Adaptation and productivity of kaliandra for biomass energy source

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Abstract. The development of wood energy forest plantations is one of the government's strategies to meet national energy needs. Kaliandra (Calliandra calothyrsus) is one tree/shrub species that is potential for biomass energy source due to its rapid growth and high calorific value. This study aims to analyze the level of adaptation and productivity of kaliandra planted in 3 spacing treatments in the Production Forest Management Unit (KPHP) Puncak Ngengas - Batulanteh, Sumbawa. The treatment of spacing applied is 4 m x 1 m or density of 2,500 trees/ha (J1), 4 m x 2 m or density of 1,250 trees/ha (J2), and 4 m x 2 m with stripe or density of 1,850 trees/ha (J3). Measurements of adaptation and plant growth were carried out until 6 months after planting. The results of this study indicate that the J2 treatment showed the best level of adaptation with a survival rate of 89.3%, followed by treatments J3 and J1 with a survival rate of 85.9% and 84.4% respectively. The J3 treatment resulted in the best growth rate of Kaliandra plants with an average diameter of 18.1 mm, an average height of 244.9 cm and the volume of individual trees of 0.00085 m³/tree. The J3 treatment also produced the highest total volume, estimated biomass production and energy productivity compared to other treatments, which were 3.5 m³/ha, 2.7 tons/ha and 51.9 GJ/ha, respectively. Treatment of spacing indicates the influence on the level of tree adaptation and growth and estimation of biomass production and calorific value. However, the treatment of spacing does not show a clear pattern related to the effect of initial spacing on growth and productivity of Kaliandra at the beginning of the year.

1. Introduction

Kaliandra (Calliandra calothyrsus) is one of the tree species that is planted and developed for energy biomass materials. Kaliandra has been traditionally utilized by Indonesian community as fodders and wood energy [1, 2]. Recently, kaliandra has been proposed for wood energy based plantation forest. Estimated that 2.85 million ha out of 3.5 million ha of degraded land in Indonesia is suitable and highly suitable for kaliandra based forest development, with potential production of 1.08 EJ/year [3].

Kaliandra is chosen as energy source biomass because it may live in dry land [4], grow easily in may soil types including degraded lands [5], can be harvested with short rotation and coppice system, and has high calorific value, i.e. 4,207 kcal/kg [6] and potential energy of 2.1 MWh/ton [1].

Many studies on kaliandra as energy source biomass have been extensively conducted, e.g.: Syamsuwida, Kurniaty, Putri and Suita [7], Amirta, Yuliansyah, Ananto, Setiyono, Haqiqi, Septiana, Lodong and Oktavianto [1], Kurniaty, Bustomi and Widyati [8]. In addition, many studies have been conducted for kaliandra as fodders [9-11] However, there is still lack of information on the adaptation and productivity of kaliandra in several spacing treatments. This study aims to analyze the adaptation
level and productivity of kaliandra in 3 spacing treatments in Sumbawa, West Nusa Tenggara. The results of the study may contribute as a reference in forest planning of kaliandra as energy source biomass, particularly in marginal lands.

2. Materials and Methods

2.1. Research Site
Kaliandra seeds were from West Java area, particularly from Tasikmalaya area. Kaliandra was planted in demonstration plot of wood energy in Kanarluk Resort, Puncang Ngengas Batulanteh Forest Management Unit (FMU). Administratively, the location of this study in in Dusun Madu, Labuan Badas Village, Labuan Badas Sub District, Sumbawa District, West Nusa Tenggara (Figure 1).

Figure 1. Research location

Geographically, Sumbawa District is located at 116°12’ to 118°22’ East latitude, and 8°8’ to 9°7’ South longitude. Sumbawa District has 6.643,98 km² spread from coastal area to mountainous area (with altitude of 0-1,730 above sea level). The area consists of hilly topography (355.108 ha/41.81%) from its total area with altitude from 100 to 500 meter above sea level [12].

Soil types in Puncang Ngengas Batulanteh FMU are dominated by latosol and brown mediteran complex, litosol complex, red brown mediteran, red brown mediteran complex, and brown mediteran and litosol complex, with relatively low fertility, and thin solum (<90 cm) and high erodibility. Climate type based on Schmidt and Ferguson in Puncang Ngengas Batulanteh FMU is D and E with annual precipitation of 746-2556 mm/year. Rainfall occurs usually started on November or December with highest daily rainfall of 215-629 mm/day. The highest rainy day is from 15-23 days, with dry month from May – November, and temperature from 24 – 32°C [13].
2.2. Procedure of Data Collection and Data Analysis

Wood energy stand of kaliandra (Calliandra calothyrsus) was developed with 3 spacings: 4 m x 1 m or population density of 2,500 tree/ha (J1), 4 m x 2 m or population density of 1,250 tree/ha (J2), and 4 m x 2 m or population density of 1,850 tree/ha (J3) (Figure 2). Every treatment is developed in plots area of 12 m x 28 m (336 m²) each with 3 repetitions. This treatment is designed for agroforestry system with under story of padi gogo.

![Figure 2. Spacing treatment of kaliandra](image)

Adaptation of kaliandra was measured by counting the survival rate of kaliandra at 6 months after planting. Individual tree growth was determined by measuring diameter (lower trunk) and tree height of 6 months old kaliandra. Trunk volume was measured based on diameter and height, with correction factor of 0.61 [14]. The productivity of kaliandra was measured by accumulating individual volume of kaliandra tree in each treatment plot, and convert it to ha. The production of biomass was estimated by considering the estimated trunk volume and population density. The biomass estimation is as follows:

\[ B_p = V \cdot \rho \]

Where \( B_p \) represents biomass dry weight of individual tree (gram), \( V \) is the tree volume and \( \rho \) is wood density of kaliandra\(^2\) (gr/cm\(^3\)). The productivity of energy is determined by assumption that one kg of dry biomass may produce 19 Mjoule energy [16].

3. Results and Discussion

3.1. Adaptation and Productivity

The results of measurement on 6 months kaliandra showed that the average of survival rate of kaliandra is 86.5%. This survival rate is relatively lower than that found in Santa, Cameroon, that the survival rate of kaliandra may reach 95% [17]. Based on the observation in the plots, the kaliandra trees were dead because they are covered by under storey (Cajanus cajan) in the early growth. The growth of C. cajan was much faster than kaliandra trees with also relatively larger and denser crown. Therefore, kaliandra trees were suppressed and dead. Besides, the high temperature and low precipitation rate in the study area cause some the kaliandra trees not to survive. According to [3], kaliandra may adapt at temperature of 22-33°C with precipitation of 2000 mm - 4000 mm. However, based on Badan Pusat Statistik Kabupaten Sumbawa [12] report, the highest temperature in Sumbawa District in 2016 reached 37.3°C, with 120 days of rainfall in a year, and annual precipitation of 1,883 mm. This condition is different from the condition in Tasikmalaya District (the origins of the seeds) with average temperature of 23 °C (range from 18-31°C) with annual precipitation of 2,297 mm [18]. With relatively different condition from the origins of the seeds, the survival rate is categorized as “successful” based on Directorate General of Replantation and Land Rehabilitation (Dirjel RRL) that required the minimum survivate rate of 65%.

\(^1\) The correction factor is based on SNI No 7724-2011 for all trees because the specific correction factor for kaliandra is not available

\(^2\) The wood density of kaliandra is 0.78 gr/cm\(^3\) [15]
Based on the comparison of spacing treatments, treatment J2 gives the highest survival rate. With relatively wide space (4 x 2 m) and lower tree density than J1 dan J3 (1,250 vs 2,500 and 1,850 per ha), J2 has wider space for tree growth and lower competition on nutrients and lights. As a result, J2 gives the highest survival rate. As also found by [19] that at early stage of growth period, spacing may affect the mortality rate. The larger the spacing among the trees, the lower the competition rate among trees and therefore the lower the mortality rate.

The measurement of kaliandra at 6 months after planting showed that the average diameter and height of kaliandra are 15.6 mm and 212.7 cm respectively. Figure 4 showed that the highest average
of diameter, height and volume is on J3 treatment, followed by J2 and J1. The growth of kaliandra in 6 months old is still in the growth range of [15] that reported the height of 6-months kaliandra is between 2.5-3.5 m. However, the average tree height of kaliandra on J1 and J2 are lower than the range reported by [15] that may be caused by in-optimal condition of the study area as discussed earlier.

**Table 1.** Analysis of variance on the effects of spacing on height, diameter and individual volume of kaliandra

| Variance source | Variable | Sum Square | Df | Mid square | F       | p-value |
|-----------------|----------|------------|----|------------|---------|---------|
| Spacing         | D        | 3490,775   | 2  | 1745,387   | 32,261  | 0,000 **|
|                 | T        | 699154,399 | 2  | 349577,200 | 56,772  | 0,000 **|
|                 | V        | 4,20E-005  | 2  | 2,10E-005  | 33,554  | 0,000 **|
| Block           | D        | 5729,036   | 2  | 2864,518   | 52,946  | 0,000 **|
|                 | T        | 612073,235 | 2  | 306036,617 | 49,701  | 0,000 **|
|                 | V        | 6,36E-005  | 2  | 3,18E-005  | 50,816  | 0,000 **|

Notes: KAS = D = Diameter (mm); T = height (cm); V = Volume per tree (m³); ** = significant

**Table 2.** Duncan post hoc test on the effects of spacing on height, diameter and individual volume of kaliandra

| Treatment | D         | T         | V         |
|-----------|-----------|-----------|-----------|
|           | Average   | Duncan test | Average   | Duncan test | Average | Duncan test |
| J1        | 14,5205   | A         | 195,3574  | A          | 0,0004525 | A        |
| J2        | 15,0769   | A         | 199,7133  | A          | 0,0005370 | A        |
| J3        | 18,1067   | B         | 244,9903  | B          | 0,0008529 | B        |

Notes: the average values in the column followed by the same letter showed not significantly different at 5% level of confidence

Based on analysis of variance, variable of spacing treatment results in a very significant on the size of diameter, height, and volume of the tree (Table 1). The Duncan post hoc analysis showed that J3 treatment results in the highest average on all variables (diameter, height, and volume) compared to J1 and J2, while J1 and J2 result in non-significant values (Table 2).

The results of analysis of variance and Duncan test among treatments above showed that there is no clear pattern between space and growth of diameter, height, and volume of kaliandra. J1 and J2 with different tree density (2,500 vs 1,250 trees/ha) give non-significant value, while in J3 with tree density of 1,850 tree/ha give the highest value for all growth variables (diameter, height, and volume). Our results are different from those found by many researchers on different tree species, that the larger the spacing gives higher growth on diameter, height and volume, e.g.: Pinus brutia [20], Pinus banksiana [21] dan Eucalyptus camaldulensis [22].

The condition of unclear pattern between tree density/spacing with the growth of kaliandra maybe because the growth of kaliandra is still in early stage (6 months) and not really affected by competition on nutrients lights, and water. Besides, kaliandra is also categorized as shrub or small tree [1, 15] that is characterized by relatively limited growth on diameter and height. Figure 3 shows that J2 with the lowest tree density gives the highest survival rate. But, as kaliandra tree start to adapt with the environment, the spacing become inconsistent on its effects on growth of kaliandra.

3.2. **Biomass production estimation**

Individual volume of kaliandra trunk showed a similar trend with diameter and height that i.e.: J3 gives the highest estimate volume followed by J2 and J1 (Table 3). However, there is a slightly
different pattern in total volume per ha. The largest tree volume per ha is yielded by J3 followed by J1 and J2. Even though the diameter and height of individual tree are larger in J2 than J1, the total volume per ha is larger in J1 than in J2 because tree density in J1 is doubled than in J2. This finding is similar to that found by Nagar, Rawat, Rathiesh and Sekar [22] on *Eucalyptus* sp that wide spacing gives significantly larger height, diameter, canopy area, and volume but narrow spacing may give larger total volume per ha [22]. Other study on *Ateleia glazioviana* in Frederico Westphalen, showed that wide spacing result in lower biomass and energy productivity [23].

| Treatment | Density (n/ha) | Individual volume (m³/pohon) | V total (m³/ha) | Biomass (ton/ha) | Energy (Gj/ha) |
|-----------|----------------|-------------------------------|-----------------|-----------------|---------------|
| J1        | 2,500          | 0.00039                       | 2.99            | 2.33            | 44.29         |
| J2        | 1,250          | 0.00053                       | 1.56            | 1.22            | 23.13         |
| J3        | 1,850          | 0.00085                       | 3.50            | 2.73            | 51.92         |
| Average   | 0.00059        | 2.68                          | 2.09            | 39.78           |               |

The estimation value of total biomass and energy productivity among treatments follows the trend in total volume. Overall, the average of kaliandra biomass production at 6 months old is 2.09 ton/ha, or equivalent to 3.98 Gj/ha. This value is relatively lower than the range values by Borchard, Bulusu, Hartwig, Ulrich, Lee and Baral [4] that kaliandra may produce biomass of 6-24 ton/ha/year that is equivalent to 111-444 GJ/ha/year. The low value of biomass and energy productivity in our study maybe caused by relatively low tree density and also the age of the trees (i.e. 6 months old).

Kaliandra that is one of the potential species in biomass source development in general is designed for short rotation with coppice system. Under this assumption, the silviculture of kaliandra in Sumbawa needs to consider the early spacing that is adjusted to the purpose of the stand development. If kaliandra is planted in monoculture, the narrow spacing is suggested to obtain larger total biomass. This finding is similar to that found by Erkan and Aydin [20] that short rotation trees should be planted in narrow spacing to obtain larger production. Nevertheless, in the case where trunk size become the main objective of the tree plantation, wide early spacing is highly recommended [21]. In addition, early spacing that is related to wood characteristics of bioenergy should also be considered. For example, [24] suggested for wide spacing on Eucalyptus to obtain wood with certain wood density and chemistry suitable for bioenergy wood.

Wide spacing may also be applied for kaliandra that is designed for agroforestry pattern, to give more space for crops planted between the trees. The space between the trees under agroforestry can be utilized for crop production until branch and or canopy between the trees meet and impossible for crop plantation. The short rotation and coppice system on kaliandra that can be 10-20 years may give open space for crop production [15]. The kaliandra based agroforestry system can be an alternative for wood energy development on forest area that is managed collaboratively with the community.

4. Conclusions and Recommendations

4.1. Conclusion
The J2 treatment showed the best level of adaptation with a survival rate of 89.3%, followed by treatments J3 and J1 with a survival rate of 85.9% and 84.4% respectively. The J3 treatment resulted in the best growth rate of Kaliandra plants with an average diameter of 18.1 mm, an average height of 244.9 cm and the volume of individual trees of 0.00085 m³/tree. The J3 treatment also produced the highest total volume, estimated biomass production and energy productivity compared to other treatments, which were 3.5 m³/ha, 2.7 tons/ha and 51.9 GJ/ha, respectively. Treatment of spacing indicates the influence on the level of tree adaptation and growth and estimation of biomass.
production and calorific value. However, the treatment of spacing does not show a clear pattern related to the effect of initial spacing on growth and productivity of Kaliandra at the beginning of the year.

4.2. Recommendations
J3 treatment with tree density of 1850 tree/ha with strip system can be recommended for kaliandra wood energy based tree plantation mainly under agroforestry system. Strip of 2 x 2 m may give dense population of kaliandra and strip of 2 x 4 m may provide wide space for crop plantation.

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