The growth and yield of Calliandra Callothyrsus trees as biomass-based energy feedstock

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Abstract: Calliandra callothyrsus is a woody plant that grows quickly and well in a wide range of natural conditions. C. callothyrsus is a tree species which easily cultivated and can be harvested in a short time (short-rotation wood crops). However, information about time and harvesting techniques that explain harvesting biomass is still needed. The aimed of this study is measured growth after trimming, the best time interval for harvesting and the results of cutting both biomass and the heating value contained. The method used is a destructive method. Observations are carried out repeatedly in a permanent plot. The permanent plot as treatment level cutting. So, this study evaluated the correlation between time and cutting level to growth and biomass harvested. The results showed that the best cutting limit was 50 cm above ground level. It is due to the high harvest biomass and the number of new stems that grow more. Meanwhile, to ensure business sustainability, the best harvest interval is 1 year. It will ensure adequate growth of new stems, large harvesting biomass and high calorific value of harvest. Harvesting potential can reach 25 m³.ha⁻¹.yr⁻¹. While the heating value will be at an interval of 3016 - 3757 kcal.kg⁻¹.

1. Introduction

Indonesia is known as the country with the largest biomass potential. This potential can be produced from trees in the forest, harvesting waste, waste wood processing, and other biomass sources. Potential of harvesting waste and waste wood processing reached 132 PJ, with potential economic value if converted in the form of pellets amounted to US$ 5.6 per ton [1]. This potential when used, it can meet the energy needs of the wood by 12.5 billion m³ in 2050 [2].

The fulfillment of this potential can be fulfilled if harvesting continues. However, the current conditions that timber from the forest continues to decline. This indicates that Indonesia's opportunity to provide biomass will be low. There is a need for a sustainable raw material supply strategy. The strategy can be in the form of energy plantations. To that end, the choice of plants is very important. Criteria that is easily cultivated species, planted once to be harvested many times in a relatively short time and contains a high calorific value. These criteria can be met by C. callothyrsus [3].

Cultivation of C. callothyrsus very feasibly to be developed. This is because investors or farmers hope that investment returns can occur in a short period of time [4]. This type of business is called short-rotation woody crops (SRWC). SRWC is very economically feasible even though it requires a large initial investment [3].

The above results need to be developed. One of them is research on the growth and yield of C. callothyrsus. Growth is largely determined by the height of the pruning and the cutting time interval.
Both of these factors affect the cutting biomass and the heating value contained. For this reason, this study was designed to obtain information on growth and yield based on clumps. The results of this study are very important for the development of science, especially to increase the productivity of C. callothyrsus. The next benefit to the community is the projection of biomass raw materials and income to be obtained.

2. Materials and Methods

2.1. Data collected
The study was conducted in the village of Babakan Jawa - Majalengka Regency. GPS coordinate are 6°52'44.47"S and 108°12'28.41"T until 6°52'42.95"S and 108°12'29.02"E in Majalengka regency. While GPS coordinate in Kuningan regency is 6°48'12.41"S and 108°26'18.55"E until 6°48'11.87"S and 108°26'19.22"E. The study was conducted from 2015 until 2017. The research stage was started with making of permanent measuring plots (PUP) with a size of 30 m x 30 m as many as 3 plots. Plots were distinguished from high slash treatment, i.e. 30 cm, 50 cm and 70 cm from the ground. After that, numbering clumps for each plot. The numbered clump is then trimmed according to treatment. Every 6 months, pruning is done on the selected clump. The selection of clumps was carried out randomly (Table 1).

| Treatment | Pruning time (yr) | 0  | 0.5 | 1  | 1.5 |
|-----------|------------------|----|-----|----|-----|
| 30 cm     |                  | 83 | 9   | 9  | 9   |
| 50 cm     |                  | 86 | 9   | 9  | 9   |
| 70 cm     |                  | 83 | 9   | 9  | 9   |

Table 1. Number of Clumps at plot

Before pruning counted the number of stems per clump. The truncated stem is divided into a piece. The length of a piece is 1 m. After that, the diameter of the pruning and tip is measured and weighed. We also measure heat values and other chemical characteristics of wood. The sample wood was chosen with the smallest, medium and medium diameter cut size criteria. To obtain comparative data with old wood, old wood samples were taken from outside the plot. Measurements were made at the chemical laboratory, forest product research and development center in Bogor.

2.2. Data analysis
We conducting data analysis with build a model that explained the relationship between the growth of new stems and age as explained in [4]. As for the general shape of the model as shown below:

\[ D = \alpha \cdot e^{\left(\frac{B}{T}\right)} \]  

Where: \( D \) = diameter trim (mm), \( adn \ t = \) age after pruning (years). The Selection of the best model if the \( p \)-value of lack of > 5%.

The next step is test the effect of age and the height of the crop for the number of new systems and biomass pruned. Testing is done with one-way ANOVA. We also predicted a model of the relationship between age and biomass.

3. Results and Discussion

3.1. Growth characteristics of C. callothyrsus
**C. callothyrsus** is a pioneer type. *C. callothyrsus* is more classified as a bush than a tree [5]. *C. callothyrsus* height can reach 12 m with a branch reach 12 m. *C. callothyrsus* will grow well if cultivated at an altitude of 800 m.dpl [2] or at an altitude of 0 - 1850 m.dpl and rainfall 700 - 4000 mm/year [5]. However, the growth of *C. callothyrsus* at an altitude of 200 - 400 m.dpl is also good [6]. *C. callothyrsus* is a viable biomass-producing plant because *C. callothyrsus* is easy to grow, easy to handle and provides high pruning results. The production of pruning with 50 cm high pruning is 5-20 m³.ha⁻¹ [2]. The diameter growth of new stem of *C. callothyrsus* after pruning will be better, especially at the age of 1.5 years after pruning (Table 2).

| Treatment | Age (yr) | No. of Clumps | Average of diameter (mm) |
|-----------|----------|---------------|--------------------------|
| 30        | 0        | 83            | 15                       |
|           | 0.5      | 9             | 5                        |
|           | 1        | 9             | 16                       |
|           | 1.5      | 9             | 29                       |
| 50        | 0        | 86            | 14                       |
|           | 0.5      | 9             | 4                        |
|           | 1        | 9             | 16                       |
|           | 1.5      | 9             | 23                       |
| 70        | 0        | 83            | 22                       |
|           | 0.5      | 9             | 7                        |
|           | 1        | 9             | 17                       |
|           | 1.5      | 9             | 27                       |

The growth trend of the new stem diameter after trimming looks the same based on the height of the pruning. The tendency is to go up. However, the best growth is at 30 cm above ground level. The average growth of stubborn diameter at 30 cm, 50 cm and 70 cm cropping height is 29 mm, 23 mm and 27 cm respectively at the age of 1.5 years. This information shows that the effect of high slash treatment on the growth of new stems is not linear.

**Table 3. Biomass, diameter and an average volume of pruning**

| Treatment | Age (yr) | Average wet weight stem (g) | Average of diameter (mm) | Average Volume (m³) |
|-----------|----------|-----------------------------|--------------------------|---------------------|
| 30        | 0.5      | 175                         | 16                       | 1.9 x 10⁻⁶          |
|           | 1        | 376                         | 13                       | 2.4 x 10⁻⁶          |
|           | 1.5      | 1215                        | 35                       | 4.3 x 10⁻⁶          |
| 50        | 0.5      | 222                         | 12                       | 1.6 x 10⁻⁶          |
|           | 1        | 273                         | 16                       | 1.2 x 10⁻⁶          |
|           | 1.5      | 590                         | 28                       | 3.1 x 10⁻⁶          |
| 70        | 0.5      | 217                         | 12                       | 9 x 10⁻⁷           |
|           | 1        | 303                         | 18                       | 1.5 x 10⁻⁶          |
|           | 1.5      | 461                         | 25                       | 3.5 x 10⁻⁶          |
The effect of high shear treatment will be significant on the weight of the new stem. The weight of the new stem will be heavier if the height of the pruning is 30 cm. The longer the time interval for the pruning, the higher the weight of the new stem.

The average weight of the new stem at 30 cm high at 1 year after pruning was 0.37 kg and at 1.5 years reached 1.2 kg. This figure is much higher when compared to the weight of a new stem at a height of 50 cm and 70 cm. The weight of the new stem at a height of 50 cm cut is heavier than the weight of the new stem at a height of 70 cm. The difference in weight of the new stem correlates with the stem diameter. The larger the diameter of the new bar pruners the higher the size of the weight. While the volume per stem will increase with increasing stem diameter and age. No effect of clipping height to weight rod.

The size of the stem weight and stem diameter is strongly influenced by the number of new stems in a clump. The number of new stems is strongly influenced by the height of the pruning. The higher the pruning, the higher the number of new stems. However, the effect of time after pruning is not significant.

| Table 4. The number of new stems that grow each clump |
|---------------------------------|-----------------|---------------------|
| Treatmen t | Age (yr) | No. of Clumps | Average of new stem |
|-----------|---------|--------------|---------------------|
| 30        | 0       | 475          | 0.5                 |
| 0.5       | 8       |              |                     |
| 1         | 6       |              |                     |
| 1.5       | 9       |              |                     |
| 50        | 0       | 578          | 3                   |
| 0.5       | 6       |              |                     |
| 1         | 9       |              |                     |
| 1.5       | 9       |              |                     |
| 70        | 0       | 597          | 3                   |
| 0.5       | 3       |              |                     |
| 1         | 6       |              |                     |
| 1.5       | 9       |              |                     |

The number of new stems that grow at 30 cm tall, 50 cm and 70 cm tall is very different. At 30 cm cut height is lower than the number of new stems at 50 and 70 cut height. The effect of age on the growth of new stems at 50 cm high pruning is better than the number of new stems at 30 and 70 cm cropping height. The best age effect if the cutting time interval is 1 year. If the time interval is added, the number of new stems that grow is no better than the age of 1 year. However, this conclusion is still incomplete because it has not considered the density of the stem and one clump.

3.2. Growth estimation model
In general, the growth parameters used to estimate productivity are a diameter. Diameter seen growth based on age. Age is an independent variable. Every age, the diameter will grow.

The effect of age on the diameter growth of C. callothyrsus stem is non-linear (Figure 1). The effect of age in question is the time after pruning until the next pruning is done. This form of influence is a positive exponential. The diameter of the new stem at the age of 0.5 years after pruning tends to be lower than the diameter of the new stem at the age of 1.5 years with a non-linear diameter increase slope.
Figure 1. Effect of age on new stem diameter growth.

Diameter growth can be explained by the following equation:

\[ D = 59.28 \cdot e^{(-1.26/\tau)}. \quad (2) \]

Table 5. Anova

| Parameter | Coefficient | Standard Error | P-value of lack |
|-----------|-------------|----------------|----------------|
| a         | 59.28       | 7.13           | 0.352          |
| b         | -1.26       | 0.16           |                |

The test results above show that with a P-value of lack > 0.05, this model is very good at explaining the growth of new stem diameter.

3.3. The growth of new stem

One-way test results on the effect of high pruning on the growth of new stems indicate that there is a difference in the growth of new stems. Although this difference is expressed with a very small coefficient of determination (R²).

Table 6. One Way Test Anova

| Source   | DF | SS  | MS  | F   | P  |
|----------|----|-----|-----|-----|----|
| Clump    | 2  | 428 | 214 | 1   | 0.0|
| Error    | 314| 519 | 16. | 2.94| 0.00|
| Total    | 316| 562 | 5.4 |     |    |

S = 4.068   R-Sq = 7.62%   R-Sq (adj) = 7.03%

Individual 95% CIs For Mean Based on Pooled StDev

| Level | N  | Mean | StDev | 1.2 | 2.4 | 3.6 | 4.8 |
|-------|----|------|-------|-----|-----|-----|-----|
| 30    | 107| 1.178| 2.528 |     |     |     |     |
| 50    | 106| 3.380| 5.111 |     |     |     |     |
| 70    | 104| 3.375| 4.153 |     |     |     |     |
The above test results indicate that with a p-value <5%, there is a difference in the effect of the height of the pruning on the growth of the new stem. From the results of the test, the average value of new stem growth shows that the growth of new stems at a height of 50 cm pruning is better than other treatments.

The results of a one-way test on the effect of age on new stem growth indicate that there is a difference in the growth of new stems. This difference is indicated with a p-value <= 5% and $R^2$ reached 18% (Table 7).

### Table 7. One Way Test Anova

| Source       | DF | SS   | MS   | F    | P    |
|--------------|----|------|------|------|------|
| Age (yr)     | 3  | 1009.7 | 336.6  | 22.82 | 0.000 |
| Error        | 313 | 4615.7 | 14.7  |      |      |
| Total        | 316 | 5625.4 |      |      |      |

$S = 3.840$   $R$-Sq = 17.95%   $R$-Sq(adj) = 17.16%

| Level | N  | Mean | StDev | Individual 95% CIs For Mean Based on Pooled StDev | $	ext{--------*--------}$ |
|-------|----|------|-------|---------------------------------------------------|--------------------------|
| 0.5   | 247| 1.976| 3.181 | ($-$-*)                                           | $	ext{--------*--------}$ |
| 1.0   | 20 | 6.650| 4.171 |                                                  | $	ext{--------*--------}$ |
| 1.5   | 23 | 7.652| 4.579 |                                                  | $	ext{--------*--------}$ |
| 2.0   | 27 | 7.163| 7.163 | ($-$-*)                                           | 2.0 4.0 6.0 8.0          |

The above test results show that the best age for pruning is 1.5 years of age. If the cutting time interval is extended to 2 years, the number of new stems will be lower if the time interval is accelerated in 1 year.

3.4. Harvested biomass

Time intervals and height of pruning will affect pruning biomass. Information about the pruning time that is right after the previous pruning and the height of the pruners will provide the appropriate pruning results and determine the technique of transporting the pruning.

### Table 8. One Way Anova

| Source | DF | SS   | MS   | F    | P   |
|--------|----|------|------|------|-----|
| Treatment | 3  | 100  | 336.6 | 22.8 | 0.0 |
|          | 9.7 | 6    | 2    | 0.0  |     |
| Error   | 3  | 461  | 14.7 |      |     |
|         | 13 | 5.7  |      |      |     |
| Total   | 3  | 562  |      |      |     |
|         | 16 | 5.4  |      |      |     |

The results of the analysis showed that p-value <= 5%, there was a significant effect of the height of pruning on the weight of the stem. The high treatment of 30 cm pruning gives better pruning results than other treatments. However, this effect is still very low because $R^2$ represents only 5%. Meanwhile, the effect of age on stem weight resulting from pruning tends to be linear and is positively exponential (Figure 2). At 0.5-year pruning, time interval will produce a lower stem weight than the 1.5-year interval.
Figure 2. Biomass based on age

Stem weight at 1.5 years after pruning is more varied than 1 year of age. This variation indicates that a long time interval will affect the growth of stem diameter and the number of new stems that grow in one clump. Mathematically, the estimation model of pruning results by age is as follows:

\[
\text{Wet Weight (g)} = 123 + 240 \text{ Age}^2
\]  

(3)

| Predictor | Coefficient | Standard Error | T     | P     |
|-----------|-------------|----------------|-------|-------|
| Constant  | 122.88      | 35.1           | 3.5   | 0.001 |
| Age^2     | 240.31      | 28.74          | 8.36  | 0.001 |

\[ S = 270.657 \quad \text{R-Sq} = 32.8\% \quad \text{R-Sq(adj)} = 32.4\% \]

The model test results show that the constant and age coefficient are good enough in explaining the model, although the coefficient of determination (R²) is only 32.8%.

3.5. Heat value

Heat value is an indicator of energy that will escape from wood during the combustion process [7]. The higher the calorific value of the energy produced will be higher so that the efficiency of energy supply will be higher. However, the heating value will change as the water content contained in the wood. Good water content for electricity energy raw material is 12% [7].
### Table 11. Heat value based on age

| Age (yr) | Calorific Value (cal/g) | Lignin value | Water Content (%) |
|----------|-------------------------|--------------|-------------------|
| 0.5      | 3065.891                |              |                   |
| 0.5      | 2920.8                  |              |                   |
| 0.5      | 3043.905                |              |                   |
| 0.5      | 3083.254                |              |                   |
| 0.5      | 3045.72                 |              |                   |
| 0.5      | 3020.903                |              |                   |
| 0.5      | 3007.584                |              |                   |
| 0.5      | 2990.467                |              |                   |
| 0.5      | 3069.769                |              |                   |
| Average  | **3016.3531**           |              |                   |
| >5       | 3671.641                | 36.55        | 7.02              |
| >5       | 3601.868                | 36.25        |                   |
| >5       | 3874.316                | 30.99        | 7.05              |
| >5       | 3883.607                | 29.28        |                   |
| Average  | **3757.858**            | **33.27**    | **7.04**          |

Lab studies have shown that if the harvest is done at the age of 0.5 years, the average calorific value of 3.016 cal/g. But if it is left up to the age of more than 5 years then the calorific value reached 3,758 cal / g with a moisture content of 7%. Unfortunately, this study has not measured water content based on age well. The heat content of the test results is still below 4250 Kcal/kg (8). The lignin content is far below of the range 69 – 245 (5).

### 3.6. Discussion

Information about the growth and yield of energy plantations is very important. Development of *C. callothyrsus* in the form of plantations will guarantee the certainty of biomass raw material supply. The method applied is in accordance with the biomass inventory method presented by [9]. That in order to obtain the biomass data generated, data collection is carried out destructively. The production of results is strongly influenced by various management actions applied [10].

High information and time to cut are very important for entrepreneurs who want to invest so that the government's goal of providing electricity in an inaccessible area can be achieved [11]. Determining these cutting points is important for reducing negative impacts, especially on water quality and water use, which has been a problem in forest management with short-term harvesting [10]. In addition, it also increases CO₂ uptake to 123 Mg CO₂eq·ha⁻¹ [12].

The results of this study indicate that the information of effective pruning time is 1 year. While the best cutting height is 50 cm. This consideration is because the rest of the pruning becomes a medium for growing new stems. The longer the media grows, the more space will be available. However, this result is not absolute because at a 30 cm cropping height it provides a larger measure of harvest weight. The choice of 50 cm pruning height treatment is based on the number of new stems that appear to reach 8 stems/clump. This result is no better than 70 cm high pruning treatment. However, if it is seen that if harvesting is not carried out exactly 1 year then the possibility of a crust at a high treatment cut 50 cm better. Statistical test results showed that the growth of new stems at 50 cm high pruning was better than other treatments. This study strengthens the results of research presented by [2].
The high pruning treatment has no effect on the size of the truncated stem diameter. Factors that influence are age or interval between harvests and are not linear. The shape of diameter growth is positive exponential. The best age for the next pruning is at the age of 1.5 years.

The test results showed that the effect of the height of the pruners was very real on the weight of the pruning stem. A 30 cm high pruning treatment gives a heavier cropping result than other treatments. Meanwhile, the age factor will affect the weight of the stem. If the pruning time is longer than 1.5 years, the weight gain will increase quadratic.

Laboratory test results show that the old stem of C. callothyrsus has a calorific value of 3,578 cal.g⁻¹ and this value is not much different from the young stem. The calorific value of young C. callothyrsus is 3,016 cal.g⁻¹. It is said not to differ greatly because the stem age tested is 0.5 years. Based on consideration of harvest time, harvesting at 1.5 years will give C. callothyrsus stems with better heating values. This information is important as information on the amount of biomass that is needed as fuel. The raw material costs reach 44% -58% of total investment [13].

Based on the measurement results in Tables 1, 2 and 3 above, it can be summarized as follows: (1) based on the size of the new stem diameter the best treatment is 30 cm pruning height with a harvest time interval of 1.5 years; (2) based on the weight of the new stems at a length of 1 m, the best treatment is 30 cm pruning height with a harvest time interval of 1.5 m; and (3) based on the number of new stems, the best treatment is 50 cm pruning height with an interval of 1.5 years; (4) stem volume at 30 cm cutting height and 1.5 years old is 4.3 x 10⁻⁶; and (5) looking at the trend of measurement results, the best treatment is 50 cm pruning height with a harvest time interval of 1.5 years. This growth is better than the feedstock supply scheme that took place in Thailand [14].

Based on these considerations the simulation results that can be obtained are as follows: if in one stretch of land developed by C. callothyrsus with a spacing of 2 x 1 m, there will be 500 clumps. At a 50 cm cutting height it will produce 17 new stems at a 1.5-year harvest interval. Thus there are 55,000 new stems that can be harvested. If the weight of the stem is 590 g, the annual production is 55 tons/ha. If the stem volume is 50 cm in height and 1.5 years old is 1.5 x 10⁻⁵, there will be 25 m³/ha⁻¹. This simulation shows that the development of energy plantations can be carried out in protected areas, community forests and production forests [14]. The determination of the development location must be at a maximum of 50 km from the processing site [15].

The results of this study are very detailed research because they explain production at the plot level and not at the stand level, as suggested by [16]. In fact, this study revealed yields per stem which measured the base diameter and tip diameter, length and weight per stem. This is of course to reduce bias.

The development of C. callothyrsus in the form of energy plantations ensures the sustainable supply of raw materials. In this form of business, it can apply short-rotation woody crops (SRWC) [17]. SRWC with a 1-year cut interval can provide economic benefits for entrepreneurs. Besides that, it is useful in reducing emissions due to nitrate (NO₃⁻) washing and nitrous soil oxidation (N₂O) [12]. Giving fertilizer to increase yields can be taken. However, fertilization actually increases nitrate and N₂O emissions [12]. But, SRWC is not cheap [18]. The utilization of SRWC can influence high air emission. We need harvesting technology and transportation system which suitable, effective and efficient [19]. It can be possible by bioenergy cultivation which with supported by the development of a sustainable bioenergy industry [19]. SWRC must be seen as a system. Management systems that can provide sustainable business certainty. For this reason, after this research, it is expected to build an optimization model and system dynamics model. This model will produce ecological, economic and social feasibility, especially in the communities around the forest [20].

There some factors are considered in bioenergy model. There are like agro-climatic conditions, management practices, conversion technologies, fertilizer management, and by the use of cleaner wood combustion technologies with emissions controls [21]. In another side, the location for SRWC location must close to farmers and processing plants [22]. Farmers is a particular variable. We also change model mental of farmers. There some ways to change model mental like social learning, psychological, and cultural factors may also be influential in the development of an individual's
personal value system, and this may impact their desire for pursuing bioenergy crops [23]. Contract system between government or business sector with farmers is needed [24].

*C. callothyrsus* has the potential to produce biomass energy in the form of electricity. The development of biomass electricity can reduce dependence on electricity, especially in areas not covered by fossil electricity provided by the state electricity company (PLN). This research reveals the growth of *C. callothyrsus* and is beneficial for companies that want to develop electricity from this biomass. The advantage is once planted to be harvested many times until a certain age. The crop can be used for electricity. Biomass-based electricity development is very feasible to develop. The results showed that the selling price of biomass-based electricity reached 0.135 per kWh with incentive factor is 1.3 [25].

4. Conclusion

*C. callothyrsus* is a plant with high calor and fast growing. The best cutting limit was 50 cm above ground level. It is due to the high harvest biomass and the number of new stems that grow more. Meanwhile, to ensure business sustainability, the best harvest interval is 1 year. It will ensure adequate growth of new stems, large harvesting biomass and high calorific value of harvest. Harvesting potential can reach 25 m³.ha⁻¹.yr⁻¹. While the heating value will be at an interval of 3016 - 3757 kcal.kg⁻¹. The development *C. callothyrsus* for electric plan is feasible and also improving forest productivity and local community economy.

5. References

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