

EVALUATION OF PLANTING DESIGN FOR CAJUPUT DEVELOPMENT (*Melaleuca cajuputi* Powel) IN KPH BOJONEGORO

(Evaluasi Pola Tanam untuk Pengembangan Kayu Putih (*Melaleuca cajuputi* Powel) di KPH Bojonegoro)

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ABSTRACT

Development of cajuput plantation currently becomes the most important activity in KPH Bojonegoro since it provides an essential contribution to maintain the future viability of company. However, the growth performance of cajuput stand relatively varies one of which is influenced by planting design. This study aims to determine the optimum planting design for supporting cajuput stand development. It was conducted by evaluating two different planting designs that generally used for cajuput establishment, namely C1 (spacing 3 m x 1 m) and C2 (spacing 5 m x 1.5 m x 1.5 m). Five parameters were used to evaluate the growth performance and oil production of cajuput stand for each planting design, i.e., survival rate, quadratic mean diameter, basal area, harvesting biomass, and cajuput oil production. Data were collected by field measurement using a sampling plot 50 m x 50 m with six replications for each planting design. Comparison mean of cajuput growth performance between two planting designs were analyzed separately for each parameter using *t-test*. Results documented there were not a significant different for all parameters, except survival rate. The planting design C2 generated higher survival rate (94.9%) than planting design C1 (64.7%). The planting design C2 was recommended for cajuput development in KPH Bojonegoro. Besides requiring the lower planting density, the use of planting design C2 can optimize land utility with a similar productivity to planting design C1.

ABSTRAK

Pengembangan hutan tanaman kayu putih saat ini menjadi aktivitas paling penting di KPH Bojonegoro karena berperan penting untuk mempertahankan keberlanjutan perusahaan. Namun, kinerja pertumbuhan tegakan kayu putih relatif bervariasi tergantung pada pola tanam. Penelitian ini bertujuan menentukan pola tanam optimum untuk pengembangan kayu putih. Penelitian dilakukan dengan mengevaluasi dua pola tanam yang digunakan untuk penanaman kayu putih, yaitu C1 (jarak tanam 3 m x 1 m) dan C2 (jarak tanam 5 m x 1,5 m x 1,5 m). Lima parameter digunakan untuk menilai kinerja pertumbuhan dan produksi minyak tegakan kayu putih pada setiap pola tanam, meliputi persen hidup, rerata kuadrat diameter, luas bidang dasar, biomassa panen, dan produksi minyak kayu putih. Data dikumpulkan melalui pengukuran di lapangan pada permanen plot dengan ukuran 50 m x 50 m, menggunakan enam replikasi setiap pola tanam. Perbandingan rerata pertumbuhan kayu putih antara dua pola tanam dianalisis secara terpisah untuk setiap parameter menggunakan uji *t*. Hasil penelitian menunjukkan tidak terdapat perbedaan yang nyata untuk semua parameter yang diuji kecuali persen hidup. Persen hidup pola tanam C2 lebih tinggi (94,9%) dibandingkan C1 (67,7%). Pola tanam C2 direkomendasikan dalam pengembangan kayu putih di KPH Bojonegoro. Selain membutuhkan kerapatan penanaman yang lebih rendah, pola tanam C2 dapat mengoptimalkan pemanfaatan lahan dengan produktivitas yang sama dengan pola tanam C1.

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I. INTRODUCTION

Determining the optimum planting design is a fundamental strategy of silviculture prescription for supporting the effort of sustainable forest management, particularly in a plantation forest (Zhang et al., 2019). Besides having directly influence on the growth performance of stand (Forrester et al., 2013), it also has a high relationship to the impact of forest engineering on the environmental condition, such as risk of erosion and site degradation (Duan et al., 2019). Moreover, several references also explain that the use of optimum planting design can facilitate the forest managers to optimize resources, not only from land capability but also including financial supports (Nguyen et al., 2014; Kaya et al., 2016; Liu et al., 2019). In this context, by developing an optimum planting design for stand management, it will be possible to gain high forest productivity with low-cost input (Nakajima et al., 2017). However, it is not easy to find the optimum planting design for each species in plantation forest. Many aspects should be considered to achieve this objective, such as land attributes, plant requirements, and social behavior (Rajati, 2015). Therefore, most forest managers commonly establish amount of field trials to determine the optimum planting design. It can be observed in general plantation forests around the world, one of them are cajuput plantation which managed by KPH Bojonegoro.

Development of cajuput plantation currently becomes the most important activity in KPH Bojonegoro because of providing a meaningful contribution to maintain the future viability of the company, after productivity of teak plantation declines significantly due to the impact of vulnerability (Rohman et al., 2014). Besides having a high economic value, cajuput could be harvested in shorter rotation than teak. Thus, it was expected to cover financial losses from teak plantation management. This program was implemented by converting number of compartments for teak plantation into cajuput plantation. It had been starting from 2016 until now. More than 1,000 ha of teak plantation have been fully converted into cajuput plantation at the end of 2019.

The primary product of cajuput is essential oils produced by its leaves extraction. It can be classified into a non-timber forest product (NTFP) with having high economic value. Some references report the cajuput oil is highly required by the pharmacy industry since its cineol content become a source of raw materials to formulate medicines (Fall et al., 2017; Sutrisno et al., 2018; Sadono et al., 2019a). In addition, cajuput is also suitable to be cultivated by agroforestry in long-time periods, thus it also plays a positive role to support food security and social forestry programs (Suryanto et al., 2017; Sadono et al., 2019b; Sadono et al., 2020). However, the growth performance of cajuput plantation in KPH Bojonegoro varies depending on the type of planting design. As an example, the use of planting design with narrow spacing will increase the number of tree density, but it decreases the space for intercropping area. Consequently, the risk of tree mortality may enhance due to the influence of high tree competition or the activity of farmers to expand intercropping area by cutting the young trees. In another side, the utilization of planting design with larger spacing will result lower tree density, but it gives more space for intercropping area. The condition may reduce the risk of tree mortality, but it might decline leaves production due to the lower tree stocking.

This study aims to determine an optimum planting design for supporting cajuput development in KPH Bojonegoro. It was conducted by evaluating two types of planting design that regularly applied for cajuput establishment since there is not an information about the best planting design for supporting cajuput management in this site. The point of view for evaluation process is the growth performance of cajuput stand as it becomes the primary concern of plantation forest management. This study is directed to explore a planting design that can optimize land productivity both cajuput stand and agroforestry practice. It will facilitate the forest managers to obtain the high cajuput productivity without sacrificing the need of community who live close to the cajuput plantation.

II. METHODS

A. Study Area

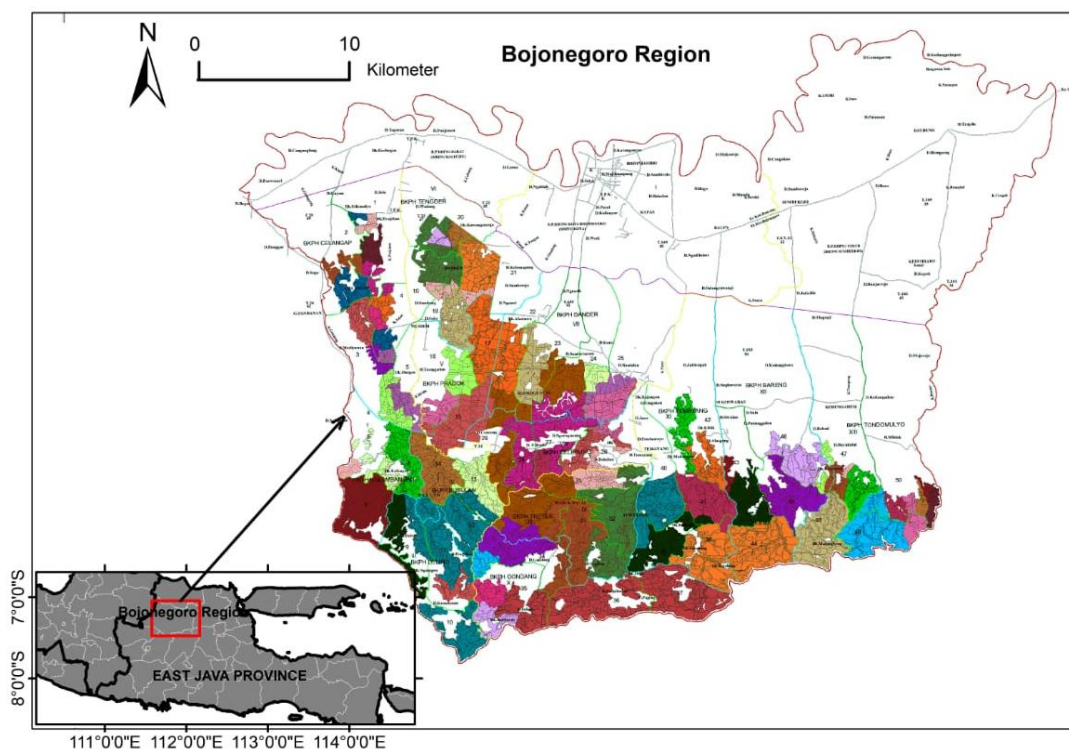
The study site located in a plantation forest which managed by KPH Bojonegoro (Figure 1). It had geographic coordinates in 7°10'38" S to 7°27'58" S and 4°54'0" E to 5°16'42" E. KPH Bojonegoro had an effective area for plantation forest approximately 47,479.3 ha, consisting of teak plantation 95.72% and cajuput plantation 4.28%. Altitude ranged from 60 to 350 m asl. Topography mostly varied with slope level ranging from 8% to 25%. Soil type was dominated by alfisol and vertisol that have acidity level around 5.5-6.5. The mean annual rainfall was 1,805 mm year⁻¹ with average minimum of 1,112 mm year⁻¹ and maximum of 2,548 mm year⁻¹. Most rainfall was recorded between December and March with the highest rainfall was observed in February. Dry periods were occurring for five months from June to October.

B. Standard Growth Performance of Cajuput Stand

Intensive management of cajuput

plantation in KPH Bojonegoro had a specific standard which commonly used to evaluate the growth performance of cajuput stand for each planting design. It was determined by considering the size of tree spacing and the wide of intercropping area. In this case, the forest manager has selected four parameters to monitor the activity of cajuput stand management, i.e. planting density, survival rate, harvesting biomass, and cajuput oil production (Table 1). The standard value of cajuput performance for each planting design was relatively different, except for survival rate with ranging from 85% to 95%.

Our study recorded that the establishment of cajuput using a planting design C1 required higher planting density than planting design C2, by approximately 54.54% or equal to 1,200 tree ha⁻¹ (Table 1). It also directly influenced on the higher standard of harvesting biomass and cajuput oil production, in which the use of planting design C1 was expected to generate productivity almost two times greater than planting design C2. This circumstance was normally occurred since the planting design C1 had narrower tree spacing with its size around 3 m x 1 m. In



Source: KPH Bojonegoro, 2020/Sumber: KPH Bojonegoro, 2020

Figure 1. Study site in KPH Bojonegoro
Gambar 1. Lokasi penelitian di KPH Bojonegoro

Table 1. Standard growth performance of cajuput stand in every planting design based on the regulation of KPH Bojonegoro

Tabel 1. Standar kinerja pertumbuhan tegakan kayu putih pada setiap pola tanam berdasarkan regulasi di KPH Bojonegoro

Variable (Variabel)	Units (Satuan)	Planting design (Pola tanam)	
		C1	C2
Planting density (Kerapatan penanaman)	tree ha ⁻¹	3,400	2,200
Survival rate (Persen hidup)	%	85 – 95	85 – 95
Harvesting biomass (Biomassa pemanenan)	Mg ha ⁻¹	7 – 8	4 – 6
Cajuput oil production (Produksi minyak kayu putih)	Mg ha ⁻¹	0.6 - 0.8	0.4 - 0.6

Source: KPH Bojonegoro, 2020

Sumber: KPH Bojonegoro, 2020

contrast, the planting design C2 had larger tree spacing by ranging 5 m x 1.5 m x 1.5 m (Figure 2). Nevertheless, both planting designs have been evenly applied in each priority site for cajuput development.

C. Data Collection

Data were collected by field survey, conducted from February to March 2020. We used a purposive sampling method to assess the growth performance of cajuput stand. This approach was selected since the distribution of planting design was not evenly noted in every compartment. There were two different planting designs that commonly applied to establish cajuput plantation in KPH Bojonegoro, namely C1 (3,400 tree ha⁻¹) and C2 (2,200 tree ha⁻¹) (Figure 2). Both planting designs were developed through agroforestry systems but having different sizes of tree spacing. Hence, the size of intercropping area for each planting design also differed.

Each planting design was represented by six compartments as replicate in the evaluation process. To minimize the influence of environmental gradient selected the compartments based on the similar criteria, including age, site index, soil type, and forest resort (Table 2). The measurement of cajuput stands in each compartment was done by using a measurement plot 50 m x 50 m. Five parameters were selected to evaluate the growth performance of cajuput stand in each planting design, namely survival rate, quadratic mean diameter, basal area, harvesting biomass, and cajuput oil production. The survival rate was defined as the ratio between actual cajuput density and

initial planting density that expressed in percentage unit. The diameter of cajuput tree was measured at 0.3 m above ground by caliper (Sadono et al., 2019a). Then, the quadratic mean diameter of cajuput stand was calculated by following equations (Kershaw et al., 2017):

$$\bar{d}_Q = \sqrt{\frac{1}{n} \times \sum_{i=1}^n d_i^2} \tag{1}$$

where \bar{d}_Q was quadratic mean diameter (cm), n indicated number of measured trees, and d_i was size of individual tree diameter (cm). Then, basal area of cajuput stand was calculated by formula (West, 2015):

$$G = \frac{\pi}{4} \times \bar{d}_Q^2 \times N \tag{2}$$

where G was basal area (m² ha⁻¹) and N described the actual tree density (tree ha⁻¹). Afterward, the estimation of harvesting biomass and cajuput oil production were done by non-destructive method with equations that generally used in KPH Bojonegoro. These equations could be expressed below (KPH Bojonegoro, 2020):

$$B_p = N \times L_p \tag{3}$$

$$C_p = B_p \times R_f \tag{4}$$

where B_p was the number of harvesting biomass (Mg ha⁻¹), L_p represented average leaves biomass production in every cajuput tree (2.5 kg), C_p indicated total cajuput oil production (Mg ha⁻¹), and R_f described rendement factor (0.9%).

Table 2. Details of compartment for evaluating the growth performance of cajuput stand
Table 2. Detail petak untuk evaluasi kinerja pertumbuhan tegakan kayu putih

Age (Umur) (years)	Soil type (Jenis tanah)	Altitude (Ketinggian tempat) m dpl	Forest resorts (Resort hutan)	Compartment (Petak)	Planting design (Pola tanam)
2	Vertisol	253	Nglambangan	41a	C1
2	Vertisol	267	Nglambangan	42c	C1
2	Vertisol	247	Nglambangan	43d	C1
2	Vertisol	230	Nglambangan	18b	C1
2	Vertisol	264	Nglambangan	18e	C1
2	Vertisol	237	Nglambangan	18d	C1
2	Vertisol	257	Nglambangan	32a	C2
2	Vertisol	206	Nglambangan	33b	C2
2	Vertisol	299	Nglambangan	36a	C2
2	Vertisol	252	Nglambangan	21b	C2
2	Vertisol	204	Nglambangan	25a	C2
2	Vertisol	275	Nglambangan	26c	C2

Source: KPH Bojonegoro, 2020

Sumber: KPH Bojonegoro, 2020

D. Data Analysis

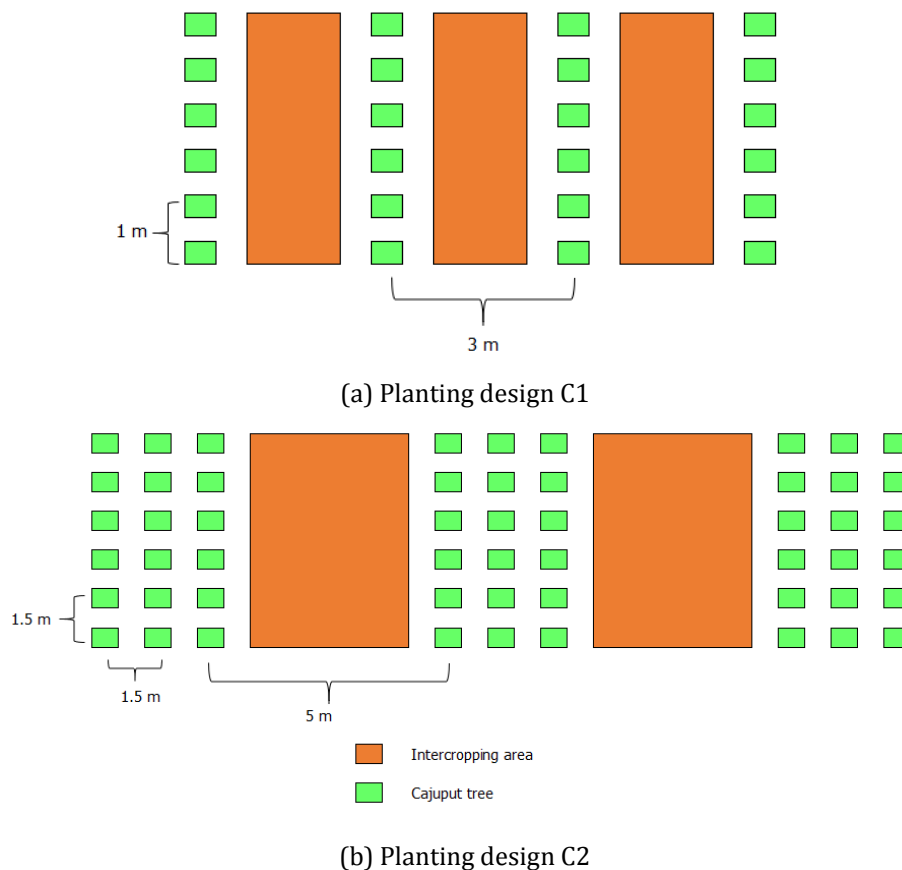
Data were analyzed using R software version 3.6.1. We used package agricolae to support the process of statistical analysis (Wirabuana et al., 2019). The descriptive test was conducted to identify the range of data distribution, like minimum, maximum, mean, standard deviation, and coefficient of variation. Normality of data was examined by Shapiro-Wilk test (Waghorn et al., 2015). Comparison mean of cajuput performance for each planting design was examined separately for every variable using t-test (Wirabuana et al., 2020).

III. RESULTS AND DISCUSSION

Summarized results of the observation documented the survival rate significantly different between both planting design. The application of planting design C2 for cajuput development substantially provided higher survival rate than planting design C1, around 94.9%. Otherwise, planting design C1 only demonstrated survival rate by approximately 67.7% (Table 1). It indicated there was a difference in survival rate almost 27.2% between two planting designs. Unfortunately, even though the survival rate was highly different, the actual tree density of cajuput in a planting design C1 were still higher than planting design C2. With the survival rate of 67.7%, the use of planting design C1 maintain actual tree stocking around 2,308 tree ha⁻¹

while by having survival rate of 94.9%, the actual tree density of planting design C2 were 2,087 tree ha⁻¹.

The lower survival rate of planting design C1 might be affected by certain factors, mainly related to stand disturbance and natural competition (Rahman et al., 2016). In the practice of agroforestry, the primary source of stand disturbance was commonly from the negative activity of farmers who cut the young trees to expand the allocation of intercropping area (Yan et al., 2020). This trend was generally occurred in most of the agroforestry which conducted in plantation forest, particularly in Java. For explanation, at the narrow spacing, the space of intercropping area considerably smaller than wide tree spacing. It indicated by the layout of every planting design (Figure 2), wherein the large of intercropping area in the planting design C1 was principally smaller than planting design C2. Hence, it indirectly signified that the productivity of crops (maize and rice) in planting design C1 was lower than planting design C2 if there was not an effort to expand the intercropping area. In another side, most of farmers who practiced agroforestry under cajuput plantation, highly dependent on the crops yield. Therefore, they did not hesitate to kill young cajuput plants by slashing and spraying with chemical compound. Moreover, the occurrence of stand disturbance in cajuput plantation could be also affected by the infection of pest and disease. However,



Source: KPH Bojonegoro, 2020/Sumber: KPH Bojonegoro, 2020

Figure 2. Planting designs for cajuput development in KPH Bojonegoro
Gambar 2. Pola tanam untuk pengembangan kayu putih di KPH Bojonegoro

according to the history of management, the problems of pest and disease in cajuput were rarely discovered in KPH Bojonegoro.

Besides decreasing the space of intercropping area, the development of cajuput using narrow tree spacing could also increase the level of tree competition since this planting design would result greater number of tree density. Consequently, more intense competition for obtaining water, nutrient, and space would be occurred. It would decline the growth performance of cajuput tree. Our statement was also supported by the results of data observation wherein the mean size dimension of cajuput tree in planting design C2 was greater than planting design C1 (Table 3). Several studies also reported higher tree density would encourage greater natural mortality (Filho et al., 2018). It was caused by more intense competition between trees for obtaining resources like water, nutrients, space, and light (Yan et al., 2015). The weaker trees would be

die naturally while the dominant trees still survived and continued the growth process (Lie & Xue, 2018).

Even though the survival rate was significant different, study observed that the growth performance of cajuput stand at 2 years after establishment between both planting design was not showed a significant different in quadratic mean diameter, basal area, harvesting biomass, and cajuput oil production (Table 3). These findings were quite interesting since this study noted the difference of actual tree density between both planting design close to 300 tree ha⁻¹. This circumstance could be happened since the growth dimension of cajuput stand in planting design C2 was relatively bigger than planting design C1. It was caused by the sufficient of growing space and more efficient utilization of resources. In general, at the narrow tree spacing, the number of tree density was very crowded and encouraged high competition (Stape & Binkley, 2010; Kirongo et al., 2012).

Table 3. Comparison growth performance of cajuput stand in every planting design
Tabel 3. Perbandingan kinerja pertumbuhan tegakan kayu putih di setiap pola tanam

Variable (Variabel)	Units (Satuan)	Planting design (Pola tanam)		P
		C1	C2	
Survival rate (Persen hidup)	%	67.70 ± 3.81	94.90 ± 2.14	<0.001**
Quadratic mean diameter (Rerata kuadrat diameter)	cm	4.46 ± 0.89	4.65 ± 0.77	0.713 ^{ns}
Basal area (Luas bidang dasar)	m ² ha ⁻¹	3.33 ± 0.49	3.86 ± 0.35	0.502 ^{ns}
Harvesting biomass (Biomassa pemanenan)	Mg ha ⁻¹	5.50 ± 0.32	5.74 ± 0.13	0.123 ^{ns}
Cajuput oil production (Produksi minyak kayu putih)	Mg ha ⁻¹	0.50 ± 0.01	0.50 ± 0.02	0.821 ^{ns}

Consequently, the mean size of tree dimension, mainly diameter and crown was smaller than trees in wide spacing (Cassidy et al., 2013; Forrester et al., 2013; Binkley et al., 2017). Since the primary product of cajuput was leaves biomass, thus it was essential to provide an optimum growing space for supporting the growth of cajuput crown.

Referring to the results, the optimum planting design for cajuput development in KPH Bojonegoro was type of planting design C2. Besides having higher survival rate, the growth of cajuput stand design C2 was not highly different C1, even though both planting designs had different planting density. The use of planting design C2 could also reduce the planting cost since it required the lower number of planting density. Furthermore, the growth performance of cajuput stand in a planting design C2 potentially fulfill the standard value of cajuput performance which determined by forest managers in KPH Bojonegoro.

IV. CONCLUSION

The development of cajuput plantation using planting design C2 (spacing 5 m x 1.5 m x 1.5 m) considerably demonstrated higher survival rate than planting design C1 (spacing 3 m x 1 m), suggest to apply a planting design C2 for supporting cajuput plantation management in KPH Bojonegoro. The planting design C2 is more efficient in practice in the field. The evaluation of planting design, it would be better to develop multi criteria in the next studies for evaluating the optimum planting design for cajuput development, included ecological and social aspects.

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AUTHOR CONTRIBUTIONS

PW: main author, conceptualization research and methodology, data analysis and interpretation, writing manuscript; RS: coauthor, providing research funds, validating research and methodology, reviewing manuscript; D: coauthor, helping field preparation, data collection, creating map of study location, providing secondary information.

CONFLICTS OF INTEREST

The authors declare there is not a conflict of interest related to financial funding and authorship order for this article.

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