Forest and Society
Vol. 7(2): 247-262, November 2023
doi: 10.24259/fs.v7i2.25752

REGULAR RESEARCH ARTICLE

Evaluating agroforestry patterns to increase land productivity of *Falcataria moluccana* private forests in Central Lombok Regency, West Nusa Tenggara

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RECEIVED 2023-03-03
ACCEPTED 2023-05-19

ABSTRACT

Developing agroforestry systems in private forests is expected to increase productivity. This study aims to determine the appropriate agroforestry design for *Falcataria moluccana*-based private forests in Central Lombok Regency. Three intercrop species were tested: small taro (*Colocasia esculenta*), ginger (*Zingiber officinale*), and vanilla (*Vanilla planifolia* Andrews). This study was established using a completely randomized design. The three planting combinations were examined in three replications for a total of nine test plots: *F. moluccana*+vanilla+small taro (FmVT), *F. moluccana*+vanilla+ginger (FmVG), and *F. moluccana*+vanilla+ginger+small taro (FmVGT). Each test plot was 10 x 10 m and was located at 3 x 3 m spacing under a 3-year-old *F. moluccana* stand. The measured variables were crop survival rates, plant yields, and microclimatic data. The correlation between the variables was examined using the Pearson Product Moment, Duncan's advanced multiple range test (DMRT), and analysis of variance (ANOVA). The market price was used to determine the crop's economic value. The best agroforestry design was based on the economic value of crop production and the land equivalent ratio. The results indicated that the combination of *F. moluccana,* vanilla, ginger, and small taro, which generated an additional income of IDR 11,851,250 ha^{-1} a year, should be widely promoted and adopted.

KEYWORDS
Intercropping; Private forest; *Falcataria moluccana*; Land productivity; Suitability of plant species.

1. INTRODUCTION

Establishing private forests supports Indonesia's forest industries (Kurniawan & Hidayat, 2020). Small-scale farmer-owned private forests (PFs), also known as hutan rakyat in Indonesia, have been expanding quickly (Fujiwara et al., 2018). PFs are forests owned by people who have a minimum area of 0.25 ha, greater than 50% in crown closures of timber species or other plants, or a minimum of 500 stems per hectare at the first planting year, according to the Ministry of Environment and Forestry (Forestry Minister Decision No. 49 in 1997). Awang et al. (2007), Hinrichs et al. (2008), and Roshetko et al. (2013) describe PFs as forest resources made up of woodlots (alas or kitren), drylands (tegalan), and home gardens (pekarangan). For instance, 4.8 million m^3 of timber in 2015 to 6.2 million m^3 of timber in 2018 were supplied by private forests as raw materials to forest industries (Kementerian Lingkungan Hidup dan Kehutanan, 2019). Although private forests have not yet significantly contributed to farmers' income (Kurniawan & Hidayat, 2020), significant productive savings assets have been produced (Ichwandi et al., 2005; Ichwandi et al., 2007). Timber from private forests can contribute meaningfully to farmers' income, varying from 15% (Roshetko et al., 2013), 15.8% (Desmiwati et al., 2021), 24-36% (Diniyati & Achmad, 2015), even 42% (Achmad & Purwanto, 2014). Many communities are very interested in managing private forests. According to the Ministry of Forestry (MoF), 1,041 ha of the total 3,186 hectares of private forest in the West Nusa Tenggara province developed between 2008 and 2012 are in Central Lombok Regency (Biro Perencanaan Kementerian Kehutanan, 2013). These private forests were established on idle lands that were not employed for other specific purposes and were primarily found on marginal lands with varied biophysics and productivity restrictions (Setiawan et al., 2014). Many of these lands might have become critical due to unsustainable management, making them targets for rehabilitation efforts. Private forest development was initially pursued to boost timber production (Darusman & Hardjanto, 2006). Private forest development is now viewed as a viable and efficient method of restoring land and forest functions (Kurniawan et al., 2018). There has been extensive research on private forests' ecological and economic impacts (Santika et al., 2019).

Farmers do not consistently profit from their efforts in developing private forests. Some farmers lose money since the private forests they created did not yield adequate financial returns. Like other farming methods, the success of private forest farming is impacted by several variables, such as the type of product produced (Teshome et al., 2015), the area of land under management (Desmiwati et al., 2021), and the technique used for managing the land (Nandini & Rahayu, 2021; Sabar & Pagilingan, 2016). The factors that influence the effectiveness of private and community forest farming include local plant species knowledge (Subedi et al., 2018); biophysical conditions (Achmad & Purwanto, 2014); benefits to be obtained, availability of species and plants, ease of marketing (Suherdi et al., 2014; Iskandar et al., 2017), maintenance costs (Irawanti et al., 2012), and access to quality tree genetic that match site characteristics and market demand (Dawson et al., 2009).

Swietenia mahagoni, Falcataria moluccana (also known as *Paraserianthes falcataria*), and *Tectona grandis* are timber species typically planted on private forest land in Central Lombok (Setiawan et al., 2014). These species are planted using mixed patterns with other timber and multi-purpose tree species (MPTS), such as fruit trees, and intercropped with food crops and livestock (Nandini, 2017). The three timber species are in high demand by farmers because they are renowned for having high-quality timber, a high selling price, and are fast-growing compared to other timber species (Iskandar et al., 2017). However, measures to increase private forest productivity are still required. For example, in Central Lombok, only 31.7% of total timber production comes from private forests (Nandini, 2017). Agroforestry and non-timber forest products (NTFPs) development are two methods for raising private forest productivity (Affandi et al., 2017). According to Diniyati & Achmad (2015), private forests of NTFPs and agroforestry systems can contribute as much as 63 to 75% of farmers' income.

Farmers prefer tree species and planting techniques that build viable agroforestry systems on their forest land (Kurniawan & Hidayat, 2020; Hernawan et al., 2020). It is important to test the compatibility of the tree species and planting pattern before widespread development. According to Ahmad et al. (2019), several elements, such as the growth site features, social factors including farmers' attitudes toward plant species, and a species' capacity to be grown, can be used to assess the suitability of the tree species and planting pattern. The species and planting designs used in the understory of agroforestry systems should also consider the many factors to increase the productivity of the overstory timber species. This study was specifically designed to evaluate understory intercropping options for *F. moluccana* (syn, *Paraserianthes falcataria,* local name sengon) selected by private forest farmer producers in Repok Pidendang Hamlet and to identify the most effective agroforestry pattern that could increase system productivity.

2. MATERIALS AND METHODS

2.1 Study area

The research was conducted in the *F. moluccana* private forest in the Central Lombok Regency's, Repok Pidendang Hamlet, Pemepek Village, Pringgarata District (Fig. 1). The research site is located on a slope ranging from 15 and 25%. Lithosol and the grey-brown regosol complex are the primary soil types. The research site's soil fertility is moderately good, with neutral pH, high organic matter content, medium cation exchange capacity (CEC), and low macro and micronutrient concentrations. According to Schmidt & Fergusson (1951), the research site, with a climatic type C, experiences 223.5mm of rainfall monthly, an average temperature of 25.2°C, and average humidity of 82.8%.

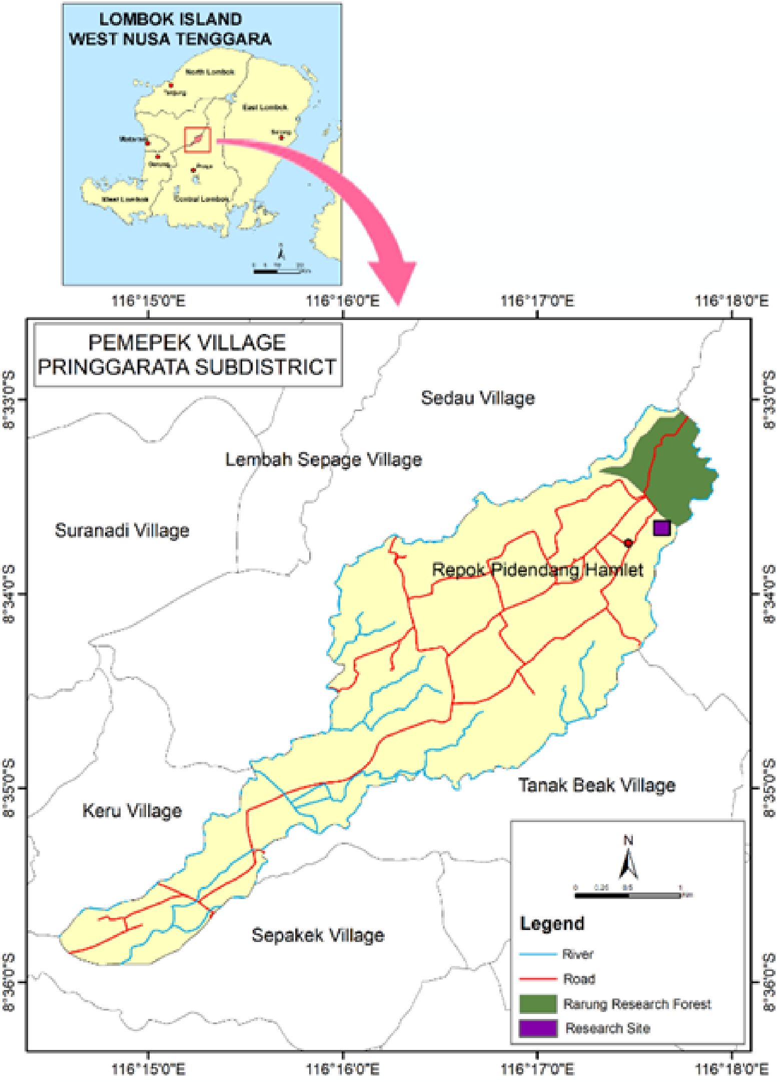

Figure 1. Research site

2.2 Research design

Farmers decided to develop an agroforestry system on their *F. moluccana* private forest by intercropping three different intercrop species: small taro (*Colocasia esculenta*), ginger (*Zingiber officinale*), and vanilla (*Vanilla planifolia* Andrews). Using a completely randomized design (CRD), an experiment was established to evaluate agroforestry patterns with these crop species. Three patterns were tested: i) *F. moluccana*+vanilla+small taro (FmVT), ii) *F. molucana*+vanilla+ginger (FmVG), and iii) *F. moluccana*+vanilla+ginger +small taro (FmVFT). Three planting patterns were each replicated three times for a total of nine test plots. Each trial plot of species combinations has a 10 x 10 m surface area and a 3 x 3 m spacing between *F. moluccana* as the primary crop. Physical and chemical soil features were uniform across the plots. A standard 0.5 kg of manure was applied to each understory plant (small taro, ginger, and vanilla).

Beginning in March 2019 through March 2021, observations were made at each trial plot. The variables observed and measured were microclimate (air temperature, soil temperature, soil humidity), crop yields (the amount of harvest and its economic value), species survival rate, tree growth (diameter and height development), and crop yields. Microclimate and survival rates were measured bimonthly; tree growth was measured twice during the observation period, while crop yields were calculated every time a harvest was conducted. In this study, only crops that provided yields were included in the evaluation. Diameter measurements were done on *F. moluccana* at diameter breast height (dbh).

2.3 Statistical analysis

The correlation between the variables were examined using statistical methods such as the Pearson Product Moment, Duncan's advanced multiple range test (DMRT), and analysis of variance (ANOVA). Statistical analysis was used to determine the relationship between species survival rates and several variables, such as microclimate and planting patterns, and the effect of planting patterns on species survival rates. The quantity of harvested crops was used to calculate production in agroforestry, which was then compared to current market values. Increments in diameter and volume allowed the researchers to examine the yield of *F. moluccana*. The equations used to estimate volume were derived from research at locations that have the same characteristics as the study locations, as follows (Susila, 2011)

$$\tilde{V} = 0{,}0005\ D^{2{,}148} \quad (1)$$

Remark: $\tilde{V}$: volume (m^3), D: dbh (cm)

Two methods were used to calculate the incremental growth, mean annual increment (MAI) and current annual increment (CAI). The formulas used were (Departemen Kehutanan, 1992; Pretzsch, 2009):

$$MAI = \frac{X_t}{t} \quad (2)$$

$$CAI = \frac{X_T - X_{T-1}}{T} \quad (3)$$

Remark: X_t: diameter or volume of trees at t age (cm), t: age of trees (year), X_T = diameter or volume of trees after the trial, X_{T-1}: diameter or volume of trees before the trial, T: measurement time interval (month).

The best productivity and the Land Equivalent Ratio (LER) value technique was used to identify the optimum agroforestry design to be created on *F. moluccana* private forest land. As defined by Mead & Willey (1980), LER is calculated by comparing the ratio of mixed crop production to monoculture production, which is expressed as follows:

$$LER_n = LER_n^A + LER_{1-n}^B = \frac{Y_n^A}{S_A} + \frac{Y_{1-n}^B}{S_B} \quad (4)$$

Remark: Y_i: yield of plant *i* planted in a mixture, S_i: yield of plant *i* planted singly

The study hypothesised that in the short-term small taro or ginger as single intercrops under *F. moluccana* would be superior to a mix of the two crops under *F. moluccana*. If the LER value is greater than 1, a mixture of plants has higher productivity than a monoculture of the crop analyzed. Ginger was a medium-term crop that was included in this analysis. This species was chosen by farmers with consideration of its economic and socio-cultural values, so it was expected to improve land productivity.

3. RESULTS

3.1 Species survival and tree growth

Species survival rate and tree growth were used to evaluate the performance of the species in the research plots during the observation period. Observations showed that small taro has the highest average survival rate of the three intercrops tested under *F. moluccana* stands (Fig. 2). Small taro has a survival rate of 72–100%, vanilla was 33–48%, *F. moluccana* was 85–100%, and ginger was 10–13%

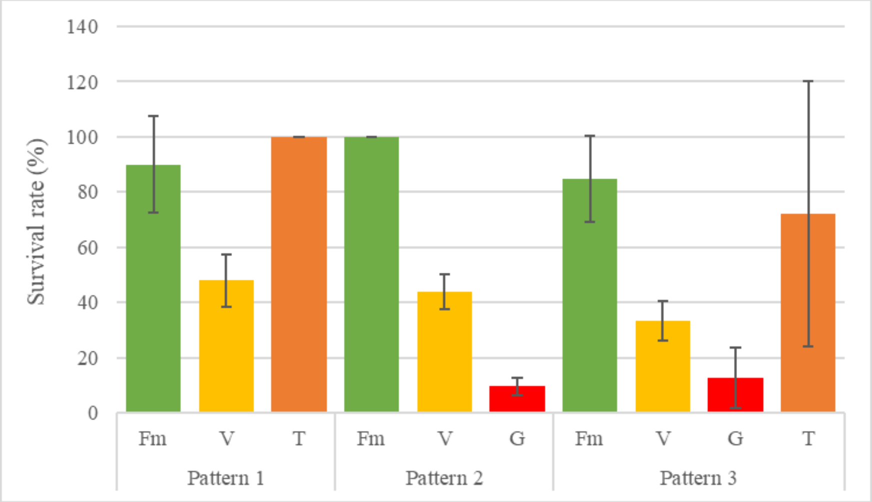

Figure 2. The survival rate of three types of plants tested in different cropping patterns. Fm is *F. molucana,* V is vanilla, T is small taro, and G is ginger

The cropping pattern that included *F. moluccana*, vanilla, and small taro (FmVT) had the highest survival rates for the component species compared to the other patterns. The average survival rate of all species in the FmVT was 79.3%, while for FmVG and FmVGT it was 51.2% and 50.7%, respectively. The highest species survival rate for each pattern were small taro in FmVT (100%) and *F. moluccana* in FmVG (100%), and in FmVGT (84.8%). Of the three patterns applied, the lowest survival rate was vanilla (47.9%) in FmVT, while in FmVG and FmVGT, the lowest survival was ginger, namely 9.7% and 12.6%, respectively.

The statistical analysis revealed that, with a sig-F value of 0.05, variations in planting patterns had a substantial impact on the survival rate. According to the DMRT test results of the three patterns examined, the survival of the species component in the *F. moluccana* + small taro + vanilla pattern was significantly different and higher than the other two patterns (Table 1).

Table 1. The effect of planting pattern on the species survival rate using DMRT

Pattern	Mean of Survival rate (%)	Standard Deviation
FVJ	23.37 [a]	2.55
FVJT	27.93 [a]	19.24
FVT	70.77 [b]	1.82

Note: FmVT: mix of *F. moluccana* + vanilla + small taro, FmVG: mix of *F. moluccana* + vanilla + ginger, FmVGT: mix of *F. moluccana* + vanilla + ginger + small taro. The same letter indicates no significantly different

At the 5% level, the species survival rate was significantly affected by the FmVT and FmVGT cropping patterns, while the FmVG pattern had no significant effect (Table 2). In the FmVT and FmVGT patterns, although there was a significant effect on survival rate, there was no significant difference between the same species in the different patterns. The differences in survival rates only occurred in *F. moluccana* and intercrop, with no significant difference between the intercrop species.

Table 2. The effect of planting pattern on the species survival rate using DMRT

Plant type	Species survival (%) by cropping pattern		
	FmVT	FmVG	FmVGT
F. moluccana	43.81 [a]	18.02 [a]	19.60 [a]
Vanilla	78.97 [b]	41.42 [b]	35.19 [ab]
Small taro	90.05 [b]	-	68.07 [b]
Ginger	-	90.05 [c]	71.31 [b]
Sig F	0.01	0.143	0.015

Note: FmVT: mix of *F. moluccana* + vanilla + small taro, FmVG: mix of *F. moluccana* + vanilla + ginger, FmVGT: mix of *F. moluccana* + vanilla + ginger + small taro. The same letter indicates no significantly different

Microclimate is a variable that is thought to affect crop survival rates. A correlation test was conducted to determine the relationship between microclimate and species survival rates at the study site. The results of the correlation analysis between microclimate and survival rate using the Pearson product-moment revealed that, although having a relatively strong connection, soil temperature, air temperature, and humidity did not significantly affect crop survival rate (Table 3).

Table 3. Microclimate correlation analysis on the species survival rate using the Pearson product-moment

Microlimate parameter	Cropping pattern					
	FmVT		FmVG		FmVGT	
	R	Sig F	R	Sig F	R	Sig F
Air temperature (°C)c	-0.107	0.893	-0.662	0.338	-0.295	0.705
Soil temperature (°C)	-0.081	0.919	-0.660	0.340	-0.092	0 .908
Soil humidity (%)	0.805	0.195	0.173	0.827	0.259	0.741

Note: FmVT: mix of *F. moluccana*+vanilla+small taro, FmVG: mix of *F. moluccana*+vanilla+ginger, FmVGT: mix of *F. moluccana*+vanilla+ginger+small taro. R: Pearson product-moment correlation coefficient

Due to logging by landowners, the average number of *F. moluccana* trees in each research plot decreased from 16 to 12 during the observation period, representing a harvest intensity of 25%.

The productivity of *F. moluccana* at the research site was generally unaffected by the agroforestry scheme used under the stands. Despite an increase in average diameter, all agroforestry patterns saw a decline in average annual increment (Table 4). The MAI diameter decreases from the 3rd to 5th years. In this case, the MAI volume decreased as the trees got bigger. The average current annual increment (CAI) ranges from 3rd to 5th years, which includes diameter and volume, and was smaller than the MAI at the age of 5 years.

Table 4. Growth and development of *F. moluccana* stands before and after the trial of agroforestry patterns at the study site

No	Parameter	Before the agroforestry trial pattern (3 years old)			After the agroforestry trial pattern (5 years old)		
		FmVT	FmVG	FmVGT	FmVT	FmVG	FmVGT
1	D (cm)	13,95± 2,51	15,37± 3,06	13,40±3,46	16,84± 4,61	17,92± 4,35	15,60± 3,12
2	MAI-D (cm)	4,65	5,12	4,47	3,37	3,58	3,52
2	V (m^3)	0,149	0,185	0,142	0,234	0,263	0,194
4	MAI-V (m^3)	0,050	0,062	0,047	0,047	0,053	0,039
5	ΔD (cm)				2,89	2,55	2,19
6	CAI-D (cm)				1,45	1,27	1,10
7	ΔV (m^3)				0,085	0,078	0,052
8	CAI-V				0,043	0,039	0,026

Note: FmVT: mix of *F. moluccana* + vanilla + small taro, FmVG: mix of *F. moluccana* + vanilla + ginger, FmVGT: mix of *F. moluccana* + vanilla + ginger + small taro, D: diameter, MAI-D: mean annual increment of diameter, V: volume, MAI-V: mean annual increment of volume, D: change in diameter, CAI-D: current annual increment of diameter, ΔV: change in volume, CAI-V: current annual increment of volume

3.2 Crop yields

Crop yields were the variables used to determine the best agroforestry pattern at the research location. During observation, only *F. moluccana*, small taro, and ginger were harvested from the experimental plots. In the observation period, vanilla had not yet been harvested, so it was not included in the crop yield analysis. Based on the number of harvests (Table 5), the *F. moluccana* stands with the most potential wood in the FmVGT design (270.9 m^3 ha^{-1}), whereas the smallest is in the FmVT pattern (219 m^3 ha^{-1}). In contrast to the ginger in the FmVG and FmVGT patterns, the small taro in the FmVT pattern yielded more than those in the FmVGT pattern. Compared to the FmVT pattern, which generated 317.5 kg ha^{-1}, the FmVGT design produced a greater annual yield (331 kg ha^{-1}). Ginger plants grown in the FmVG pattern yielded 140 kg ha^{-1} compared to 90 kg ha^{-1}in the FmVGT pattern.

Table 5. Species yields in the three crop patterns

Species	Species yields by Crop Pattern		
	FmVT	FmVG	FmVGT
Ginger (kg/ha)	-	140,0	90,0
Small taro (kg/ha)	317,5	-	331,1
F. molucana (m3/ha)	219,0	262,9	270,9

Note: FmVT: mix of *F. moluccana*+vanilla+small taro, FmVG: mix of *F. moluccana*+vanilla+ginger, FmVGT: mix of *F. moluccana*+vanilla+ginger+small taro.

The land equivalence value (LER) computation revealed that ginger plants cultivated with *F. moluccana* had a higher LER of 1.04 than small taro plants with an LER of 0.64. The LER for the combination of *F. moluccana*, vanilla, ginger, and small taro (FmVGT) had a value of 1.68.

An income analysis was also conducted. The analysis considered crop production revenue and leaves out associated costs as inputs were provided from farmers' existing resources at no cash investment. The results showed that the FmVGT pattern provided an enormous additional revenue for the farmers' income, namely IDR 11,851,250 ha year^{-1}, compared to the FmVT pattern (IDR 5,600,000 ha year^{-1}), and the FmVT pattern (IDR 7,936,250 ha year^{-1}). The income from *F. moluccana* timber that could be gained is IDR 109,493,016 ha year^{-1} (FmVT), IDR 131,430,734 ha year^{-1} (FmVG), and IDR 135,450,657 ha year^{-1} (FmVGT), based on the current potential of *F. moluccana* and the assumption that the selling price of *F. moluccana* in West Nusa Tenggara is IDR 2,500,000 m^{-3}. Results from the study indicate the *F. moluccana*-based agroforestry pattern with a mixture of vanilla, ginger, and small taro is the best pattern that can be established in *F. moluccan*a's private forest.

4. DISCUSSION

Agroforestry development under *F. moluccana* stands has been widely applied in Indonesia. Studies have shown that various agroforestry patterns developed under *F. moluccana* stand can increase land productivity and improve the farmers' economy (Iskandar et al., 2017; Irawanti et al., 2012; Siregar et al., 2007). The survival rate is an indicator of the success of agroforestry development. The higher the survival rate, the higher the yields (Hayward et al., 2012). Evaluation results of three agroforestry patterns under *F. moluccana* stands in Central Lombok showed that the combination of *F. moluccana* with vanilla and small taro (FmVT) had the highest survival rate, while *F. moluccana* with vanilla, ginger, and small taro (FmVGT) had the lowest (Fig. 2). The high survival rate in FmVT was contributed by *F. moluccana* and small taro. In all plots, small taro has a survival rate of up to 100%, caused by the growth of tillers that develop around the parent plant. The small taro parent plants had tillers that spread around them, making the surrounding area lusher and increasing the survival rate. Of the three species of plants tested, ginger had the lowest survival rate. The survival rate of vanilla and ginger plants is thought to be influenced by weed density and microclimate (Detsis et al., 2020; Jiang & Jin, 2021). Weeds are nuisance plants that are widely found in the study area. Continuous weeding is required since weed growth is relatively intense, especially during the rainy season. Without weeding, plants would not be able to compete for nutrients for growth and would eventually perish (Gage & Schwartz-Lazaro, 2019).

Compared to ginger plants, small taro plants appear to be more tolerant to weeds and have high plant density, allowing them to survive and grow even under stress. Ginger plants require regular crop rotation and thorough weeding to prevent the spread of disease (Nasriati & Pujiharti, 2012). While the yield for ginger was high in this study, it did not integrate well with the other intercrops (Table 5). Nasriati & Pujiharti (2012) reported similar findings. However, yields from the combination of small taro, vanilla, and ginger under *F. moluccana* generated approximately three times greater profit than monoculture options (Table 5). According to Mead & Willey (1980) and van der Werf et al. (2021), as well as this study, land cultivated with multiple crops, especially with intercropping, will yield more benefits than monoculture. The results of the survival rate analysis (Fig. 2) show that *F. moluccana* and small taro in FmVT are higher than in FmVGT. However, land productivity and income show the opposite result, where FmVT is smaller than FmVGT. This condition occurred because many taro plants on FmVT failed to form tubers during harvesting, so their production was less than that on FmVGT. The lack of potassium and water availability were two factors that may affect tuber formation in small taro (Toor et al., 2021; Nurchaliq et al., 2013). However, due to limited data, small taro in FmVT do not produce tubers optimally and still need further analysis.

Under *F. moluccana* stands, determining the type of crop and planting strategy greatly influences the survival rate (Tables 1 and 2). This condition relates to competitive, complementary, cooperative, and compensating forces between plants (Justes et al., 2021). Crop growth is also closely related to microclimate conditions (Widiya et al., 2019). Some crop species shed their leaves during the dry season to prevent evaporation and develop new leaves during the rainy season. When temperatures are low, as they are during the rainy season, the anatomical and morphological conditions of the plant will differ from those of plants that drop their leaves (Jung et al., 2020). Ginger utilizes this strategy, dropping its leaves during the dry season, maintaining the tubers in the soil with reserve energy; during the wet season, as was the case in the study area, the leaves regrow.

The amount of rainfall, the temperature, and the humidity are a few microclimate variables that influence crop growth. These climatic factors all relate to crop growth in a certain way. According to Jung et al. (2020), there is an inverse relationship between microclimate conditions and plant growth at the research location. In this study, microclimate had little impact on the survival rate, as shown in Table 3. It is believed that other factors not observed in this study caused the influence of the microclimate to be minimized. For instance, Onwuka (2016) claims that temperature and humidity play a role in soil nitrogen decomposition. The survival rate is believed to correlate with the microclimate at the study site because of the dynamic soil processes. N-total is a crucial component for plant growth (Zhang et al., 2013), whereas CEC is a soil element frequently indicating soil fertility (Gunawan et al., 2019). CEC is an adsorbent for soil nutrients like Ca, Mg, Na, and K, major building blocks for plant growth. Generally, the higher the CEC value, the more productive the land will be (Hartati et al., 2013).

The examination of CAI and MAI revealed that *F. moluccana*'s productivity had declined (Table 4). If site quality is supportive, growth increases when trees are young (3-5 years). The competition between *F. moluccana* was thought to cause a decrease in stand productivity. As trees grow to a larger size, silvicultural activities such as pruning and thinning are necessary to maintain tree growth, yields, timber properties and tree resilience (Roshetko et al., 2004; Víquez & Pérez, 2005; Seta et al., 2021; Moreau et al., 2022). At the research site, *F. moluccana* timber is used for subsistence purposes, meaning only the timber required for household use or cash needs is harvested, and full-scale *F. moluccana* logging is avoided. During the observation period, the stocking of *F. moluccana* trees decreased by 25%. *F. moluccana* stands thinning, and harvesting can be used to reduce competition (improve productivity), even if done unplanned. However, in this study, the reduction was insufficient to reduce competition between trees, so tree growth did not reach optimal results (Table 4). Growth enhancement can be achieved by increasing the number of trees thinned, as has been done by Roshetko et al. (2013), Seta et al. (2021), and Kanninen et al. (2004). As happened in the *F. moluccana* community forest in Kintamani, at the same age, several trees were selectively thinned for sale in the market, which increased the tree's average productivity (Susila, 2011). Infertile soil conditions also cause less optimal development of *F. moluccana*. As happened in Kulon Progo, Yogyakarta, the incremental growth and survival of *F. moluccana* were lower compared to three other timber species, so it was not recommended as a short-cycle companion species with teak (Sudomo et al., 2021). The planting time of the agroforestry pattern is also thought to affect the productivity of *F. moluccana*. Using an agroforestry system can raise the risk of crop failure and its economic advantages (Paut et al., 2018). The agroforestry pattern is generally applied to a year-old *F. moluccana* stands or after steady plant growth. Under good biophysical conditions and good management, intercropping planting will increase the tree's growth, as was done for *F moliccana* in the Philippines (Nissen et al., 2001).

In this study, the stands were three years old, so the growth effect was no longer optimal. Table 4 shows the increase in stand diameter. As observed, the annual diameter increment decreases if CAI is less than MAI. At 20 and 21 years old, this increment is expected almost identically to the stands of *Eucalyptus urophylla* in Bajawa Flores (Susila & Darwo, 2015). The diameter must be measured at least three times to document the trend in the diameter growth curve (otherwise, the CAI growth trend will be a straight line). In this study, tree growth measurements were only conducted twice, at the beginning and end of the trial activity. By increasing the measurement intensity, more data will be available to provide an overview of the tree's growth.

Under the proper environmental conditions, the fast-growing wood species *F. moluccana* can thrive (Krisnawati et al., 2011). This species, categorized as short-cycle timber, can be harvested for carpentry wood between the ages of 5 and 12 (Krisnawati et al., 2011; Susila, 2011). Because there was an average of seven trees in each 10 × 10 m plot in this study, the expected volume increment of *F. moluccana* was calculated to be 25.2 m^3 ha^{-1} a year. According to the Forestry Research and Development Agency of the Republic of Indonesia (Badan Litbang Kehutanan, 2009), the increase in stand volume for wood species with short life cycles (less than ten years old) is 25-45 m^3 ha^{-1} $year^{-1}$, 15-30 m^3 ha^{-1} $year^{-1}$ for wood species with medium life cycles (between 10 and 30 years old), and 15 m^3 ha^{-1} $year^{-1}$ for wood species with long life cycles (between 30 and 50 years old). Despite being within the minimum range of stand volume increments as defined by the Forestry Research and Development Agency of the Republic of Indonesia, the results of the volume measurements ensure that *F. moluccana* at the study site is a short-cycle wood species.

Some land quality parameters, such as soil organic content, nitrogen content, altitude, soil drainage, soil solum, soil texture, rainfall, and the number of seasons (wet and dry) in a year, have an impact on the growth of woody plants (Detsis et al., 2020; Alrasjid, 1991). The stands density, which creates competition for sunlight and space, is another factor responsible for the decline in increment. According to Krisnawati et al. (2011), *F. moluccana* plants would produce satisfactory quality at a spacing of 6 × 6 m or 10 x 10 m. However, the plants in the study region were planted at a spacing of 3 x 3 m, indicating that the *F. moluccana* stands at the study site were too dense. Silviculture, including the adding fertilizer, can increase *F. moluccana* productivity by improving spacing and manipulating the growth site (Susanto & Baskorowati, 2018). By selectively thinning *F. moluccana* stands, it is possible to improve tree growth. According to Susila (2011), the average yearly increment for tree diameter and height has increased when selectively thinning 9-year-old *F. moluccana* stands established at 3 × 3 m spacing as in the research area of Kintamani, Bali. In this study, tree harvesting operations are conducted infrequently and at different times depending on the preferences and demands of farmers and purchasers.

The LER calculation results show that the FmVGT pattern has the greatest value compared to FmVG and FmVT. Of the three patterns, FmVT has the smallest value. This study's agroforestry pattern integrating three intercrops with *F. moluccana* produced the best results. This indicates that planting in a mixed pattern of various types of crops will provide greater benefits than planting in fewer combinations. This is in line with

Mead & Willey (1980) and van der Werf et al. (2021). Calculations in this study show the economic value of the FmVGT patterns was greatest from both intercropping and *F. moluccana* compared to the other patterns. Those calculations applied various assumptions, specifically not including production costs, as all inputs were provided from on-farm sources without cash expenditures and determining the economic value of timber by considering the similarity of tree age and spacing in the patterns. Even though production costs were not considered for the reason stated, it is suspected that the results will not change the fact that a combination pattern involving more diverse species will still provide higher additional income than monoculture, as stated by Mead & Willey (1980) and van der Werf et al. (2021). The income obtained from intercrop yields is received directly by farmers. Still, income from *F. moluccana* timber is often deferred as timber is managed as a living asset for savings by farmers. Additionally, timber is usually harvested according to their needs. Thus, developing agroforestry patterns in community forests is prospective enough to increase farmers' income.

5. CONCLUSION

Developing agroforestry systems under *F. moluccana* stands is a viable option to increase the productivity of private forests. The three agroforestry patterns tested in this study were the combination of: *F. moluccana* with vanilla and small taro (FmVT); *F. moluccana* with vanilla and ginger (FmVG); and *F. moluccana* with vanilla, ginger, and small taro (FmVGT). They were developed to increase the productivity of *F. moluccana* private forests in Central Lombok. The evaluation showed that the FmVT pattern had a higher overall crop survival rate (79.3%). The characteristics of small taro, which can grow with the tiller, cause the survival rate of taro to be high. At the study site, microclimate had no significant effect on survival rate or growth. It is suspected that other biophysical factors, such as soil quality and nutrient content, as well as environmental disturbances, including pests and diseases, play a role in the survival rate and growth at the study site, and these need to be analyzed further. The FmVGT pattern was the best agroforestry pattern for yield and income generation. Results indicate the FmVGT patterns had an LER of 1.68 and generated an economic value of IDR 11,851,250 ha $year^{-1}$ from the intercrop yields. In this study, the contribution of *F. moluccana* agroforestry patterns to farm income comes from small taro and ginger yields, as *F. moluccana* timber is only harvested to meet household needs for timber or emergency cash. Developing agroforestry under *F. moluccana* stands is a wise and viable option to increase the productivity of private forests and farmers' income.

Author Contributions: Conceptualization: RN, IWS, RA; methodology: RN, IWS; fieldwork and data collecting: RN, IWS, GS; data analysis: RN and IWS; drafting: RN, IWS, RA; review and manuscript editing: RN, IWS, RA, GS.

Competing Interests: The Authors declare that they have no conflict of interest or financial conflicts to disclose.

Acknowledgments: The research reported in this paper was part of Developing and Promoting Market-Based Agroforestry Options and Integrated Landscape Management for Smallholder Forestry in Indonesia Project (FST/2016/141), funded by the Australian Centre for International Agricultural Research (ACIAR). The author would like to thank the Instrument Standardization Agency of the Ministry of Environment and Forestry of the Republic of Indonesia and World Agroforestry (ICRAF) for facilitating this activity; and also, Dr Budiadi from Universitas Gadjah Mada, who has assisted during the preparation of the manuscript. Additionally, the authors acknowledge the individuals who helped implement activities in the field.

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