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Growth of *Betung* Bamboo (*Dendrocalamus asper*) and Food Crop Production Under Agroforestry Bamboo Systems

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Abstract

One of the main species in community forests is betung bamboo (Dendrocalamus asper). Optimizing land use under bamboo can be achieved by cultivating food crops. This research aimed to determine the growth of betung bamboo and the production of food crops. The experimental design used a split plot design with four cultivation patterns as the main plots: agroforestry bamboo pattern i.e. agroforestry bamboo + rice (P1), agroforestry bamboo + rice + cassava (P2), agroforestry bamboo + rice + taro (P3), and mixed food crops (rice + cassava + taro) (P4), while the subplots were rice varieties: rindang 2 (V1), protani (V2), and unsoed (V3). The observed parameters were bamboo growth, soil fertility, and food crop production. The results showed that seven-year-old betung bamboo had an average of 6.01 mature stems per clump, an average plant height of 7.23 m, and a stem diameter of 7.12 cm. The numbers of young stems and shoots per clump was 1.45 and 3.71. The highest betung bamboo growth was in the agroforestry pattern (length: 8,49 m, diameter: 7.17 cm, thickness: 1.95, total weight: 21.31 kg). The highest rice yield was observed in the P2V1 treatment (4.17 kg). The highest cassava tuber yield per plant was observed in P4 (2.12 kg). The taro tuber yield was relatively higher in the agroforestry pattern with a distance of >1 m from the bamboo clump (0.52 kg plant^{-1}). The land equivalent ratio (LER) and area time equivalent ratio (ATER) of bamboo and food crop agroforestry have a value above 1, so it is more efficient in land.

Keywords: *agroforestry, bamboo, cassava, rice, taro*

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Introduction

Farmers in Indonesia require more land constraints. Agriculture in Indonesia was dominated by farmers with less than 0.5 ha land ownership, with 16,274,430 households (58.73%) (BPS, 2021). Farmers with limited land and capital have strategies to meet various needs. Agroforestry is the choice of farmers to increase yields and land efficiency and reduce agricultural costs (Low et al., 2023). Agroforestry is also an adaptation for small farmers who face uncertainty, increase the resilience of local agriculture, and provide various benefits to their daily lives (Jha et al., 2021). Agroforestry practices aim to meet the water, food, energy, and income needs of rural communities (van Noordwijk et al., 2016). Privately forest in the Law of the Republic of Indonesia Number 41 of 1999 is defined as forest located on land burdened with land rights. Even though the population in Java is high and the economic value of privately owned forests is low, privately owned forests are still growing on the island (Tanguay & Bernard, 2020).

One of the agroforestry components in community forests on Java is bamboo. Bamboo plays socioeconomic, ecological, and cultural roles (Ihsan et al., 2023). Bamboo cultivation can create jobs, increase income, reduce poverty, and increase carbon absorption (Abbas & Amanabo, 2017). Bamboo is easy to cultivate, produces high biomass, and produces fewer emissions than annual crops (Patel et al., 2020). Bamboo has the advantage that old shoots can be harvested yearly, and young shoots can be left for the following year (Kirchhof, 2021). Bamboo can be cultivated on marginal land, thereby increasing its economic value, empowering village communities, and involving various sectors to grow the rural economy (Lombardo, 2022). Bamboo is generally managed traditionally by relying on the resources owned by farming households (Nath et al., 2018). Bamboo management is traditionally carried out to meet the long-standing need for making traditional bamboo crafts (Lynser et al., 2015). However, traditional bamboo cultivation has low productivity (Ooi et al., 2022). Bamboo processing is carried out through traditional, small, and large industries (Luo et al., 2020). The bamboo industry has several advantages because of its fast cycle, product diversification, low risk, and high market potential (Wang et al., 2021). The economic value of bamboo derived from bamboo crafts is expected to increase with product innovation (Lee et al., 2021). The bamboo economy can be improved through on-farm, off-farm, market, and government policy activities (Ekawati et al., 2023).

One species of bamboo that is easily found in community forests is *betung* bamboo (*Dendrocalamus asper*). *Betung* bamboo is used as a sustainable and environmentally friendly building material. *Betung* bamboo shoots contain high fibre content, which can be used in the food industry (Camargo et al., 2022). The development of *betung* bamboo cultivation can be combined with farmers' food fulfilment activities. Bamboo agroforestry with food crops can be promoted to optimize land use and increase the economic value of bamboo cultivation (Zhanga et al., 2019). Bamboo research in Indonesia has thus far been more related to the traditional use of bamboo (Sinyo & Sirajudin, 2017; Mainaki & Maliki, 2020) or research on bamboo species diversity (Ritonga et al. 2020; Siahaan et al., 2020).

Developing food crops, such as bamboo, is expected to support the Indonesian government's efforts to achieve food self-sufficiency. Production of milled dry unhusked rice in Indonesia in 2020 was 54.65 million ton, one of which was sourced from rice cultivated on dry land totalling 3.783 million ton with a tendency to decrease by 2.32% (MoA, 2021). Monoculture upland rice production with superior varieties and intensive maintenance can reach 5.5 ton ha^{-1} (Sahara & Kushartanti, 2019), while the production of upland rice in an agroforestry pattern with eucalyptus trees is 3.03 ton ha^{-1} (Nadif et al., 2021). These data show that upland rice in the agroforestry pattern still requires effort to increase productivity. Several superior rice varieties that are suitable for planting on dry land include: shady, protani, and unsoed. The rindang variety of rice is a superior variety released by the Research and Development Center of the Ministry of Agriculture in 2017. The shady variety is tolerant of shade, drought, and 40 ppm Al poisoning which is quite good for planting in lowland dry land (Hamdani & Susanto, 2020). The protani and unsoed varieties are superior upland rice varieties developed by the agricultural faculty at Jenderal Soedirman University. Both varieties have high protein content and high yields (Riyanto et al., 2022).

Food crops in dry land that are widely cultivated, besides rice, include cassava (*Manihot esculenta*) and taro (*Colocasia esculenta* L.). Cassava can be planted in open areas in monocultures or agroforestry. Cassava cultivation under a 2-year-old teak stand produces 32 ton ha^{-1} tubers (Wahyuningsih & Sutrisno, 2019). Taro is a functional food source that contains carbohydrates, proteins, fats, minerals, and vitamins (Wenda & Nangoi, 2020). Taro can be cultivated under trees and other annual crops to be more efficient and provide better income (Azzahra et al., 2020). Food crop cultivation between bamboo stands needs to pay attention to the aspect of sunlight, which is an essential factor for the growth of crops (Capellesso et al., 2022). In addition, the agroforestry planting pattern is expected to be resistant to drought, efficient in using water (Tzuk et al., 2020), and supported by tillage to increase the diversity of plant species that can grow under bamboo (Camargo et al., 2022). Most farmers believe that bamboo roots are expansive, so the land under the bamboo stand is unsuitable for cultivating annual crops (Ananfack et al., 2023). Therefore, preventive efforts are needed to limit the spread of bamboo root (Lombardo, 2022). This can be done by tilling the soil at a depth of 0–30 cm around the bamboo clump because, at this depth, the development of fibrous roots is the highest (Xiao et al., 2021). Bamboo agroforestry provides high economic value for up to three years provides high economic value by managing fertility and choosing suitable types of crops (Akoto et al., 2020). However, after three years, the production of food crops under bamboo began to decline (Dev et al., 2020). Therefore, the correct cultivation pattern of bamboo with food crops is required. This research aims to determine the growth and production of *betung* bamboo agroforestry with some food crop species i.e.: rice, cassava, and taro.

Methods

The research was conducted in Sukaharja Village, Ciamis Regency, West Java Province, Indonesia (Figure 1). Bamboo was planted in December 2015, while understory crops such as rice, cassava, and taro were planted in December 2021.

Materials and tools The research materials consisted of *betung* bamboo clumps planted in 2015, rice seeds, cassava and taro seeds, manure, chemical fertilizer (NPK), and fungicides. The research tools used were hoes, buckets, calipers, plant height-measuring instruments, and scales. The upland rice varieties used were rindang 2, protani and unsoed.

Research procedures This research has the following research stages: a) Bamboo clumps planted in 2015 were set at a maximum density of 7 stems per clump. Bamboo branches are cleaned with the aim of reducing shade, b) Bamboo stems resulting from thinning are used as bamboo samples to determine the quality of bamboo stems before carrying out bamboo agroforestry and food crops, c) Planting upland rice starts from tilling the soil. Next, planting holes were made by drilling with a distance between the holes of 25 cm × 30 cm. Each planting hole is given 5–6 upland rice seeds. Subsequently, the hole was covered again with soil. Maintenance of upland rice plants includes: cleaning weeds when the plants are 21 days, 42 days, and 60 days old, fertilizing and controlling pests and diseases, d) Taro and cassava are planted around the upland rice planting area with a spacing of 1 m × 1 m, e) At the end of the research (1 year after thinning the bamboo) bamboo samples were collected to determine the quality of the bamboo stems after carrying out bamboo and food crop agroforestry.

Experiment design This research used a split plot design with four cultivation patterns as the main plots: a) agroforestry bamboo + rice (P1), b) agroforestry bamboo + rice + cassava (P2), c) agroforestry bamboo + rice + taro (P3), and d) mixed food crops rice + cassava + taro (P4). Three varieties of rice were used as subplots: a) rindang 2 (V1), b) protani (V2), and c) unsoed (V3). The treatment combination consisted of 12 experimental units, each repeated three times. Each experimental unit had an area of 100 m^2. The cultivation and planting layout is shown in Figure 2.

The observed parameter of bamboo growth included the number of stems (adult, young, shoots) per clump with an observation period of 1 year, while the observed parameter in rice was 1,000 grain weight and dry grain production in a 12 m^2 upland rice planting experimental plot with an

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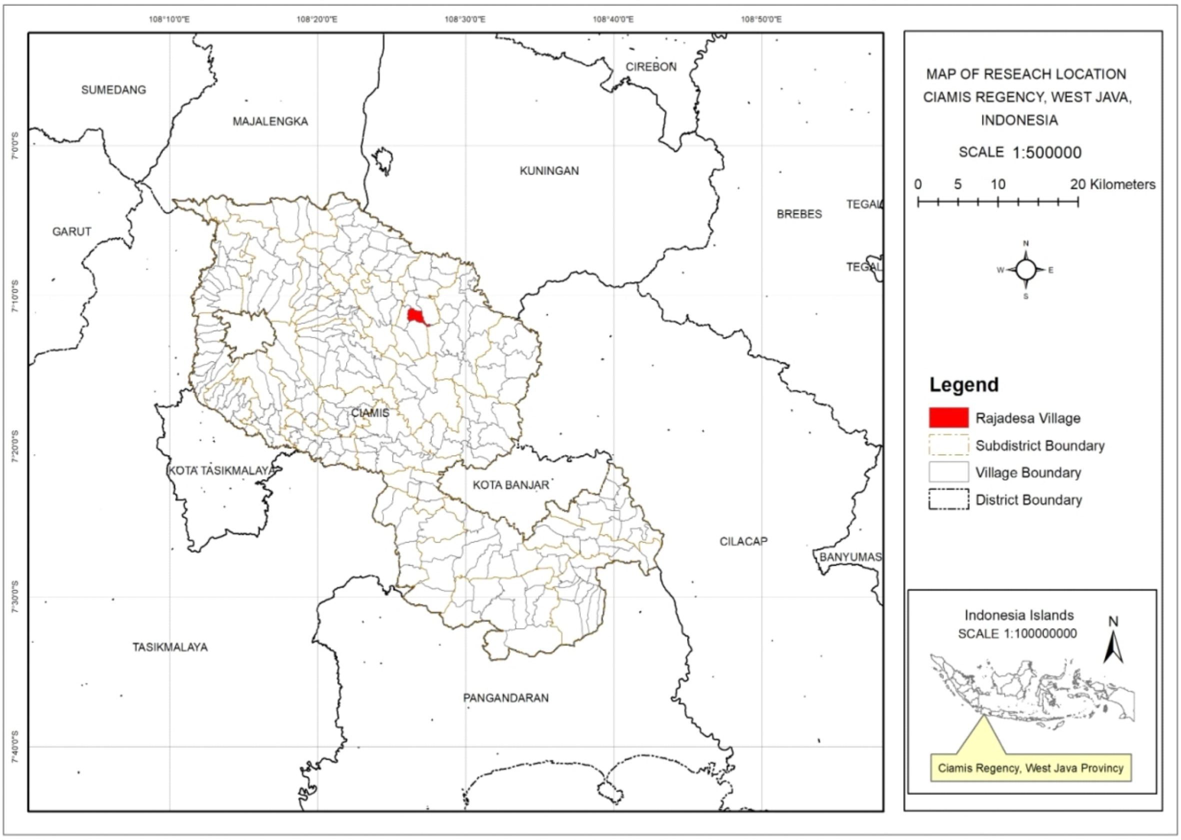

Figure 1 Map of research location.

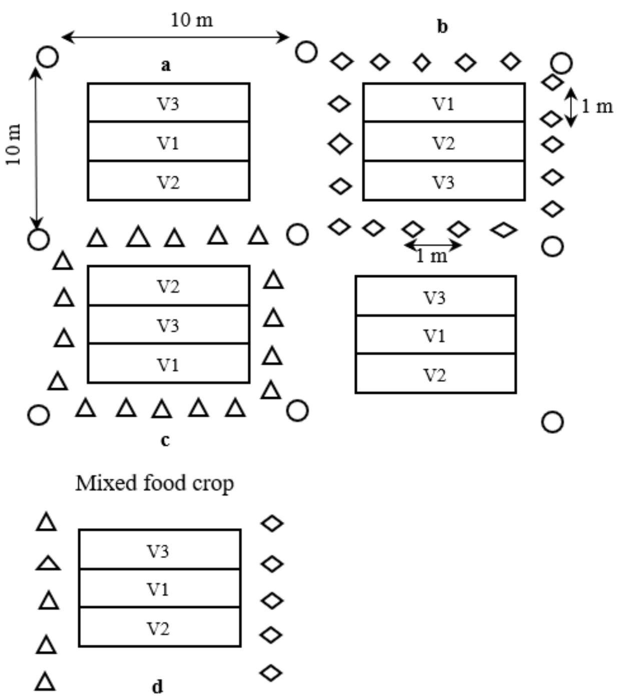

Figure 2 Layout of rice, cassava and taro planting between bamboo plants. a) bamboo + rice; b) bamboo + rice + cassava; c) bamboo + rice + taro; d) rice+cassava+taro; ○ = bamboo, ◇ = cassava, △ = taro.

observation period of 4 months. The quality of bamboo stems was measured using destructive sampling to determine stem length, stem diameter, stem weight, branch weight, and total bamboo biomass weight. Observations of bamboo stem quality were carried out 1 year after thinning. The bamboo stem sample was split into 3 sections: the bottom, middle, and top (Figure 3). Bamboo quality measurements were carried out two times, before and after agroforestry (in 2021 and 2022). The number of bamboo stem samples were 30. The diameter and stem thickness were measured at each end of the segment (Figure 3). Production of cassava and taro was observed by counting the number of tubers and tuber weight per plant at the end of the observation period (7 months old).

The effects of planting bamboo and annual crops on soil fertility were determined through soil sample analysis. Soil samples were taken at 030 cm depth from three collection points, then mixed into 1 for each treatment. Soil samples were analyzed in a soil laboratory to determine the chemical fertility of the soil in the soil laboratory of the Ministry of Agriculture, Yogyakarta. Soil samples were taken at the beginning of bamboo planting in 2015 and after completion of annual planting in 2022.

Data analysis Data on bamboo growth and production variables were analyzed using quantitative descriptive analysis. This method presents the data and information used in research in simple statistics, tables, figures, and descriptions. Data on soil fertility and annual crop production were analyzed using diversity analysis. If there were differences between treatments, the analysis was continued with the Duncan advanced test (Duncan Multiple Range

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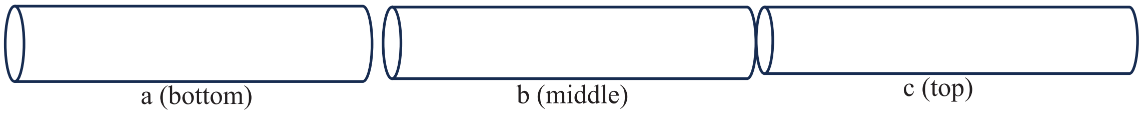

Figure 3 Measuring the quality of bamboo stems based on three segments. Note: the length of each segment is based on the length of the sample stem in section 3.

Test/DMRT). Land equivalent ratio (LER) and area time equivalent ratio (ATER) values were calculated to determine the efficiency of land use according to Equation *[1]* and Equation *[2]* (Mead & Willey, 1980).

$$LER = \frac{Yab}{Yaa} + \frac{Yba}{Ybb} + \frac{Yca}{Ycc} \quad [1]$$

$$ATER = \frac{\frac{Yaa}{YaaxTab}}{\frac{Yaa}{AaaxTaa}} + \frac{\frac{Yba}{AbaxTba}}{\frac{Ybb}{AbbxTba}} + \frac{\frac{Yca}{AcaxTca}}{\frac{Ycc}{AcaxTca}} \quad [2]$$

note: *Yab* = agroforestry bamboo + rice + cassava + taro yield, *Yaa* = rice yield on mixed crop rice, cassava, and taro, *Yba* = agroforestry cassava/taro yield, *Ybb* = cassava/taro yield on mixed crop rice, cassava, and taro, *Yca* = agroforestry bamboo + cassava + taro yield, *Ycc* = monoculture bamboo yield, *A* = land area, and *T* = time until harvest.

Results and Discussion

Study area The research was conducted on land belonging to Sukaharja Village, Ciamis Regency, West Java, which is located at an altitude of 530 m above sea level (Figure 1). Rainfall in 2020 was around 3,800 mm, it is 9.6 km from the city of Rajadesa District and has a village area of 6.6 km^2. Sukaharja consists of 7 hamlets with 14 RWs and 44 RTs with a population of 5,517 people. There are 1,569 people who work as food crop farmers, 614 people in plantations, and 137 people in animal husbandry. Most of the population is dominated by people with basic education levels (SD–SMP). Land use in Sukaharja Village is dominated by dry land farming, covering an area of 422 ha, while paddy fields are only 148 ha with simple irrigation and rain-fed, and the yard area is 148 ha (BPS Kabupaten Ciamis, 2018). The research location before bamboo planting was land cultivating seasonal crops: cassava, peanuts, and corn. Some woody types found include *sengon*, mahogany, and africa.

The effect of bamboo agroforestry on soil fertility The soil pH parameters did not show significant differences before and after bamboo planting (Table 1). This is in line with Kaushal et al. (2020), who found that planting seven types of bamboo in India did not provide significant changes to soil pH. Planting bamboo as a whole can increase the soil chemical fertility. The highest organic soil C content and soil organic matter were found in the soil around the bamboo clumps (<1 m). The increase in organic C and soil organic matter around bamboo comes from falling litter and bamboo root residues (Kaushal et al., 2020). The same results were shown in the long-term management of Lei bamboo (*Phyllostachys violascens*) forests, which were able to increase soil N, P, and K content (Yao et al., 2022). Bamboo agroforestry increases the available P and K content compared to their content before planting bamboo. Although the K content of bamboo agroforestry has increased, it is still lower than the K content in the mixed food crop area. The same is done in the intensive management of moso bamboo by tilling the soil and fertilizing it to increase the P available around the bamboo roots (Ni et al., 2021). The increase in P and K available in bamboo planting areas is caused by the degradation and decomposition of bamboo litter (Liu et al., 2017). In the area of land with mixed seasonal crops, although there are no bamboo plants, the position of the land at the bottom of the demonstration plot is likely to receive an accumulation of litter carried by the flow of rainwater, thereby increasing soil fertility. Bamboo plants have been proven to improve degraded land (Sawarkar et al., 2023).

The soil fertility status has changed 7 years after bamboo planting. The organic C and organic material content around bamboo clumps can originate from bamboo litter or manure application during plant maintenance (Gai et al., 2021). Planting bamboo increases the number of soil microbes (rhizobium, azotobacter, actinomycetes, and fungi). This will increase the availability of P and K nutrients (Singh et al., 2020). Planting bamboo also affects soil microbial activity, and vice versa, and soil microbial activity influences the growth of bamboo plants (Fuke et al., 2021). Planting bamboo with an agroforestry pattern can increase the diversity of soil microbial species to maintain soil fertility compared with the monoculture pattern (Bian et al., 2021). An agroforestry system with the same commodity in the long term can cause a decrease in productivity because of reduced soil fertility due to biomass extraction (Dubiez et al., 2019). One of the efforts to maintain soil fertility is to manage the biomass to be returned to the soil. Biomass derived from a mixture of several components accelerates the decomposition process, thereby accelerating the input of nutrients to the soil (Kaba et al., 2021).

Growth and quality of *betung* bamboo stems The treatment of bamboo agroforestry planting patterns and food crops resulted in better growth and quality of *betung* bamboo. The average number of young stems per clump was 1.45, and the average number of shoots per clump was 3.71 (Table 1).

Betung bamboo showed an increase in mature stems per clump, diameter, and total height. From 2018 to 2019, the number of mature bamboos decreased owing to thinning in 2018 by cutting the stems of generation 1 and generation 2. The results showed that *betungbetung* bamboo planted in 2015 continued to increase in size until the end of the observational period. In 2020, the number of stems and bamboo shoots per clump was the lowest compared to other years. This is because in 2019, there was a long dry season, which affected the production of young stems and bamboo shoots the following year. Bamboo shoots require 60% more water than the old stems (Tong et al., 2021).If water availability is limited, young stem and bamboo shoot growth will be affected.

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Table 1 Average of pH, C organic, organic matter, N total, K available, P_2O_5 content and ECE in the plot before and after bamboo and crop cultivation

No	Time and location of soil samples	pH (H_2O)	C organic (%)	Organic matter (%)	N total (%)	K available (ppm)	P_2O_5 available (ppm)	ECE (cmol (+) kg^{-1}
1	Before bamboo cultivation (seasonal crops cultivation dominated by corn, beans, cassava)	5.15^{ns}	1.342^{c}	2.314^{b}	0.034b	12.8^{d}	0.56^{b}	-
2	After the cultivation of bamboo and food crops							
a	< 1 m from bamboo clump (No vegetation/only bamboo roots)	4.63^{ns}	2.24^{a}	3.86^{a}	0.157a	21^{b}	7^{ab}	14.63^{a}
b	at the food crops area under bamboo stand (pady, cassava, and taro)	5.67^{ns}	1.79^{b}	3.35^{a}	3.35a	3.35^{a}	3.35^{a}	13.45^{b}
c	at the food crops area without bamboo (pady, cassava, and taro in open area	4.67^{ns}	2.17^{a}	3.74^{a}	0.200a	25^{a}	2^{ab}	

Note: Values followed by different letters (a, b, c, d) in the same column are significantly different (p-value < 0.05) which indicates that the treatment has a significantly different effect, ns: not significantly different.

Table 2 Population and quality of bamboo stems before and after bamboo agroforestry and food crops

Parameters	Before agroforestry bamboo + rice + cassava + taro	After agroforestry bamboo + rice + cassava + taro
Number of stem/clumps		
- Mature stem	4.60	6.01
- Young stem	0.75	1.45
- Bamboo shoot	0.56	3.71
Bamboo stem quality		
- Length (m)	7.19	8.49
- Diameter (cm)	4.86	7.17
- Thickness (cm)	1.63	1.95
- Section length (kg)	32.59	27.87
- Stem weight (kg)	8.90	17.09
- Branch weight (kg)	7.59	4.22
- Total weight (kg)	16.49	21.31

Betung bamboo, at the age of 7 years, is still experiencing an increase in the number of stems per cluster and stem size. This increase is because bamboo is the most efficient in using CO_2 and water to produce large biomass (Peixoto et al., 2021). However, *betung* bamboo generally has slower growth than other types of bamboo, one of which is slow root development (Kaushal et al., 2020). The diameter growth of *betung* bamboo is in the range of 0.050.38 cm month^{-1} (Hassan et al., 2022). Environmental factors influence the growth of *betung* bamboo in terms of both morphology and stem quality. *Betung* bamboo can grow optimally at an altitude of 600–900 m above sea level (Aribal et al., 2022), while the research location has a height of 450 m above sea level, which results in the growth of bamboo plants being less than optimal. Apart from that, land management with an agroforestry pattern can increase the growth of *betung* bamboo. Bamboo management with agroforestry, fertilizing food crops under bamboo, and managing bamboo clumps can increase the height and diameter of bamboo stems, number of shoots, and soil fertility (Miao et al., 2022).

The quality of bamboo stems increased after applying the agroforestry pattern. In addition, it contributed 80.2% of the total bamboo weight, whereas branches (twigs and leaves) contributed 19.8%. The increase in bamboo biomass can be influenced by the addition of nutrients from planting annual crops (Piouceau et al., 2014). Phosphorus content affects the thickness of bamboo stems (Abasolo & Fernandez, 2005). Table 1 shows that the soil phosphorus content increased to positively impact the bamboo stem thickness. The quality parameters of the bamboo stems that experienced a decrease were the length of the bamboo nodes and weight of the branches. This condition is thought to be caused by the allocation of bamboo photosynthesis results, which is more directed at increasing the number of stems per clump and the thickness of bamboo. The addition of bamboo biomass is directed at the stem so that the branch biomass is reduced. This phenomenon is caused by the increased total nitrogen in the soil from bamboo agroforestry practices.

The quality of bamboo stems increased after agroforestry practices were implemented by planting rice, cassava, and taro crops. The presence of annual plants is accompanied by fertilization activities, which improve soil fertility.

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Table 3 Average of 1,000 grain weight for three varieties of rice

Rice variety	Average weight of 1,000 grain (g)				
	All systems	Bamboo + rice	Bamboo + rice + cassava	Bamboo + rice + taro	Rice + cassava + taro
Rindang	26.54[a]	26.79	30.23	30.06	18.48
Protani	23.99[b]	23.00	26.94	24.65	21.27
Unsoed	23.25[c]	24.50	24.91	24.87	18.21

Note: Values followed by different letters (a,b) in the same column are significantly different (P<0.05)

Increasing soil fertility affects the quality of the bamboo stems produced. An increase in nitrogen stimulated bamboo shoot growth and cell elongation during the fast growth phase (14 m). Subsequently, nitrogen plays a role in the lignification process of the stem so that the quality of the stem is better (Yang et al., 2022). Increasing soil P content also increases the height, diameter, development of bamboo roots, and total bamboo biomass (Liu et al., 2023).

Food crops production ***Rice production*** The weight of 1,000 grains was influenced by varietal differences in rice (Table 3). This result is consistent with that of previous research. Rindang varieties produce the most significant 1,000 grain weight. The results of other research show that the weight of 1,000 grains of rindang varieties was 26.85 g (Mustikatini et al., 2022), while the protani and unsoed varieties had 1,000 grain weight of 20.46 g and 21.12 g, respectively (Riyanto et al., 2022).

Rice development using an agroforestry pattern is influenced by the use and availability of shade-tolerant seeds, managing competition by regulating tree-planting positions, reducing tree canopies, and interacting with fertilization levels (Rodenburg et al., 2022). Superior shade-tolerant varieties are more efficient in utilizing sunlight for photosynthesis to create optimal energy (Hamdani & Susanto 2020). In addition, rice spacing needs to be widened so that limited sunlight can still hit all parts of the rice clump and the rate of photosynthesis remains optimal (Deng et al., 2022). The distance and density of annual plants maintain land productivity resilience and minimize trade-offs (Roupsard et al., 2020). The quality of rice yields in an agroforestry pattern depends on the agroforestry pattern and fertilizer applied (Rodenburg et al., 2022). If managed well, bamboo groves can maintain understory plant production. Strobilanthes cusia plants grow and have good production under bamboo stands, which still transmit up to 56.7% light, and with fertilization of understory plants (Pamungkas et al., 2023). The treatment effect on rice production is presented in Table 4.

Table 4 Average of rice production in agroforestry systems

Agroforestry systems	Average of grain production (g m^{-2})
Bamboo + rice	
• Rindang	0.24[abc]
• Protani	0.28[ab]
• Unsoed	0.07[de]
Bamboo + rice + cassava	
• Rindang	0.35[a]
• Protani	0.06[de]
• Unsoed	0.08[de]
Bamboo + rice + cassava	
• Rindang	0.22[abcd]
• Protani	0.08[de]
• Unsoed	0.05[e]
Rice + cassava + taro	
• Rindang	0.29[ab]
• Protani	0.11[cde]
• Unsoed	0.18[abcde]

Note: Values followed by different letters (a, b, c, d, e) in the same column are significantly different (*p*-value < 0.05)

The interaction treatment that produced the highest rice yield was the planting pattern of agroforestry bamboo + rice of the rindang 2 variety + cassava (0.35 kg m^{-2}) or 3.475 ton ha^{-1}. This rice production is higher than the rice yield planted between *Dalbergia sisso* trees (0.062.4 tons ha^{-1}) (S. Patel et al., 2017), rice among mango trees with productivity 2,97 kg 12 m^{-2} (Miyagawa et al., 2017), and rice planted under the *sengon* (*Falcataria mollucana*) with a productivity of 2.58 ton ha^{-1} (Wijayanto & Karimatunnisa, 2022). The rindang 2 variety can produce a higher rice yield in bamboo agroforestry cropping patterns and mixed food crops such as rice, taro, and cassava. This higher productivity is because the rindang 2 variety was developed as a rice variety for planting under the shade, with an average yield of 4.2 ton ha^{-1} and a potential yield of 7.39 ton ha^{-1} (Sasmita et al., 2019). The rindang 2 variety planted under coconut trees yielded 3.98 ton ha^{-1} (Sution & Kartinaty, 2022).

The production stability of a variety under shade, apart from being influenced by genotype, is also influenced by disease incidence (Zulfa et al., 2019). One of the reasons for the non-optimal production of rice among bamboo is pests and diseases. The disease that attacks the rice in this research is 'leaf blight' caused by the bacterium *Xanthomonas oryzae* pv. *Oryzae* and blast disease caused by the fungus *Pyricularia grisea*. Diseases that attack upland rice in agroforestry patterns are caused by shade, which creates a more favorable microclimate for the growth of bacteria and fungi (Senjaya et al., 2018). The types of pests that attack rice plants are urethral pests (*Lepidiota stigma*), which attack rice roots at the beginning of planting, and stem borer pests (*Sesamia inferens*) when rice is mature. Providing excess nitrogen fertilizer can increase stem borer pest attacks because plant growth and water content in the stems increase, making them favored by stem borer pests (Munira et al., 2022).

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Cassava and taro production Cassava and taro planted on the edges of rice plants and around bamboo clumps were harvested at the age of 8 months after planting. Distance from the bamboo plant influences cassava and taro production. The results of further tests on cassava and taro production in the distance treatment from bamboo clumps are presented in Table 5. The results showed that cassava production (number of tubers and tuber weight) was influenced by cropping patterns, but the biomass production of cassava plants was not significantly different between treatments. The highest production of cassava tubers was produced by cassava planted in the mixed rice + cassava + taro cropping pattern (number of 8.66 tuber plant^{-1}, weight of 2.12 kg plant^{-1}). Cassava grew at a distance of ≤ 1 m from the bamboo clump, resulting in the lowest tuber production, both in number and weight. With intensive monoculture management, cassava tuber production in Nigeria is 0.968 kg plant^{-1} (Enesi et al., 2022). This shows that cassava produced from an agroforestry pattern differs greatly from that produced from a monoculture pattern. Other research results show that cassava production using agroforestry is still high. Agroforestry-planted cassava research on bamboo at a young age (13 years) yielded 11.49 ton ha^{-1}, 12.15 ton ha^{-1}, and 13.09 ton ha^{-1}, respectively (Akoto et al., 2020). Cassava between young eucalyptus trees can produce up to 10.25 ton ha^{-1}, while monoculture planting can produce tubers of 12,486.69 ton ha^{-1} (Nieri et al., 2021).

Taro production did not differ significantly between cropping pattern treatments. The treatment resulted in a significant difference in the aboveground biomass parameters. Taro planted near bamboo (≤1 m) produced the highest biomass up to harvest time, whereas taro grown without bamboo had the lowest. This is because harvesting occurs during the dry season, when taro plants without bamboo shade dry out more quickly, whereas taro plants planted under bamboo are still relatively green. This indicates that the presence of shade can protect taro plants from drought. Taro growing in the shade has a larger leaf area and higher biomass (Gondim et al., 2018). Taro planted in the shade with suitable varieties can produce tubers of 1.2 kg plant^{-1} greater than those grown in the open area (Derebe et al., 2019). However, if the spacing between shade trees is too tight, taro production can be reduced (Boampong et al., 2020; Prehaten et al., 2021).

Utilization of land under bamboo through the development of tuber-type food crops, such as taro and cassava, is expected to optimize food reserves during the dry season. Cassava plants planted in annual crop areas have higher production owing to the optimal availability of sunlight. The problem with cassava developed using agroforestry patterns is that it still requires proper cultivation management and improvement of shade-tolerant varieties (Dettweiler et al., 2023). One of the advantages of cultivating cassava using agroforestry is that it can suppress weed growth and reduce maintenance costs for farmers who experience limited energy and capital (Weerarathne et al., 2017). The biotic and abiotic factors that affect taro productivity are water availability, weeds, soil fertility, and seed quality (Bammite et al., 2018). Under environmental stress conditions, genetic factors can significantly influence taro productivity (Gerrano et al., 2019). Drought-resistant genetics can increase taro production because taro has a high nutrient and water use efficiency during the dry season (Gouveia et al., 2020). Taro planted on infertile land must be supplemented with organic material for optimal production (Sachan & Krishna, 2018).

Land use efficiency The agroforestry pattern of *betung* bamboo with food crops (rice, cassava, and taro) had LER and ATER values > 1 (Table 6). This shows that the higher the LER and ATER values, the higher the land use efficiency compared to monoculture, so cultivation is feasible. The P1V2 cropping pattern (agroforestry bamboo + protani rice variety) showed the highest LER and ATER values. This is because the Protani rice variety planted under bamboo stands has a higher production than when grown in monoculture. The bamboo agroforestry pattern with seasonal crops has been shown to increase productivity and land-use efficiency. The agroforestry pattern that produces the highest LER and ATER values shows that this pattern can double the productivity of the system compared with the monoculture pattern, which is in line with the goals of intensification of sustainable agriculture (Biswas et al., 2022). The total economic value of a mixture of agroforestry product types will be consistent in the long term (Staton et al., 2022). Farmer income from different cropping patterns is presented in Table 7.

Table 5 Average of number of tuber, tuber weight and aboveground biomass for cassava and taro in bamboo agroforestry

Agroforestry systems	Average of production		
	Number of tuber/ plant	Tuber weight (kg plant^{-1})	Above ground biomass weight (kg plant^{-1})
Cassava production under bamboo + rice + cassava pattern			
• ≤ 1 m from bamboo	3.8^{b}	0.53^{b}	0.76^{a}
• > 1 m from bamboo	5.47^{b}	0.95^{b}	0.97^{a}
Taro production under bamboo + rice + taro pattern			
• ≤ 1 m from bamboo	3.93^{ns}	0.31^{ns}	0.24^{a}
• > 1 m from bamboo	6.00^{ns}	0.52^{ns}	0.18^{ab}
Cassava and taro production under rice + cassava + taro pattern			
Cassava	8.66^{a}	2.12^{a}	1.73^{a}
Taro	6.11^{ns}	0.27^{ns}	0.05^{b}

Note: Values followed by different letters (a, b) in the same column are significantly different (p-value < 0.05), ns: not significant different

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Table 6 Land equivalent ratio and area time equivalent ratio value of bamboo agroforestry systems

Agroforestry systems	Land equivalent ratio	Area time equivalent ratio
Bamboo + rice		
• Rindang	2.32	2.52
• Protani	3.19	3.56
• Unsoed	1.67	1.84
Bamboo + rice + cassava		
• Rindang	2.87	3.09
• Protani	2.37	2.37
• Unsoed	2.09	2.15
Bamboo + rice + taro		
• Rindang	2.18	2.08
• Protani	2.33	2.26
• Unsoed	2.18	2.09

Table 7 The economic value of farmers' income from different cropping patterns

Treatment	Bamboo			Rice			Cassava			Taro			Total
	Yield (stems ha^{-1} $year^{-1}$)	Price (IDR) × 1,000	Income (IDR) × 1,000	Yield (kg ha^{-1})	Price (IDR kg^{-1}) × 1,000	Income (IDR ha^{-1}) × 1,000	Yield (kg ha^{-1})	Price (IDR kg^{-1}) × 1,000	Income (IDR ha^{-1}) × 1,000	Yield (kg ha^{-1})	Price (IDR kg^{-1}) × 1,000	Income (IDR ha^{-1}) × 1,000	income (IDR ha^{-1}) × 1,000
P1V1	700	10	7,000	695	5	3,475	-	-	-	-	-	-	10,475
P1V2	700	10	7,000	810	5	4,050	-	-	-	-	-	-	11,050
P1V3	700	10	7,000	207	5	1,035	-	-	-	-	-	-	8,035
P2V1	700	10	7,000	1,013	5	5,065	3,771	1.5	5,656	-	-	-	17,721
P2V2	700	10	7,000	177	5	885	3,771	1.5	5,656	-	-	-	13,541
P2V3	700	10	7,000	219	5	1,095	3,771	1.5	5,656	-	-	-	13,751
P3V1	700	10	7,000	646	5	3,230	-	-	-	2,064	3	6,192	16,422
P3V2	700	10	7,000	224	5	1,120	-	-	-	2,064	3	6,192	14,312
P3V3	700	10	7,000	158	5	790	-	-	-	2,064	3	6,192	13,982
P4V1	-	-	-	2,333	5	11,665	2,120	1.5	3,180	270	3	810	15,655
P4V2	-	-	-	846	5	4,230	2,120	1.5	3,180	270	3	810	8,220
P4V3	-	-	-	1,447	5	7,235	2,120	1.5	3,180	270	3	810	11,225

Remarks: Bamboo is harvested 50% from old bamboo, bamboo planting distance 10 m × 10 m, cassava/taro planting distance = 1 m × 1 m, USD1 = IDR15,000

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The agroforestry bamboo + rice + cassava (P2V1) produces the highest income for farmers of IDR17,721,000 ha^{-1}year^{1}. This is because farmers obtain 3 types of products that have quite high economic value. Saqib and Khan (2022) stated that the income of agroforestry farmers depends on the area and number of annual crops. Therefore, the income obtained from agroforestry patterns can be higher than that obtained from cultivating bamboo plants. Farmers who implement the P2V1 agroforestry pattern can increase their income by 17.2% compared to the P3V1 monoculture planting pattern. Farmers' income can increase by 25% from agroforestry patterns compared to planting annual crops (Barnes et al., 2023). Intercropping patterns can reduce seasonal crop yields due to competition for light, moisture, and nutrients, but farmers can obtain higher incomes due to efficiency in land use (Chavan & Dhillon, 2019). In the bamboo agroforestry pattern, the quality of the bamboo produced increased after the agroforestry pattern with food crop species was introduced. This is because intercropping can increase plant growth while increasing the income of farmers (Pandey, 2019).

The production of single-annual crops in monocultures is often higher. However, the yield of several products from the agroforestry pattern will be higher, as indicated by the LER value >1 (Wang et al., 2021). In dry areas, the production of individual annual plant species can be higher in agroforestry land than in monoculture land because of the role of trees in reducing water-limiting factors (Temani et al., 2021). Thiesmeier and Zander (2023) stated that although the monoculture pattern has a higher economic value than agroforestry, the agroforestry pattern has environmental services, higher carbon uptake, and the sustainability of agricultural practices. The choice of agroforestry patterns can be based on topographical conditions, water availability, soil properties, resource competition, and susceptibility to pests and diseases (Kheiri et al., 2023). Agroforestry can reduce environmental impacts and increase economic efficiency (Caicedo-Vargas et al., 2022). The economic benefits of agroforestry will be even more attractive if the government has political and financial support, considering the environmental services provided (Rosso et al., 2021).

Conclusion

Bamboo can be cultivated in agroforestry with food crops such as rice, cassava, and taro. *Betung* bamboo clumps up to seven years old still produce new stems with better height, diameter, and number per clump than the previous generation. *Betung* bamboo, until the age of seven, is still growing in height, diameter, and number of stems per clump. The use of shade-tolerant rice varieties is a significant factor in agroforestry success. Planting upland rice of the rindang 2 variety using an agroforestry bamboo + rice + cassava pattern produces the highest production, whereas the highest production of cassava is obtained from a mixed planting pattern of rice + cassava + taro. Taro tuber yield was relatively higher in the agroforestry pattern with a distance of >1 m from the bamboo clump. The LER and ATER values obtained from bamboo agroforestry are above 1, which indicates that this planting pattern has higher productivity and efficiency than the monoculture pattern, whereas the highest economic value is produced in the agroforestry planting pattern of bamboo + rindang 2 variety of rice + cassava varieties.

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