified into four patterns: candlenut dominating, mixed agroforestry, mahogany dominating, and simple agroforestry pattern. The income generated by these patterns is as follows: candlenut dominant (USD 900.88), mixed pattern (USD 2903.39), mahogany dominant pattern (USD 264.76), and simple pattern (USD 1040.10). Mahogany has the greatest carbon stock (136 tons/ha), followed by the dominant pattern of candlenut (91 tons/ha), mixed pattern (74 tons/ha), and simple pattern (29 tons/ha). Based on the assessment measured both on the economic component and carbon stock, the mixed agroforestry pattern has the highest performance since it more likely fits the principles of sustainable forest management.

In addition, there are three recommendations, namely practical, academic and policy implications, that should be considered. First, community empowerment activities through training on better cultivation systems to improve the quality of non-timber forest products thereby opening-up wider market opportunities. Second, there is a need for further study that focuses on resilience and vulnerability on environmental aspects in each identified agroforestry pattern. Regarding environmental aspects, it includes soil organic matter, surface runoff, soil structure, and biodiversity. The last, for policy implication, the mixed agroforestry pattern has the potential benefit of being a model in the formulation of strategic planning community development programs at the provincial forestry office.

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