A comparison of tree biometric performance of four tropical energy wood species

M Yulianti*, W C Adinugroho, and H Krisnawati
Forest Research and Development Center, Ministry of Environment and Forestry, Bogor, 16610, Indonesia

Email: mira_solvay@yahoo.com

Abstract. Four energy wood species, i.e. Weru (Albizia procera (Roxb.) Benth.), Akor (Acacia auriculiformis Benth), Pilang (Acacia leucophloea (Roxb.) Willd), and Kaliandra, (Calliandra calothyrsus Mein.) that are suitable for substituting fossil energy in Indonesia were tested in experimental plots in Majalengka, West Java, Indonesia. In this paper, we assessed the performance of the planted species of up to 3.5 years old by measuring and analyzing the significant biometric parameters (height, diameter, volume, and biomass) of the trees growing on the plots. In each measurement, tree diameter and height were recorded. Volume and biomass were calculated by using allometric equations. The results showed that A. auriculiformis performed better than the other three species in terms of height, diameter, volume, and biomass. The performance was then followed by C. calothyrsus, A. procera, and A. leucophloea. The mean annual increment of volume and biomass of A. auriculiformis was 12.90 m³/ha/yr and 7.32 tonnes/ha/yr, respectively.

1. Introduction
Fossil fuel is one of the energy sources that is still widely used by global community [1]. However, the availability of fossil fuels in the world is running low because fossil fuels used are still non-renewable natural resources [2]. If the situation continues without any replacement of alternative energy, it will lead to energy crisis [3]. The establishment of energy wood-based forests is currently implemented in Indonesia by developing energy-producing timber plantations as an effort to use energy resources sustainably, which, on the other hand, will have implications for the time expiration of fossil energy sources [4]. New and renewable energy should be the main concern, not only as an effort to reduce the use of fossil energy but also to realize clean or environmentally friendly energy [5]. The benefits of new renewable energy can also reduce emissions, mitigate climate change and provide a clean environment and clean energy for all and future generations [6].

In forestry sector, renewable energy can be in the form of energy wood biomass [7]. Many potential wood species have been tested for energy woods. In Indonesia, there are several species potentials for energy woods that are suitable for use as renewable fossil energy substitutes. The species are usually fast-growing species and have high heat value. One of the factors considered for establishing plantation forest for energy is species selection, i.e. the species which has characteristics of energy wood that are ideal for planting. The characteristics include fast growth with dense branching, high specific gravity, high increment, able to live in a variety of growing conditions, and high ability to sprout after pruning. High heat is also a criterion for selecting the species that is expected to gain a high amount of energy in a short crop rotation [8].
This study assessed the biometric performance of four energy wood species to compare the productivity of the species that are good for energy wood production. The four species being studied included Weru (*Albizia procera* (Roxb.) Benth.), Akor (*Acacia auriculiformis* A. Cunn ex Benth.), Kaliandra (*Calliandra calothyrsus* Meisn.), and Pilang (*Acacia leucophloea* (Roxb.) Willd). Weru is widely used as firewood, building wood, fodder, live fences, ropes of wood bark, and chosen as one of the energy-producing species [9]. The advantages of Weru as an energy wood are partly because the species has the character of fast-growing, dry resistance, and can be trimmed. Besides, the species is easily cultivated because it has a useful life process and fast initial growth and is widely cultivated in agroforestry systems [10]. For energy wood, this species has an increment of 25 m$^3$/ha/yr, a specific gravity of 0.67 with an energy production of 301.5 GJ/ha/yr, and a calorific value of 7382 kcal/kg [9].

Akor is one of woody species that can be used as a source of biomass energy for fuel wood, charcoal and pellet making [11]. The shape of the stem is generally not good, bent with low branching and a lot, so planting this species is mainly directed as energy wood [9]. This species produces high quality firewood and charcoal with heat value for dry wood kiln of 4711 kcal/kg and for wood charcoal of 7639 kcal/kg increment of 17 m$^3$/ha/yr, specific gravity of 0.77 with energy production of 235.6 GJ/ha/yr and a calorific value of 7322 kcal/kg [10].

Kaliandra is a plant species that has a potential as a biomass-based energy source (wood pellet). This species has a calorific value of 4600 kcal/kg and is usually used for charcoal. The heat generated at 7200 kcal/kg can be used as wood production [11] and has the best performance in producing leaves (as animal feed and green fertilizer). The species is a forage tree legume that can be used as an alternative to animal feed as a food source of protein as well as for wood production (for firewood) [12].

Pilang has a high calorific value of 5218 kcal/kg with energy productivity as large as 258.3 GJ/ha/yr. This is a fast-growing species, which can grow on dry land, savanna and marginal land (critical land) with a low rainfall between 400 and 500 mm per year and dry season of 9-10 months. Its natural distribution covers the arid regions of India, Sri Lanka, Bangladesh, Burma, Thailand, and in Indonesia, it grows naturally in Java, Bali and Timor [13].

2. Material and Methods

2.1. Materials

This study was carried out in four experimental plots with the plot size of 25 x 50 m each. The planting sites are in RPH Sukajaya, BPKH Cibenda, KPH Majalengka. Administratively, they are located in Kertajati Sub-District, Majalengka District, West Java Province. The average temperature condition ranges from 26.3°C to 29.8°C and the rainfall is around 1974 mm/yr with 109 rainy days. The sites are in a lowland area with an altitude of approximately 50 meters above sea level and soil conditions contain clay, limestone, and marl. The plants were measured at ages of 20, 25, 31 and 38 months for diameter at breast height (DBH) and height. The description of data from the measurement plots are shown in Table 1.

2.2. Methods

2.2.1. Diameter at Breast Height (DBH) and height

Diameter and height were recorded at measurement times of 20, 25, 31, 38 months since planting. Tree diameter was measured at 130 cm above ground level. In the case of multi-stemmed trees (several trunks at ground level), each stem circumference at 130 cm was measured. Tree height was measured for total height from the ground to the top of tree.
Table 1. Description of data from measurement plots

| Species                | Age at measurement time (yr) | N*  | Diameter (Min-Max) (cm)* | Height (Min – Max) (m)* |
|-----------------------|-------------------------------|-----|--------------------------|------------------------|
| Albizia procera       | 1.7 yr; 2.1 yr; 2.6 yr; 3.2 yr | 80  | 1.3-6.4                  | 1.5-7.5                |
| Acacia auriculiformis | 1.7yr; 2.1 yr; 2.6 yr; 3.2 yr | 122 | 2.5-15                   | 1-10                   |
| Acacia leucophloea    | 1.7 yr; 2.1 yr; 2.6 yr; 3.2 yr | 84  | 0.8-8.5                  | 0.4-5.5                |
| Calliandra calothyrsus| 1.7 yr; 2.1 yr; 2.6 yr; 3.2 yr | 126 | 1.5-8.5                  | 2-7                    |

*trees measured at 3.2 yr

2.2.2. Volume estimation
Estimation of total tree volume was carried out using a general formula:

\[ V = \frac{1}{4} \pi \times D^2 \times H \]  

(1)

where, \( V \) = tree volume (m\(^3\)), \( D \) = DBH (cm), \( H \) = total tree height (m), \( \pi \) = 3.14

2.2.3. Biomass estimation
Biomass potential was estimated using allometric equations. In this study, the biomass measured was above-ground biomass. Schematic protocol based on woody physiognomy types was recommended for applying general aboveground biomass (AGB) models for woody individuals [11]. Multi-stemmed trees or shrub species have different biomass characteristic with single principal stem trees. Therefore, two types of allometric equations were used in this study.

Allometric equation: \( AGB_{est} = 0.0673 (\rho \times DBH^2 \times H)^{0.976} \) (2) was used to calculate aboveground biomass of Weru, Akor, and Pilang. While allometric equation \( AGB_{est} = e^{(2.474 \ln D - 2.757) \times 1.0787} \) (3) was used to calculate aboveground biomass of Kaliandra, where, \( AGB_{est} = \) estimated aboveground biomass (kg), \( \rho = \) tree density (kg/cm\(^3\)), DBH = diameter at breast height (cm), \( H = \) Height (m)

3. Results and Discussion
Tree growth performance can be measured quantitatively based on tree biometric parameters by identifying the tree from its physical characteristics, such as height, diameter, volume, and biomass. Tree growth will be determined by the ability of the tree species to obtain sunlight, water, nutrition, and air in the range of variability in specific climate and soil conditions. The growth performance of the four energy wood species in these environmental conditions can be explained as follows:

3.1. Height performance
Height is one of the growth performance parameters that can be used to observe the ability of tree growth at a location, especially during periods of initial growth. We found that the fastest-growing stands in the experimental plot were Akor stand. It has a height of up to 10 m at 3.2 years old. Pilang stand was the slowest growing tree that has a height of only 3 m. The height growth of this species looks stagnant since the age of 2.1 years old (Figure 1). In multi-stem vegetation or shrub species like Kaliandra, these characteristics with low and wide canopies are a more efficient way of growth.
The average height of the four species in the experimental plots increased with age. Akor stand was the highest stand with an average height value of 7.02 m at 3.2 years old, followed by Kaliandra stand of 4.89 m, Weru stand of 3.23 m, and Pilang stand of 1.87 m (Table 2). The difference between four species on height indicates that Kaliandra stands with the smallest CV shows the height less dispersed than the other stands with the larger CV (Akor, Weru, and Pilang).

**Table 2.** Statistics of height growth of four energy wood species

| Species  | Age = 1.7 yr | Age = 2.1 yr | Age = 2.6 yr | Age = 3.2 yr |
|----------|--------------|--------------|--------------|--------------|
|          | Mean | Std | CV | Mean | Std | CV | Mean | Std | CV | Mean | Std | CV |
| Akor     | 3.76 | 0.83 | 22.05 | 4.66 | 1.18 | 25.26 | 6.49 | 1.48 | 22.85 | 7.02 | 1.53 | 21.87 |
| Pilang   | 1.32 | 0.62 | 47.23 | 1.57 | 0.74 | 47.23 | 1.78 | 0.89 | 49.98 | 1.87 | 0.85 | 45.44 |
| Weru     | 1.65 | 0.42 | 25.45 | 2.12 | 0.59 | 27.92 | 2.79 | 0.79 | 28.10 | 3.23 | 0.97 | 29.95 |
| Kaliandra| 2.54 | 0.59 | 23.40 | 3.31 | 0.77 | 23.34 | 4.41 | 1.06 | 23.96 | 4.89 | 0.91 | 18.54 |

**3.2. Diameter performance**

Diameter is one of the important factors for determining stand volume. This parameter is an indicator that can be used to describe tree size because the diameter is the most easily used for measurement [15]. In the experimental plots, the Akor stand has the largest diameter compared to the others. The Akor stand reached a diameter of 13 cm at 3.2 years old, followed by Kaliandra stand of 9 cm and Weru stand of 6 cm. The smallest diameter was the Pilang stand of 4 cm (Figure 2).
Figure 2. The diameter of four energy wood species: a) 1.7 yr, b) 2.1 yr, c) 2.6 yr, and d) 3.2 yr

Akor stand was the largest with an average diameter of 7.95 cm at 3.2 years old, followed by Kaliandra (4.52 cm), Weru (3.52 cm), and Pilang (2.76 cm). The average diameter of the four species in the experimental plots increased linearly over time, indicating continued growth. Akor stands with the smallest CV shows the diameter of the tree less dispersed than the other stands with the larger CV, Kaliandra, Weru, and Pilang (Table 3).

Table 3. Statistics of the diameter of four energy wood species

| Species       | Age = 1.7 yr | Age = 2.1 yr | Age = 2.6 yr | Age = 3.2 yr |
|---------------|--------------|--------------|--------------|--------------|
|               | Mean  Std  CV | Mean  Std  CV | Mean  Std  CV | Mean  Std  CV |
| Akor          | 3.05  1.12  36.72 | 4.98  1.73  34.78 | 6.37  2.12  33.30 | 7.95  2.47  31.13 |
| Pilang        | 1.87  0.75  40.24 | 2.24  1.04  46.40 | 2.62  1.86  71.02 | 2.76  1.29  46.90 |
| Weru          | 1.47  0.36  24.71 | 1.74  1.02  58.33 | 2.73  1.03  37.84 | 3.52  1.36  38.69 |
| Kaliandra     | 2.70  0.56  20.58 | 3.16  1.36  42.88 | 4.17  1.36  32.63 | 4.52  1.57  34.74 |

3.3. Volume potential

At the last observation, we found that the Akor stand has the highest survival rate. The total number of individuals in the Akor stand was 113/plot, Kaliandra (89/plot), Pilang (84/plot), and Weru (81/plot). The potency of the total volume of these stands was: Akor > Kaliandra > Weru > Pilang. Akor was the stand with the largest volume compared to the others. It has a volume of 40.88 m³/ha at 3.2 years old, followed by Kaliandra stand of 9.25 m³/ha, Weru stand of 2.69 m³/ha, and Pilang stand of 1.28 m³/ha. The potency of the volume reflects how large the potential wood biomass for green energy feedstock in which the volume parameters correlate with the biomass.
In general, the growth of volume for four energy wood species has linear trends up to < 3.5 years old. Akor stands to show the highest slope compared to the others. It is shown that the Akor stand is the energy wood species that has the fastest volume growth, among others (Figure 3).

![Figure 3. The trend of volume for four energy wood species at < 3.5 yr](image)

### 3.4. Biomass production

Biomass is the total amount of organic matter that lives above the ground in trees, including main stems, leaves, branches, twigs, and bark. Calculation of forest biomass can be used to measure the number of resources available in the forest, such as timber, and to assess the changes in forest structure. Biomass is an important variable of forest ecosystems in various environmental conditions in terms of their structure and function. Besides, the calculation of biomass also illustrates the role of forests in the carbon cycle [16].

Akor was the stand that produced the largest biomass in the experimental plot. It produced 1.86 tonnes/ha at 1.7 years old, followed by Kaliandra stand of 0.74 tonnes/ha, Pilang stand of 0.18 tonnes/ha, and Weru stand of 0.11 tonnes/ha. At 2.1 years, Akor stands produced biomass of 6.94 tonnes/ha, Kaliandra stand of 2.81 tonnes/ha, Pilang stand of 0.35 tonnes/ha, and Weru stand of 0.29 tonnes/ha. At 2.6 years old, Akor stands produced biomass of 15.01 tonnes/ha, Kaliandra stand of 4.19 tonnes/ha, Pilang stand of 0.82 tonnes/ha, and Weru stand of 0.74 tonnes/ha. At the end period of the observation, Akor was the species that was able to produce the highest biomass. Akor stand produced biomass of 23.20 tonnes/ha at 3.2 years old, followed by Kaliandra stand of 3.52 tonnes/ha, Weru stand of 1.41 tonnes/ha, and Pilang stand of 0.71 tonnes/ha. The biomass trend of four species was linear at < 3.5 yr, as shown in Figure 4.

![Figure 4. The trend of biomass for four energy wood species at < 3.5 yr](image)
Comparison of diameter, height, volume, and accumulation of biomass in stands that grow on soil types and relatively similar environmental conditions shows that each energy wood species has different abilities to extract and use nutrients available for growth [17]. The amount of biomass accumulation is not only influenced by the physical characteristics of the tree (diameter, height). The magnitude of wood density also influences it. The density of wood shown a significant negative correlation, although weak, trees with a specific density of stems (including bark) of 0.2-0.49 show that the growth of stem diameter is relatively faster than trees with a specific density of more than 0.5 [18].

3.5. Volume and biomass increment
The biomass increment of Akor stand on this site (7.32 tonnes/ha/yr) is not significantly different compared with the biomass increment found in Hutan Rakyat Desa Nglanggeran, Gunungkidul, Yogyakarta, which is 7.04 tonnes/ha/yr [19]. The Kaliandra stand has a volume increment of 2.92 m³/ha/yr and a biomass increment of 1.11 tonnes/ha/yr. These are comparable with those recorded in Punak Ngegas-KPHK Unit Batulanteh, Sumbawa, which found the potential of Kaliandra biomass 2.7 tonnes/ha/yr [20]. The volume increment of the Wenu stand was 0.85 m³/ha/yr, and for biomass, the increment was 0.44 tonnes/ha/yr. The Pilang stand has volume and biomass increments of 0.41 m³/ha/yr and 0.22 tonnes/ha, respectively. Akor was the stand with the highest increment on volume and biomass. It has been because the tree has the largest diameter and the highest height compared to the other species. Forest biomass differs significantly from each stand depending on species structure and composition, contributing to carbon accumulation and carbon density. Accumulation of carbon stored in standing biomass and organic soil in the experimental plots and competition of individual trees from medium and large diameter classes contribute dominantly to biomass accumulation [21]. The biomass of the tree species is also affected by the growth of the species [22].

![Figure 5. Volume and biomass stand increment of four energy wood species](image)

4. Conclusion
Biomass-based energy wood as new renewable energy from the forestry sector is needed. There is not much growth information, and inventory data are available for energy wood species in Indonesia. It was considering the importance of the growth information necessary to develop experimental plots and conduct periodic measurements to get the information required on the stand growth of the energy wood species. The experimental plots of four energy wood species show that Akor is the fastest growing species and has the largest volume and biomass. However, this is an initial growth, and further research is needed to develop energy wood cultivation.
Reference

[1] Kholiq I 2015 Pemanfaatan energi alternatif sebagai energi terbarukan untuk mendukung substitusi BBM Jurnal IPTEK 19 75-91

[2] Noviyanti AR, Yuliati YB, Solihudin, Eddy DR, and Tjokronegoro R 2016 Silika sekam padi Jurnal Material dan Energi Indonesia 6(2) 1-6

[3] Manieniyan V, Thambidurai M, and Selvakumar R 2009 Study on energy crisis and the future of fossil. Proceedings of SHEE 10 2234-3689

[4] Sudrajat R 1983 Pengaruh bahan baku, jenis perekat, dan teknik kempa terhadap kualitas briket arang (Laporan LPHH) 165

[5] Yudha SW 2017 Pemerintah perlu mengoptimalkan pemanfaatan energi baru terbarukan. (Yogyakarta: Humas UGM) https://Ugm.Ac.Id/Id/News/13754/

[6] Owusu PA and Asumadu-Sarkodie S 2001 A review of renewable energy sources, sustainability issues and climate change mitigation Cogent Engineering 3(1) 1167990

[7] Yulianti M, Nurrochmat DR, and Kuncahybo B 2018 Simulasi model pengembangan gasifikasi listrik berbasis biomasa hutan tanaman energi Risalah Kebijakan Pertanian dan Lingkungan 5(1) 56-77

[8] Koeslulat E, Prayitno TA, Sutapa JPG, and Irawati D 2016 Karakteristik energi tiga jenis pohon cepat tumbuh padi acekelas diameter Jurnal Agroforestri 11(6) 23-31

[9] Bustomi S 2010 Pengelolaan Hutan Tanaman Kayu Energi (Bogor)

[10] Orwa C, Mutua A, Kindt R, Jamnadass R, and Anthony S 2009 Agroforestry Database: a tree reference and selection guide version 4 (World Agroforestry Centre)

[11] Permatasari P, Susanto D, and Kusuma R 2018 Pertumbuhan stek pucuk kaliandra (Calliandra Calothyrsus Meissn.) dengan beberapa komposisi media tanam dan konsentrasi root up. Bioprospekt 13(2)

[12] Nurjanah S, Ayuningsih B, and Hernaman IS 2016 Penggunaan kaliandra (Calliandra Calothyrsus), Indigofera Sp. dan campurannya dalam ransum sebagai pengganti konsentrat terhadap produktivitas domba garut jantan Jurnal Ilmiah Peternakan Terpadu 11 23-31

[13] Suita E and Bustomi S 2014 Berkecambah benih pilang techniques for increasing seed viability of Acacia leucophloea (Roxb.) Wild. Jurnal Penelitian Hutan Tanaman 11(1) 45-52

[14] Conti G, Gornè LD, Zeballos SR, Lipoma ML, Gatica G, Kowaljow E, and Fernandes P 2019 Developing allometric models to predict the individual aboveground biomass of shrubs worldwide Global Ecol Biogeogr. 28(7) 961-75

[15] Li YF, Yang HP, Wang HX, Ye SM, and Liu WZ 2019 Assessing the influence of the minimum measured diameter on forest spatial patterns and nearest neighbourhood relationships Journal of Mountain Science 16(10) 2308-19

[16] Brown S 1997 Estimates biomass and biomass change of tropical forest (FAO Forestry Paper) 134

[17] Purwanto RH, Rohman, Maryudi A, Teguh Yuwono, Permadi DB, and Sanjaya M 2015 Potensi biomass dan simpanan karbon jenis-jenis tanaman ber kayu di hutan rakyat desa Nglanggeran, Gunungkidul, Daerah Istimewa Yogyakarta Jurnal Ilmu Ke hutan 6(2) 128-41

[18] Siarudin M and Indrajaya Y 2020 Adaptation and productivity of kaliandra for biomass energy source IOP Conference Series: Earth and Environmental Science 415

[19] Hu Y, Su Z, Li W, Li J, and Ke X 2015 Influence of tree species composition and community structure on carbon density in a subtropical forest PLoS ONE 10(8) 1-9

[20] Daniel TW, Helms JA, and Barker FS 1980 Priniples of Silvikultur (New York: Mc. Graw Inc.)

[21] Suzuki E 1999 Diversity in specific gravity and water content of wood among Bornean tropical rainforest trees Ecological Research 14 211-24
[22] Wang D, Bormann FH, Lugo AE, and Bowden RD 1991 Comparison of nutrient-use efficiency and biomass production in five tropical tree taxa *Forest Ecology and Management* **46** 1-21

**Acknowledgment**

Data used in this paper was part of the research funded through the Research and Development Center for Forest Productivity Improvement. The authors thank to the Integrative Research Coordinator on Plantation Forest Management for Energy Wood for the period 2010-2014, Ir. Sofwan Bustomi, M.Si. and his team for initiating and developing activities.