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Full Length Research Article

Productivity of Cajuput Stands at Various Age Levels in Telawa Forest Management Unit, Central Java, Indonesia

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ABSTRACT

Cajuput (*Melaleuca cajuputi* Powell) plants are essential oil-producing plants that have ecological and economic benefits. The ideal pruning life is one way to optimize the productivity of cajuput stands. This study aims to analyze the productivity of cajuput stands at various age levels in Telawa Forest Management Unit by considering shoots, stem diameter, shoot diameter, biomass, and land suitability analysis. Data was collected by making three temporary survey plots by simple random sampling at 5, 9, 13, 17, and 21-year-old stands. The results showed that cajuput stands experienced increased productivity, as seen in stem diameter, shoot diameter, and biomass. In addition, the higher the stand density, light intensity, and humidity positively affect the total biomass, with an increase in the life of the stand. Based on the study's results, the best cajuput productivity occurred at 17-year-old stands, with an average biomass of 1,031.43 kg/ha and an allometric equation of 18.40 kg. The decrease in cajuput productivity occurred at 21-year-old stands, 40% compared to the 17-year-old stands, and the 21-year-old stands have the lowest land index value. Despite the decline in productivity, the main effects still need to be studied over a more extended period.

1. Introduction

Cajuput (*Melaleuca cajuputi* Powell) plants produce essential oils that are important in the industrial field. Apart from being an industrial raw material, cajuput plants are helpful in the restoration of marginal land and provide benefits to the surrounding community (Kartikawati and Rimbawanto 2014). Cajuput plants began to be planted in Indonesia in 1926. Java Island began in Gundih for reforestation purposes, especially on marginal land (Rimbawanto et al. 2021). Indonesia can only supply 650 tons/ha of cajuput oil raw materials on a domestic industrial scale out of a total demand of 3,500 tons/ha (Rimbawanto et al. 2017). The productivity of cajuput oil in Indonesia is around 713 kiloliters/ha (Mindawati and Waluyo 2019). The basis for this calculation is the yield value of cajuput oil raw materials of 0.97% (Mulyana et al. 2018).

Cajuput leaf is one of the leaves that produces the most essential oil. Cajuput leaves are pruned and then distilled to produce oil. Increasing cajuput plant productivity can be achieved through genetic and physiological breeding, manipulation of growing locations, planting patterns, and the development of distillation units (Rimbawanto et al. 2021). Guenther (2011) stated that the age of cajuput leaves, the way the leaves are filled in the kettle, the type of tree, the way the leaves are stored, and the distillation process all affect the production of cajuput oil. These elements can impact the quantity and quality of cajuput oil produced. Determining the ideal pruning age for cajuput plants is one way to optimize productivity in managed cajuput plantation forests. The optimal age of cajuput plants is still determined empirically, and yield settings still depend on estimates.

Cajuput plants are harvested by pruning the leaves. According to Ariyanti (2022), the productivity of cajuput plants is measured by the production of leaves and twigs harvested by cutting down 1.5 m tall cajuput trees, as well as essential oils produced from the distillation of both. According to Perum Perhutani (2010) in Kartikawati and Rimbawanto (2014), the average productivity of Perum Perhutani cajuput leaves in 2006-2010 was approximately 1.8 kg/tree with an average yield of 0.8%. According to (Rimbawanto et al. 2021), the average production of cajuput crops in the descendant test plot in Paliyan Gunungkidul is 6 kg per tree, or 3.75 tons of leaf/ha if planted with a planting distance of 4 m × 4 m. The heavier the leaves obtained per unit area, the more productive the garden is. Therefore, the more trees planted per unit area with ideal planting spacing and nutrients, the more leaves will be obtained (Aisyah and Herlina 2018).

Cajuput plants on the island of Java are grown through an agroforestry system, with a planting distance of 3 m × 1 m or 4 m × 2 m. Meanwhile, if cajuput plantations are managed by monoculture, the planting distance is generally 1 m × 1 m or 2 m × 1 m (Rimbawanto et al. 2017). According to research conducted at Perum Perhutani, cajuput trees will remain productive in producing leaves until 30 years, after which they must be replanted (Rimbawanto et al. 2017). The same thing was obtained by Budiadi et al. (2005) in the research on the biomass cycle of cajuput plants in Sukun Forest Management Unit Section, namely an increase in biomass at 15 years old.

This study focuses on the productivity of cajuput stands at various age levels in Telawa Forest Management Unit or *Kesatuan Pemangkuan Hutan* (KPH). Telawa Forest Management Unit has 2,748.6 ha of cajuput plantation forests covering forest areas in Boyolali, Grobogan, and Sragen Regencies. This study observed cajuput at 5, 9, 13, 17, and 21-year-old stands. The observation of the stand is based on the condition of the stand (number of shoots, stem diameter, shoot diameter, and biomass) and the land suitability analysis. Therefore, this study reveals age's influence on cajuput stands' productivity.

2. Materials and Methods

2.1. Research Time and Location

This research was carried out from December 2023 to January 2024 at Perum Perhutani Telawa Forest Management Unit Central Java Regional Division. The location of research was carried out in Karangwinong and Gemolong Forest Management Unit Section or *Bagian Kesatuan Pemangkuan Hutan* (BKPH) (**Fig. 1**). The calculation of biomass samples was carried out at the Forest Management Laboratory, Faculty of Agriculture, Universitas Sebelas Maret (UNS) Surakarta. The soil pH and organic carbon content analysis was conducted at the Laboratory of Soil Physics and Conservation and the Laboratory of Soil Chemistry and Fertility, Faculty of Agriculture UNS Surakarta.

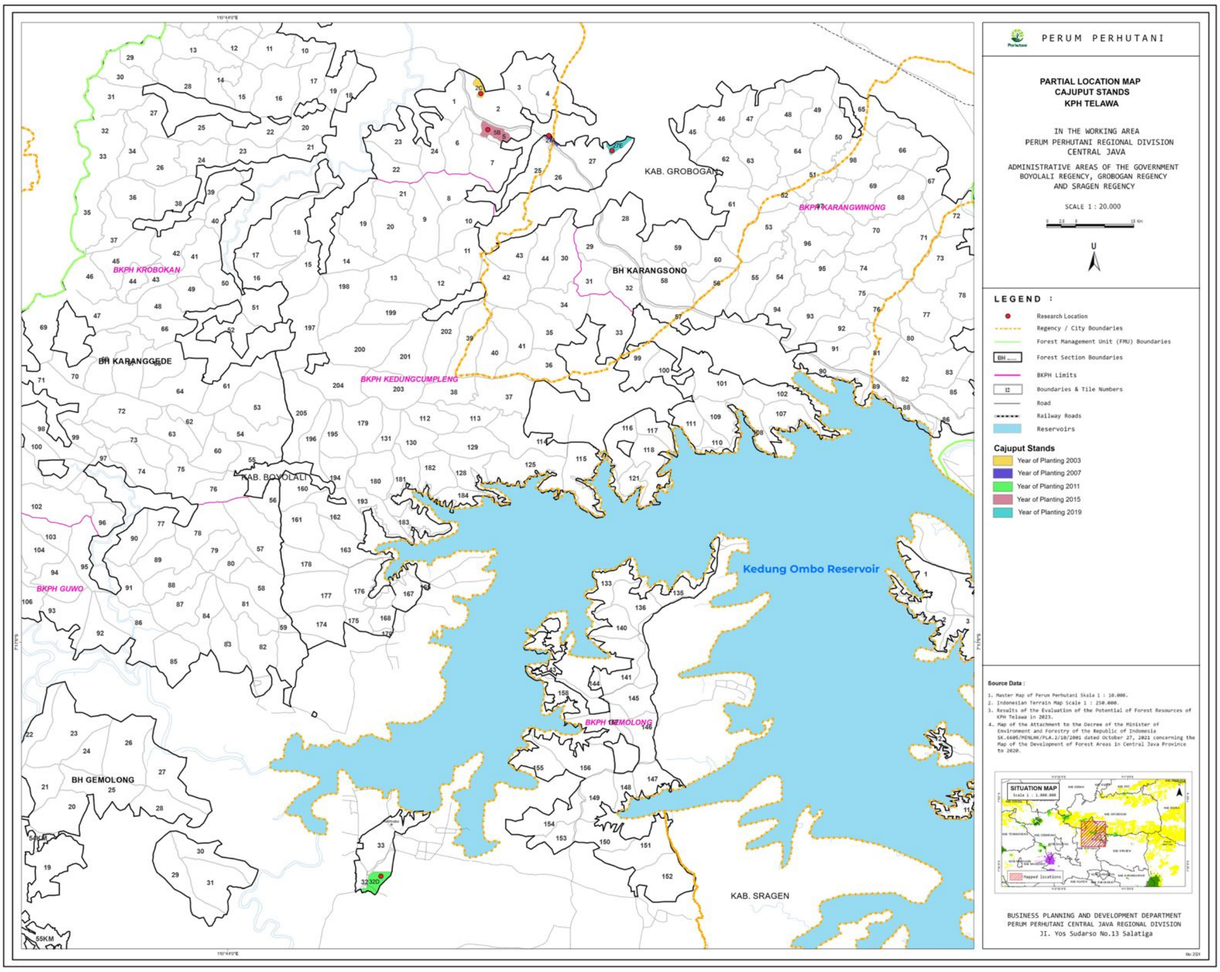

Fig. 1. Map of the research location.

2.2. Research Materials

2.2.1. Field research materials

This study observed cajuput 5, 9, 13, 17, and 21-year-old stands in Telawa Forest Management Unit with an agroforestry planting system. The tools used in this study include stationery, roll meter, tape meter, caliper, stick, clinometer, lux meter, thermohygrometer, ground drill, infiltration pipe, stopwatch, ruler, cabinet envelope, calculator, analytical digital scale, 50 kg hanging digital scale, mine rope, tally sheet, leaf cutter, plastic clip, camera, Avenza Maps Application, and Maverick.

2.2.2. Laboratory research materials

This study conducted laboratory tests, including leaf and twig moisture content, pH testing, and soil organic carbon. Laboratory analysis used bottles, mortar, 25 mL flasks, droppers, orbital shakers, digital pH meters, ovens, spectrophotometers, aquifers, K_2Cr, H_2SO_4, and C-Organic standard solution 5,000 ppm. The calculation of soil pH using the electrometry method is carried out by taking a sample of soil that has been sifted and wind-dried as much as 5 g and then putting it into the flakes (Eviati et al. 2023). Mix soil samples with distilled water in a ratio of 1:2.5, then the solution is shaken with an orbital shaker until homogeneous and let stand for 30 minutes. The concentration of H+ extracted with water stated active (actual) acidity.

Meanwhile, organic carbon analysis using the Walkley and Black methods was carried out by taking a sample of sifted and wind-dried soil of 0.125 g and putting it into a 25 mL measuring flask. After that, 1.25 mL of K_2Cr is added, then shaken. Furthermore, 1.87 mL of H_2SO_4 was added. Furthermore, the next day, the absorption of the clear solution was measured with a spectrophotometer at a wavelength of 561 nm. As a comparison, it makes standards of 0, 125, and 250 ppm. Standard zero mixes 2.5 mL of K_2Cr and 3.75 mL of H_2SO_4. Standard 125 mixes 2.5 mL of K_2Cr, 3.75 mL of H_2SO_4, and 1.25 mL of 5,000 ppm, as well as standard 250 mixes 2.5 mL of K_2Cr and 3.75 mL of H_2SO_4 and 2.5 mL of 5,000 ppm (Eviati et al. 2023).

2.3. Stages of Research Implementation

This research was done by making temporary survey plots on cajuput 5, 9, 13, 17, and 21-year-old stands in Telawa Forest Management Unit. The age selection is based on the situation in the field by grouping age classes with an interval of 4 years. At each age of cajuput plants, temporary survey plots were made in a circle with an area of 0.10 ha (circle radius 17.84 m) with three replicates, so there are 15 temporary survey plots. The sample was determined by simple random sampling with 15 survey plots. The establishment of survey plots was carried out based on the Regulation of the Minister of Forestry Number P.33/Menhut-II/2009 concerning Guidelines for Periodic Comprehensive Forest Inventory (*Inventarisasi Hutan Menyeluruh Berkala*/IHMB) in the Business of Utilizing Timber Forest Products in Production Forests for plantation forests with an age class of ≥ V (Menteri Kehutanan Republik Indonesia 2009). The area of survey plots is 0.1 ha, and the distance between temporary survey plots is 200 m. Sampling of cajuput stands used the illustration scheme in **Fig. 2**, and the details of sampling in the field are presented in **Table 1**.

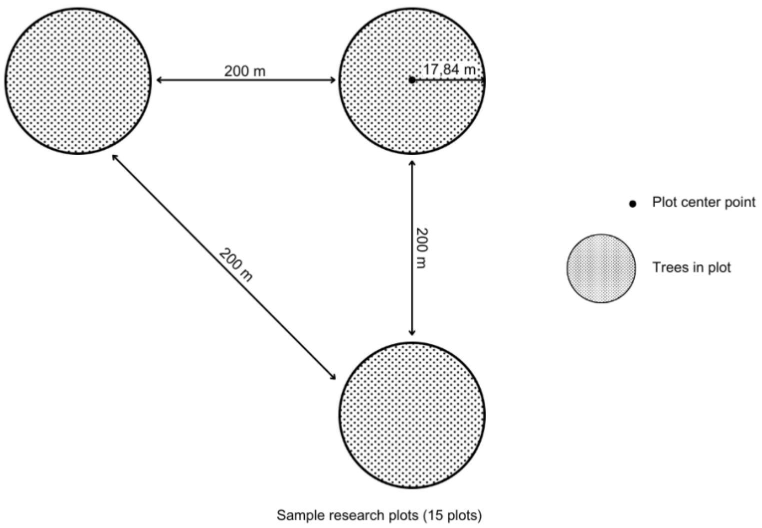

Fig. 2. Data collection scheme and sampling at the location of the sample plot.

Biomass was calculated by oven-dried samples of leaves and twigs of cajuput plants and analysis of biometric equations (BSN 2011; Purwanto et al. 2022). The oven-dried biomass sample and allometric equations were obtained based on the calculation results. Sampling was done by pruning the shoots by leaving one of the highest branches and then separating the leaves and twigs with a maximum diameter of 0.5 cm. After that, each part was weighed with a wet weight of ± 100 g. One hundred fifty samples of cajuput leaves and twigs were tested at the UNS Forest

Management Laboratory. The sample is dried in an oven at 80°C for 24 hours until it reaches a stable weight (BSN 2011). The constant dry weight is recorded every 8 hours to calculate the biomass's moisture content and total weight.

Table 1. Sampling location

Age (year-old)	Planting year	BKPH	RPH	Swath	Planting distance (m x m)	Plot area (ha)	Tree potential (N/ha)
5	2019	Karangwinong	Brangkal	27E	3 × 1	4.7	3.333
9	2015	Karangwinong	Brangkal	5B	3 × 1	9.7	3.333
13	2011	Gemolong	Kadirejo	32D	6 × 1	8.5	1.666
17	2007	Karangwinong	Brangkal	27A	3 × 2	1.6	1.666
21	2003	Karangwinong	Brangkal	2C	3 × 2	2	1.666

Notes: BKPH = Forest Management Unit Section or *Bagian Kesatuan Pemangkuan Hutan*; RPH = Forest Management Resort or *Resort Pemangkuan Hutan*.

Each part of the leaf organ and twig is calculated using the following formula (Budiman et al. 2015):

$$BO = \frac{BK}{BB}\ Bbt \qquad (1)$$

where *BO* is biomass organ (leaf biomass and twig biomass), *BK* is the constant dry weight of the sample (g), *BB* is the sample wet weight (g), and *BBt* is the wet weight per part of the tree (leaf wet weight and twig wet weight).

Calculation of cajuput leaf and twig biomass in survey plots (Mulyana et al. 2018):

$$B_{plot} = \frac{\sum_{i=1}^{n} Bi}{L} \qquad (2)$$

where B_{plot} is the biomass of cajuput leaves in the plot, *Bi* is the biomass of cajuput leaves from the *i*-th tree, and *L* is the plot area (ha).

The estimation of biomass calculations is carried out with an allometric equation (Purwanto et al. 2022):

$$DW = 0.136 \times D^{2.19} \qquad (3)$$

where *DW* is *Dry Weight* or biomass (kg), and *D* is *diameter* (cm).

The diameter of the stem of cajuput plants is measured by measuring the stem's diameter at 10 cm from the ground surface using a caliper (Diansyah 2017). Data was collected by measuring the tree's height using a stick juxtaposed with a meter tape on each sample tree. Measurement of crown diameter is done by measuring the projection of the crown on the site, namely the longest crown and the shortest crown in the four cardinal directions in sequence with a tape meter (Sadono 2018). The slope of the survey plot location was measured with a clinometer.

The soil infiltration rate calculation and drainage class determination were done using a double-ring infiltrometer tube (Kiptiah et al. 2021). The temperature and humidity measurements in each survey plot were carried out with a thermohygrometer in areas that receive direct sunlight at a distance of at least 2 m from the shade (Milantara et al. 2023). Effective depth measurement using a soil drill and a meter by measuring from the soil surface to the soil layer that cannot be penetrated by plant roots or layers that already contain rocks (Bockheim et al. 2014).

Light intensity measurements were carried out on each plot outside the shade using a lux meter held 75 cm high from the forest floor at 06.00–07.00, 12.00–13.00, and 17.00–18.00 WIB

(Karyati et al. 2023). Land suitability is evaluated through a matching system pattern, which compares land characteristics with the prerequisites for growing cajuput plants (Sadono et al. 2020). The soil pH was calculated using electrometry by taking a sample of sifted and dried soil as much as 5 g. The concentration of H^+ extracted with water was declared active (actually) (Eviati et al. 2023). Soil C-Organic analysis was carried out using the Walkley and Black methods with a spectrophotometer at a wavelength of 561 nm (Eviati et al. 2023).

2.4. Data Analysis

The analysis of cajuput plant productivity was carried out using biomass calculations. (Rimbawanto et al. 2021). The weight of the biomass harvested determines the best productivity of cajuput plants; the heavier the leaf weight obtained by the wide union, the more productive it is (Rimbawanto et al. 2021). Furthermore, multiple linear regression analysis was carried out to determine the linear relationship between the variables of age influence on the growth parameters (number of shoots, stem diameter, shoot diameter, biomass, and the land suitability analysis) of cajuput plants. Data processing was done with SPSS 27 software through Analysis of Variance (ANOVA) with a significance level of 5% (Al Toriq and Puspitawati 2023). A further Duncan Multiple Range Test (DMRT) is carried out if different treatments have a significant effect.

3. Results and Discussions

3.1. Cajuput Stand Biomass

The cajuput stand biomass was calculated to estimate the productivity of cajuput stands at certain age conditions. The results of this study showed that the highest total average biomass of the oven method at the age of 17 was 1,031.43 kg/ha, followed by the age of 9 at 799.94 kg/ha. The results of biomass analysis of the cajuput stand oven method are presented in **Fig. 3**.

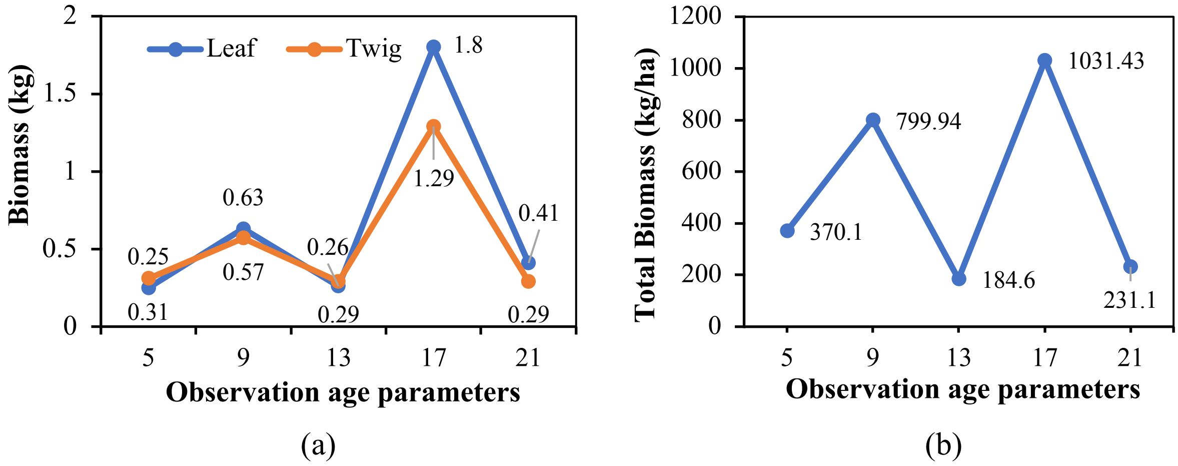

Fig. 3. a. Average biomass of cajuput stands; b. total biomass of cajuput stands.

The results of the biomass calculation revealed that the 9-year-old stands have a total biomass of 799.94 kg/ha with a planting distance of 3 m × 1 m. Meanwhile, the 3 m × 2 m planting distance stand at 21 has a 231.10 kg/ha biomass (**Fig. 4**). According to Rahmadwiati et al. (2022), the carbon stock in the stands has a significant relationship with the density, dominance, and area of the tree base. The same thing was conveyed by Pebriandi et al. (2014), stating that the difference in the amount of carbon stored was due to the difference in plant density in each location. The calculation of biomass using the oven method in the field obtained the lowest total of 184.6 kg/ha at 13-year-old stands with a planting distance of 6 m ×1 m. The calculation results of the highest total biomass with a planting distance of 3 m × 2 m at 17-year-old stands of 1,031.43 kg/ha.

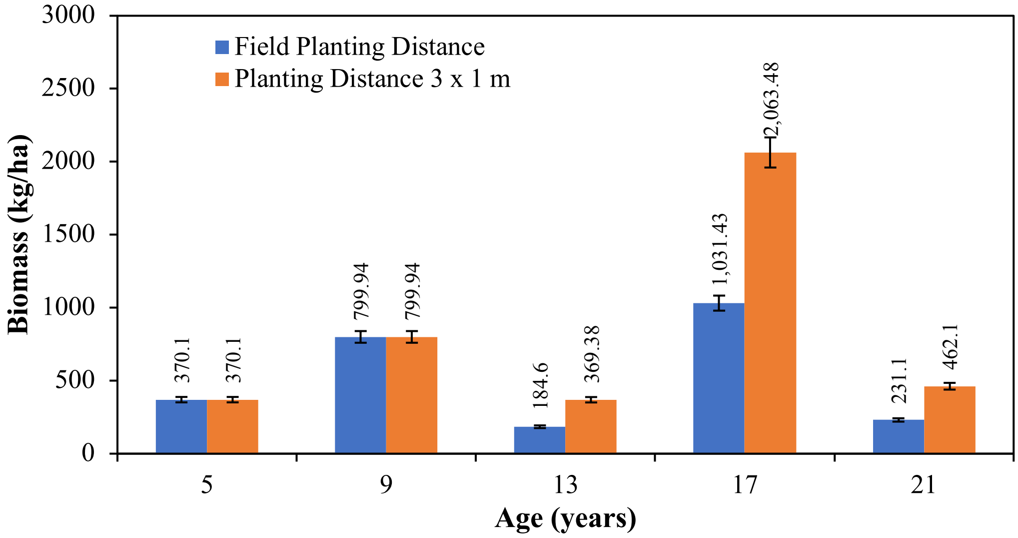

Fig. 4. Average biomass of planting distance 3 m × 1 m.

The total biomass in a plant is influenced by the level of organic matter. Based on **Fig. 4**, if it is assumed that all cajuput stands have a planting distance of 3 m × 1 m, at the age of 17, it has the highest total of 2,063.48 kg/ha. The 13-year-old stands still gets the lowest biomass value, 369.38 kg/ha. The organic matter in dryland forests has better capabilities than in mangrove forests and affects the dry weight of plants as a place to store carbon (Windarni et al. 2018). The same thing was conveyed by Siregar and Putri (2019). The photosynthesis process of plants will increase as the dry weight of the stand increases, so the amount of biomass absorbed will affect the dry weight of the plant.

The results of this study show that the leaf biomass is higher than that of twigs (**Fig. 3**). According to Mulyana et al. (2019), research at Yogyakarta Forest Management Unit found that the biomass composition of the leaves was higher than that of cajuput twigs; at 9 months, the leaves produced cajuput oil yield above 0.7%. A similar thing was found in Purwanto et al. (2022) comprehensive study that the biomass composition of cajuput plants is distributed in leaves (15%), twigs (11%), and stems (74%). Cajuput stands at the research site can produce the highest leaf and twig biomass of 3.09 kg/tree. According to Mulyana et al. (2019), cajuput stands in Yogyakarta Forest Management Unit and can produce productivity ranging from 1,400–2,000 kg/ha. Meanwhile, according to Kodir et al. (2016), 1 kg/tree/harvest of cajuput plants was obtained on the land of a former coal mine. The same thing was obtained by Rimbawanto et al. (2021). The average leaf production in the Probolinggo cajuput forest is 1–3 kg/tree.

The study results from calculating biomass through the allometric equation were obtained, and the 17-year-old stands showed the highest average biomass of 18.40 kg (**Table 2**). The cajuput stand with the lowest biomass value was the 13-year-old stands with a value of 8.38 kg. The total biomass yield of this study was highest at 5-year-old stands at 56,742.81 kg/ha, which was influenced by the total plants in hectares. According to Istomo and Farida (2017), stand biomass will increase along with stand density and stock carbon value. The same thing was found in the field at the 17-year-old stands, with the highest average biomass of 18.40 kg, while the total biomass lower than the 5-year-old stands was 56,742.81 kg/ha. The average calculation of cajuput stand biomass with an allometric equation is presented in **Table 2**.

Table 2. Average biomass of cajuput stand allometric equation method

Age	Biomass (kg)	Total biomass (kg/ha)
5	17.14	56,742.81
9	10.36	18,447.60
13	8.38	8,628.16
17	18.40	33,112.90
21	11.14	39,662.98

Cajuput plants in Yogyakarta Forest Management Unit experienced a decrease in leaf production obtained from the 19-year-old stands (Suhartati and Raharjo 2018). A considerable level of stand density is expected to increase production. Although the density of stands is positively correlated with the productivity of stands when combined with the age of the stands, there is a significant relationship between stand density and productivity (Khan et al. 2020). This study found a decrease in productivity at 13-year-old, with an average biomass of 8.38 kg and an average increase of 17-year-old by 18.40 kg. According to Mulyana et al. (2019), there is a gradual decrease in the productivity of cajuput stands from 27 to 31-year-old. In this study, the decrease occurred at the age of 21 by 40% compared to the age of 17.

Based on the calculation of the allometric equation, the highest biomass value was also found at the 17-year-old stand, which was 217.8 kg/ha (**Fig. 5**). Based on the biomass calculation, the 17-year-old stands produces 30.95 kg/ha. The lowest average amount of biomass was observed in the 13-year-old stands, the oven-dried biomass was 5.54 kg/ha, and the allometric equation was 94.36 kg/ha. The difference in values was caused by the results of the allometric equation calculating the total biomass of stems, twigs, and leaves that were pruned to a height of 1.5 m (Purwanto et al. 2022). Meanwhile, the SNI 7724: 2011 oven calculation took samples of leaves and twigs of cajuput plants (BSN 2011). Tree biomass production can be affected by diameter and height (Khan et al. 2020). Environmental factors, including water, temperature, air, air humidity, and optimal sunlight, influence these parameters.

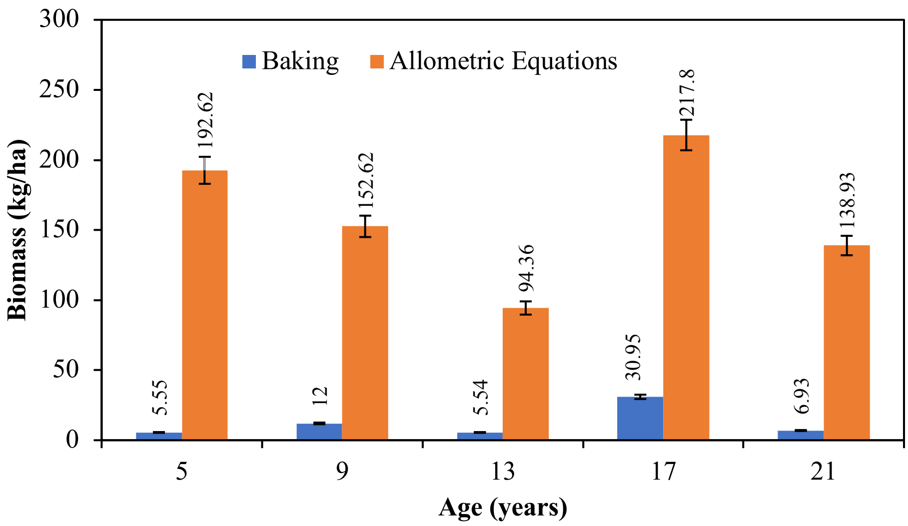

Fig. 5. Mean of the oven-dried biomass and the allometric equation.

3.2. Land Suitability Analysis

Telawa Forest Management Unit manages cajuput stands through an agroforestry system by combining crops such as corn, cassava, bananas, and peanuts. Agroforestry systems have a role in stabilizing soil structure and increasing soil productivity by planting various types of plants. In this study, observations at five different ages of cajuput stands in agroforestry systems with corn plants. This study also analyzed suitable soil parameters for cajuput land, such as drainage, adequate depth, pH, and C-organic soil. Soil drainage is the ability of the soil to pass water and air vertically. The same thing was conveyed by Alvares et al. (2023). Soil with optimal permeability makes a productive cajuput tree growth zone. Based on **Table 3**, the lowest drainage value at the age of 13 in test 2 is 2.05 cm/hour, which is included in the S1 criteria. Alvares et al. (2023) added that clay will provide a productive environment for cajuput plants because it contains available water.

The air temperature on each plot is classified as unqualified for growing cajuput plants (Sadono et al. 2020). Based on the observation results, the highest environmental temperature was 43.7ºC at repeat 1 of 9-year-old and included permanent non-conformity (N2). Meanwhile, the lowest temperature in the third test of the 13-year-old stands was 33.2ºC according to the marginal criteria (S3). In the research of Sadono et al. (2020) in RPH Gubugrubuh, Gunungkidul Regency has an air temperature of cajuput plants ranging from 23.2ºC to 32.4ºC. Plants with simple agroforestry patterns have higher microclimate temperatures associated with lower canopy cover, so the decomposition rate in these land use patterns will also be higher (Priyadarshini et al. 2020; Wijayanto et al. 2022). Alvares et al. (2023) added that their research produced the lowest productivity spread across regions with higher annual temperatures and low rainfall. Generally, rainfall at the research site is very low (N1), ranging from 31.8–45.05 mm/year (Perum Perhutani KPH Telawa 2023). Cajuput plants can grow optimally in the rainfall range of 1,201–1,500 mm/year (Sadono et al. 2020). Cajuput on the Java island grows optimally with an average annual rainfall below 2,000 mm/year, a temperature range of 17–33ºC, and calcareous soil (Rimbawanto et al. 2021).

C-Organic content in the soil can be formed through the stages of decomposition of organic matter. It is essential in supporting sustainable land management, especially in soil fertility factors, improvement of physical properties, maintaining nutrient availability, and survival of microorganisms in the soil (Farrasati et al. 2019). C-Organic is one of the most critical parameters in determining soil quality. The average C-Organic content of the soil was highest at the 9-year-old observation location at 3.37%, followed by the 17-year-old stands at 3.27%. Meanwhile, the 13-year-old stand has the lowest C-Organic content, with an average of 2.37% (**Table 3**). C-Organic can be affected by external factors such as soil type, temperature, and rainfall. In addition, litter on land cover can affect the amount of organic matter. Budiman et al. (2015) stated that the addition of litter biomass will increase with the increase of crown density so that the number of litters can vary. According to Sari et al. (2017), soil organic carbon content and organic carbon reserves have a positive correlation; soil organic carbon reserves are determined by soil density and depth. Suardi et al. (2016) added that the soil organic carbon of the agroforestry system is higher than that of the monoculture system at 49.75 C/ha. The function of soil organic matter is to provide plant nutrients and an energy source for microorganisms and soil fauna.

Table 3. Analysis of the suitability of the research site at Telawa Forest Management Unit

Deuteronomy	Elevation (masl)	Slope (%)	Temperature (°C)	Rainfall (mm/year)*	Drainage (cm/h)	Adequate depth (cm)	Soil Acidity (pH)	C-Organic (%)	Land index	Land conformity land
					5 years					
1	67	6	38.3	45.05	3.61	46	7.45	3.75	67.5	S2
2	61	7	35.8	45.05	2.95	37	7.61	2.55	67.5	S2
3	60	7	34.9	45.05	3.08	43	7.58	2.67	67.5	S2
					9 years					
1	83	9	43.7	45.05	2.68	63	7.68	2.55	62.5	S2
2	81	11	40.8	45.05	2.08	71	7.39	3.81	70	S2
3	84	4	39.6	45.05	3.07	54	7.44	3.76	70	S2
					13 years					
1	124	4	35.2	31.8	7.05	89	7.65	2.16	67.5	S2
2	124	5	35	31.8	2.05	73	7.46	3.61	75	S1
3	138	5	33.2	31.8	6.05	68	7.58	2.42	67.5	S2
					17 years					
1	81	5	39.1	45.05	3.51	73	7.6	2.99	65	S2
2	81	4	39.5	45.05	4.68	82	7.52	3.67	70	S2
3	81	7	38	45.05	3.6	91	7.55	3.16	72.5	S2
					21 years					
1	87	5	38	45.05	3.15	45	7.64	2.65	65	S2
2	66	8	35.7	45.05	2.78	46	7.56	3.34	70	S2
3	87	9	36.5	45.05	2.08	38	7.57	2.87	65	S2

Land parameters: all columns except Deuteronomy.

Note: *Annual rainfall data based on Perum Perhutani 2023 work report (Perum Perhutani KPH Telawa 2023).

The biomass content in tree stands varies depending on diameter, height, planting pattern, and nutrient status (Setyawan 2020). Based on **Fig. 5**, the age of 13 years has the lowest biomass value influenced by soil fertility, namely soil pH and C-Organic. Soil acidity analysis found that the average 13-year-old research location pH 7.56 was included in the current non-conformity criterion (N1). According to Subhan and Benung (2020), cajuput plants will grow optimally on the texture of clay sticky until clayey soils with a pH of 4–7. Acidity or pH is an essential element in the absorption of plant nutrients. The same thing was conveyed by Subhan and Benung (2020). The soil acidity level will inhibit plant growth; increasing plant growth requires soil acidity conditions that are close to neutral. Organic matter, due to its decomposition and release of organic acids, will affect the process of increasing soil pH (Yuniarti et al. 2020).

The light intensity measurements in this study were carried out three times, shown in **Table 4**, stating that the light intensity reception varied at each time and location of observation. The reception of sunlight on the forest floor will vary due to the canopy, altitude, location, and time (Taryono et al. 2023). Meanwhile, Zannah et al. (2023) added that light is the main factor in photosynthesis's energy sources in producing carbohydrates so plants can germinate optimally. The evapotranspiration process will take place optimally, and water availability is limited due to the influence of light intensity, which increases the soil temperature (Yunus et al. 2015).

Table 4. Light intensity and humidity of the observation site

Age	**Light intensity (x100 lux)**			**Relative humidity (%)**
	6–7	**12–13**	**17–18**	
5	35	787	253	44
9	196	941	79	37
13	64	664	37	50
17	207	927	128	52
21	47	627	31	45

Table 4 shows that the air humidity ranges from 37–52%. Plant growth will increase as the temperature and humidity decrease. The same thing was conveyed by Karyati et al. (2016), which is that an increase in air temperature will cause the vapor pressure to increase so that there is a decrease in air humidity. According to Taryono et al. (2023) in his research, rainfall, air temperature, and humidity are factors for plant growth. Humidity conditions affect the availability of nutrients and the absorption of plant nutrients. The highest humidity at the observation site at the 17-year-old stands was 52%. The lowest humidity at the 9-year-old stands was 37%. The effect of air humidity fluctuations is influenced by wind movement, temperature, air pressure, vegetation, and water availability.

3.3. Factors Affecting the Productivity of Cajuput Plants

The regression analysis showed that stand age and growth parameters' determination coefficient (R2) influenced 0.623 or 62.3% (**Table 5**). Meanwhile, a value of 37.7% was influenced by other factors that were not tested in this study. Other factors that can affect the productivity of cajuput stands are the nitrogen (N) nutrient content of the soil and the density of the stands. According to Lan et al. (2023), the optimal N nutrient content in the soil will provide better cajuput stand productivity. Plants that lack N can cause rapid leaf drop, dwarf plants, and chlorosis. Meanwhile, according to Sedjarawan et al. (2014), the density of stands will affect the light that enters the vegetation, so the lack of sunlight will cause slow growth, and the diameter of the stem will tend to be small.

Table 5. Average growth parameters and DMRT further test

Age	Plant Diameter (cm)	Number of Shoots	Shoot Diameter (m^2)	Biomass (kg)	Land Suitability Analysis
5	9.531^c	51.482^a	0.859^b	17.142^c	67.5^c
9	7.263^b	84.234^b	0.608^a	10.363^b	67.198^b
13	6.836^a	92.789^c	2.582^c	8.7376^a	68.515^d
17	9.531^d	127.865^d	2.596^c	18.396^d	68.868^e
21	7.408^b	95.647^c	0.905^b	11.141^b	66.650^a

Note: Numbers followed by the same letter in a column show no significant difference at a 95% confidence level.

This study conducted a follow-up analysis with DMRT on significantly different variables using a significance level of 95% (α=0.05), presented in **Table 5**. The results of the DMRT test showed that the highest plant diameter data was found at 17-year-old stands when the value was significantly different from other ages. The diameter of the plants produced at the age of 9 and 21 years has no real difference in value. Regarding the number of busts, the 17-year-old stands show the highest number and significantly differs from other ages. This aligns with the highest biomass at 17-year-old stands, substantially different from other ages. Cajuput stand biomass with DMRT test produced no significant difference in the 9 and 21-year-old stands. The crown diameter of the 17-year-old stands has the highest value with other ages and is significantly different from the 13-year-old stands. In the land suitability analysis, the 17-year-old stands has the best data and significantly differs from other ages.

4. Conclusions

The productivity of cajuput stands is observed at various age levels after the first harvest. Based on the research results on the productivity of cajuput stands at various age levels in Telawa Forest Management Unit, it can be concluded that the best cajuput productivity is at the 17-year-old stands. The 17-year-old stands at the highest average value in all growth parameters. The biomass of leaf cajuput stands is higher compared to twig biomass. This study found a decrease in productivity at the age of 13 years, an increase in the average age of 17 years, and then a decrease again at the age of 21 years by 40%. The productivity of cajuput stands is affected by stem diameter, shoots, shoot diameter, and biomass. The low productivity of cajuput stands is followed by low soil fertility, namely C-Organic and pH. To obtain more comprehensive data, conducting further research on soil N content, Current Monthly Increment (CMI), and Mean Monthly Increment (MMI) is essential.

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