
Rosalie C. Mendoza1*, Ramon A. Razal1, Willie P. Abasolo1, Roberto G. Visco2, and Canesio D. Predo2

1Department of Forest Products and Paper Science, College of Forestry and Natural Resources, University of the Philippines Los Baños, College, Los Baños, Laguna, Region IVA 4031 Philippines
2Institute of Renewable Natural Resources, College of Forestry and Natural Resources, University of the Philippines Los Baños, College, Los Baños, Laguna, Region IVA 4031 Philippines

This study assessed the potential of young kawayan tinik (Bambusa blumeana J.A. & J.H. Schultes) plantation for energy production by determining changes in biomass and calorific content over a three-year period. Yearly determination of biomass and culm growth was done for the plantation in Fort Magsaysay Military Reservation (FMMR) in Nueva Ecija, Philippines, by harvesting entire aboveground culms and non-culm portions of the plant. Culms were separated from branches and leaves and culm dimensions, height and diameter, and mass were obtained for both the culm and non-culm portions. Basal clump diameter was also measured and the number of culms per clump was counted. The chemical properties (volatile matter, fixed carbon, and ash) of the culm and the branches plus leaves (B+L) were likewise determined. Calculations were done for individual culm and total aboveground dry biomass per clump. Analysis of variance showed that both basal clump diameter and culm height were significantly affected by clump age, while culm number per clump and culm diameter did not vary significantly from year to year. Aboveground dry biomass increased with clump age. Chemical properties except for the ash content of the culms were all significantly affected by clump age. Analysis of variance also showed significant effect of clump age to the measured gross calorific values (GCVs) of culms while the corresponding value for B+L samples did not vary with clump age.

Keywords: aboveground biomass, bioenergy, chemical properties, culm characteristics, gross calorific value, kawayan tinik

INTRODUCTION

The need for renewable energy resources cannot be overemphasized in view of constantly increasing oil prices, global warming and climate change, and depletion of fossil fuel sources. Potential sources of bioenergy from different forms of biomass are being explored and their properties are being determined as they can provide valuable information on the long-term economic value and sustainability of these alternative energy sources. Bamboo as a renewable energy resource is of great interest, with more than 10 million tons produced annually – almost all of it from Asia (Panayotou and A shton 1992). Currently,
many countries from around the world are producing charcoals, briquettes, and fuel pellets from bamboo.

Kawayan tinik is one of the most important bamboo species in the Philippines, where it is well-distributed geographically. Razal and Palijon (2009) stated that kawayan tinik is the most desirable bamboo species for construction because the mature culms have high specific gravity and lower shrinkage when dried. Rao and co-authors (1998) also listed kawayan tinik as one of the major priority bamboo species of national and regional importance because it provides income to rural industries, contributes to environmental rehabilitation, and possesses high commercialization potential. The common uses of the culm are for construction purposes, furniture making, parquet, concrete reinforcements, kitchen utensils, chopsticks, hats, toys, papermaking, basketry, farming implements, and many other uses for transport and household. It is also planted for the purpose of preventing soil erosion and windbreak purposes. It also serves as living fences or boundary marks between land properties.

Evangelista (2012) studied the use of kawayan tinik as raw material for pellet production. He observed that the calorific values of kawayan tinik nodes and internodes are 3972 and 4161 kcal/kg, respectively. When kawayan tinik was made into charcoal, carbonized nodes and internodes have higher calorific values of 6283 and 5566 kcal/kg, respectively (Evangelista 2012). The high cellulose content of kawayan tinik (Semana 1967, Espiloy 1996, Razal 2013) makes this species a good raw material for charcoal and pyroligneous liquor production. In Ilocos Norte, Philippines, a group of researchers at Mariano Marcos State University developed a technology that produced kawayan charcoal briquettes with an average density of 0.46 g/cc, ash content of 8–11% and heat value of 4201 kcal/kg (Rosario 2011).

This study contributes to the development of alternative, renewable materials such as kawayan tinik for energy production. The main objective of this research is to characterize the aboveground biomass and corresponding bioenergy content of one-, two-, and three-year-old plantation-grown kawayan tinik clumps. Specifically, it aimed to determine the clump and culm variables, aboveground dry biomass, chemical properties and GCV's of one-, two-, and three-year-old clumps. This can help promote kawayan tinik plantations as bioenergy sources. Kawayan tinik, being a “multi-purpose” bamboo species, would require a strategic plantation development and harvesting scheme. Studies looking into the properties of kawayan tinik as affected by clump age and information on the potential performance as an energy crop are still lacking. In order to more efficiently use kawayan tinik as raw material for energy production efficiently, it is essential to carry out a detailed characterization of its biomass.

MATERIALS AND METHODS

Experimental Site

Harvesting and collection of culms and non-culm biomass were made from bamboo clumps in a bamboo plantation established in 2013 in FMMR, Nueva Ecija, Philippines. Different edaphic, physiographic, and climatic variables of the site were collected to provide baseline data on the site conditions. Soil organic matter, pH, nitrogen, phosphorus, and potassium were analyzed. A Global Positioning System device was used to determine the coordinates of the sample clumps. From these coordinates, the Digital Elevation Model with pixels measuring 30 m x 30 m was used to generate elevation, slope, and aspect of the site. Rainfall, temperature, and relative humidity values for the duration of the study were obtained from the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA) – Cabanatuan Station, which is nearest to the bamboo plantation.

Clump and Culm Variables

Basal clump diameter, number of culms per clump, culm height, and diameter were measured for each sample clump. Basal clump diameter was measured by projecting the edge of the clumps at opposite sides using a diameter tape. Smallest and largest diameter readings were averaged and recorded as the clump diameter. Living culms in each sample clump were counted and recorded. To determine the height of the culms, felled culms were measured from base to top using a meter tape. The diameter of all the culms in the sample clump was measured using a digital Vernier caliper. Diameter from the base and top portions were averaged and recorded.

Aboveground Dry Biomass

To estimate the biomass production potential of kawayan tinik, clumps were destructively sampled. The selected clumps were felled at ground level after measuring the basal clump diameter. B +L samples were separated from the culms and their fresh weights were recorded immediately after felling using a spring weighing scale. Representative culms and B +L samples were collected for moisture estimation. After recording the fresh weights, culms were dried at 103 ± 2 °C until their constant weights were attained, while B +L samples were dried at 80 °C to prevent the samples from burning. Estimates of dry weight biomass were obtained from the fresh weights of culms and B +L samples and their moisture contents.

Chemical Properties

Culm and B +L samples were milled for proximate analysis following ASTM D-1762 (modified) to determine the amount of volatile combustible matter, fixed carbon,
and ash content of the material. The volatile combustible matter was determined by heating the samples inside the furnace at 950 °C. Prior heating was done by placing the samples in front of an open and operational furnace for 5 min. After preliminary heating, the samples were placed inside the furnace and remained there for 6 min. The samples were then cooled in a desiccator for one hour and weighed again afterward. The volatile matter was calculated by getting the mass difference of the sample before and after the heating process. Ash content, on the other hand, was determined by placing the samples in the furnace at 600 °C for 6 h. The samples were cooled inside a desiccator for 1 h and the mass difference of the samples before and after the heating process was determined. The fixed carbon value was calculated by subtracting the sum of percent volatile combustible matter and the percent ash content from 100%.

Determination of GCVs
The GCVs were obtained using a Shimadzu bomb calorimeter following ASTM D 2015-96. Pulverized and oven-dried culm and B+L samples weighing 5 g were prepared for triplicate analysis.

RESULTS

Clump and Culm Variables
Table 1 shows that – on average – basal clump diameter, the number of culms per clump, the average culm height, and the average culm diameter increased with age from 1 to 3 yr. Statistical analysis showed that clump diameter is significantly affected by its age, with a p-value of 0.0129. Specifically, one-year-old and two-year-old clumps are both significantly different from three-year-old clumps. Lowest basal clump diameter was recorded in a one-year-old clump with a value of 16 cm, while the highest basal clump diameter was observed in a three-year-old clump with a value of 71.25 cm.

The number of culms per clump appeared to be unaffected by clump age, although it was observed that the lowest number of culms per clump was in a one-year-old clump (5 culms) and the highest was observed in a three-year-old clump. Ideally, as a bamboo plantation becomes older, more culms are produced by the clumps until such age that growth ceases (Virtucio and Roxas 2003). In general, culms of B. blumeana that are younger than three years old are not utilized in the Philippines as they are still deemed unsuitable for furniture or construction. Thus, no thinning is performed and – for purposes of the study – no removal of culms was done until the targeted age (1, 2, or 3 yr) of the study clump was attained.

Culm height increased from one-year-old to three-year-old clumps. However, highest culm height was recorded in a two-year-old clump with a value of 6.30 m and lowest in a one-year-old clump (1.38 m). Average culm heights of two-year-old and two-year-old clumps are not significantly different from each other.

Statistical analysis revealed that culm diameter values of one-, two- and three-year-old clumps are not significantly different from one another, although average culm diameter was lowest in one-year-old clumps and highest in three-year-old clumps. However, culm age is directly proportional to the culm diameter. The lowest average

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Clump sample number</th>
<th>Average</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basal clump diameter (cm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>16.00</td>
<td>22.70</td>
<td>21.85</td>
</tr>
<tr>
<td>2</td>
<td>25.65</td>
<td>24.25</td>
<td>24.50</td>
</tr>
<tr>
<td>3</td>
<td>45.025</td>
<td>41.25</td>
<td>71.25</td>
</tr>
<tr>
<td>Culm number per clump (pc)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>13</td>
<td>12</td>
<td>23</td>
</tr>
<tr>
<td>Culm height (m)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2.15</td>
<td>1.85</td>
<td>1.38</td>
</tr>
<tr>
<td>2</td>
<td>3.96</td>
<td>3.27</td>
<td>6.30</td>
</tr>
<tr>
<td>3</td>
<td>4.80</td>
<td>4.03</td>
<td>6.08</td>
</tr>
<tr>
<td>Culm diameter (cm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2.24</td>
<td>1.38</td>
<td>1.24</td>
</tr>
<tr>
<td>2</td>
<td>2.15</td>
<td>1.97</td>
<td>3.04</td>
</tr>
<tr>
<td>3</td>
<td>2.35</td>
<td>2.20</td>
<td>2.76</td>
</tr>
</tbody>
</table>

Note: Means with the same letter are not significantly different from one another according to Tukey’s post-hoc test; ns – not significant
culm diameter recorded was from culms harvested from one-year-old clump (1.24 cm) – from the sample clump with the highest number of culms. Highest average culm diameter (3.04 cm) was recorded during the second year of collection for the 10 culms measured in the clump.

Aboveground Dry Biomass
Figure 1 shows the graphical comparison of the average individual culm and its corresponding B + L dry biomass computed for the three clump ages. Analysis of variance showed that dry weights of both individual culm and its B + L are significantly affected by clump age. A linear relationship between these variables is also exhibited in Figure 1. As clump age increases, dry weight also increases. The average dry weight of culms from one-year-old clumps is 0.18 kg while its B + L weighs 0.21 kg. The highest individual culm (4.53 kg) and B + L (1.29 kg) dry weights were recorded for three-year-old clumps.

Figure 1. Average individual culm and corresponding B + L dry biomass of one-, two-, and three-year-old kawayan tinik clumps.

Figure 2 shows that total culm dry biomass increased considerably from a value of 1.31 kg during the first year to as high as 80.75 kg when the clumps reached three years. B + L dry biomass multiplied by almost 20 times during the same period – from 1.56 kg to 20.90 kg. On average, the total aboveground dry biomass of one-year-old clumps consists of 45.65% culms and 54.64% branches and leaves. Total aboveground dry biomass values of two-year-old clumps are 64.43% for culm and 35.57% for B + L. Three-year-old clumps have a total aboveground dry biomass consisting of 79.44% culms and 21.56% B + L.

Chemical Properties
Table 2 shows the average fixed carbon, volatile matter, and ash content of the culms and B + L of one-, two- and three-year-old clumps of kawayan tinik. Samples from one-year-old clumps have the highest fixed carbon content compared to the two other clump ages. The fixed carbon content of culms from one-year-old clumps is 27.08% of its total dry weight while for B + L, it is 26.86%. The lowest fixed carbon content of culms was observed in two-year-old clump samples, with a value of 17.99%. The B + L of three-year-old clumps has the lowest fixed carbon content, with a value of 17.13%. Statistical analysis showed that fixed carbon content of culm samples from one- and three-year-old clumps are significantly different from that of two-year-old clumps. The fixed carbon contents of B + L samples from the three clump ages are all significantly different from one another.

Meanwhile, the B + L of one-year-old clumps was also observed to have the lowest volatile matter content (66.31%), while the highest value was recorded for samples from three-year-old clumps (70.30%). Statistical analysis showed that volatile matter content of culm samples from two- and three-year-old clumps are significantly different from that of one-year-old clumps while for the B + L samples, samples from one- and three-year-old clumps are significantly different from one another.

Proximate analysis showed that the ash content of culms and B + L samples differed, with the B + L samples having an ash content as high as 12.57% against the highest ash content of culm samples, which is 2.47%. Both values were recorded from culms and B + L of three-year-old clumps. B + L from one-year-old clumps are significantly different from three-year-old clumps. Ash contents of culms are not significantly different from one another.

GCVs
Comparing the GCVs of culm and B + L at any given clump age (Figure 3), it can be seen that culm samples have higher means than B + L samples. Analysis of variance showed that GCVs of culm samples from one-year-old clumps and three-year-old clumps are significantly different from two-year-old clumps. The highest average GCVs were recorded both from the culms and B + L of three-year-old clumps. The average GCV of culm samples is 4377.33 kcal/kg, while B + L samples recorded a value of 4031 kcal/kg.
Clump and Culm Variables

According to Yen (2016), bamboo productivity can be categorized into two distinct phases. The first phase is culm height growth that happens very rapidly, and the second phase is culm strength that increases together with dry biomass accumulation until they reach maturity and can be utilized for human use. The productivity and properties that each clump exhibits are highly dependent on the quality of the planting stocks used in the plantation, site conditions, silvicultural treatments, and other external factors. At an early stage, bamboo clumps are still adapting to the site conditions. Growth competition among culms, especially in very young clumps where competition is very pronounced, and mortality of young culms can also affect the results gathered in the study. However, data on the quality of the planting stocks used, culm mortality rate and other anthropogenic disturbances are not available.

Site conditions like physiography can affect the growth of bamboo. The elevation of the FMMR site was recorded to be within the range of 70–78 masl. Virtucio and Roxas (2003) cited that Bambusa species like kawayan tinik grow well in this range. Studies on the effect of elevation on clump and culm variables of kawayan tinik were also done by Uchimura (1978) and Colis (1996). Uchimura (1978) observed that the measured culms form clumps at lower elevation are taller and bigger in diameter than those growing in higher elevation. Colis (1996) noticed

### Table 2. Proximate analysis (dry weight basis) of culms and B+L from one-, two-, and three-year-old kawayan tinik clumps.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Clump age</th>
<th>Clump sample number</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Fixed carbon (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Culm</td>
<td>1</td>
<td>27.63</td>
<td>26.07</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>18.07</td>
<td>17.91</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>20.90</td>
<td>18.70</td>
</tr>
<tr>
<td>B+L</td>
<td>1</td>
<td>26.25</td>
<td>26.11</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>20.28</td>
<td>21.53</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>17.40</td>
<td>17.70</td>
</tr>
<tr>
<td>Volatile matter (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Culm</td>
<td>1</td>
<td>70.28</td>
<td>72.93</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>79.26</td>
<td>80.14</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>76.20</td>
<td>79.20</td>
</tr>
<tr>
<td>B+L</td>
<td>1</td>
<td>64.92</td>
<td>67.32</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>71.73</td>
<td>68.72</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>69.40</td>
<td>71.30</td>
</tr>
<tr>
<td>Ash (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Culm</td>
<td>1</td>
<td>2.08</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2.67</td>
<td>1.95</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2.95</td>
<td>2.06</td>
</tr>
<tr>
<td>B+L</td>
<td>1</td>
<td>7.99</td>
<td>9.75</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>8.84</td>
<td>6.57</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>13.20</td>
<td>11.00</td>
</tr>
</tbody>
</table>

Note: Means with the same letter are not significantly different from one another according to Tukey’s post-hoc test; ns – not significant

**DISCUSSION**

**Clump and Culm Variables**

According to Yen (2016), bamboo productivity can be categorized into two distinct phases. The first phase is culm height growth that happens very rapidly, and the second phase is culm strength that increases together with dry biomass accumulation until they reach maturity and can be utilized for human use. The productivity and properties that each clump exhibits are highly dependent on the quality of the planting stocks used in the plantation, site conditions, silvicultural treatments, and other external factors. At an early stage, bamboo clumps are still adapting to the site conditions. Growth competition among culms, especially in very young clumps where competition is very pronounced, and mortality of young culms can also affect the results gathered in the study. However, data on the quality of the planting stocks used, culm mortality rate and other anthropogenic disturbances are not available.

Site conditions like physiography can affect the growth of bamboo. The elevation of the FMMR site was recorded to be within the range of 70–78 masl. Virtucio and Roxas (2003) cited that Bambusa species like kawayan tinik grow well in this range. Studies on the effect of elevation on clump and culm variables of kawayan tinik were also done by Uchimura (1978) and Colis (1996). Uchimura (1978) observed that the measured culms form clumps at lower elevation are taller and bigger in diameter than those growing in higher elevation. Colis (1996) noticed
that elevation is inversely proportional to clump diameter, number of culms produced, and culm diameter.

A aspect or the orientation of the slope with respect to the sun’s position indirectly affects bamboo growth. According to Rosario (2011), under Philippine condition, sunlight is more intense and has longer duration on southwest facing slopes than northeast facing slopes. Virtucio and Roxas (2003) also stated that north-facing slopes are more beneficial for bamboo growth than west-facing slopes because north-facing slopes are less exposed to intense sunlight that is detrimental to bamboo growth. Most of the sample clumps selected in the study were facing north. Supposedly, considering the statements cited above, good growth can be expected from the site. However, aspect alone does not dictate the performance of kawayan tinik clumps. Many other factors can affect the productivity of the plantation.

Slope influences bamboo growth by modifying the solar radiation that bamboo clumps receive. Colis (1996) observed that as slope increases, culm height and diameter of kawayan tinik decreases. He further reported that clumps growing in areas with an average slope of 7% are more productive than those growing in steeper slope (34%). In this study, the slope range of the plantation turned out to be within the range of 0–30%. Two of the sample clumps harvested during the third year were located in an area with a slope range of 0–8%. This may have affected the higher values of the measured clump and culm variables of three-year-old clumps.

Climatic factors like rainfall, temperature, and relative humidity directly affect bamboo growth. After the plantation establishment in September 2013, the site experienced very low rainfall starting December 2014 up to May 2014, with zero rainfall in January when the propagules were still adapting to the site. In 2014, the lowest annual rainfall was recorded when the plantation was completing its first-year growth. Mean temperature and relative humidity appeared to be uniform during the conduct of the study. According to Virtucio and Roxas (2003), moisture is the most important factor that affects bamboo growth. Uchimura (1978) further stated that there is no single environment factor more limiting to bamboo growth than rainfall. The rainfall recorded in the site appeared to be critical during the early stage of growth of the kawayan tinik propagules, with adverse effect on the growth of the clumps in the succeeding years.

Silvicultural treatments like irrigation, regular fertilizer application, and weeding were observed to be lacking in the plantation. There was no irrigation – 200 g complete fertilizer was applied only once in every clump during the planting of branch cuttings, and weeding was only done during site preparation prior to planting. Decipulo and co-authors (2009) reported that optimum culm production in kawayan tinik required a combination of 80-160 kg N/ha/yr and 30 kg P/ha/yr. Rosario (2011) also reported that 20–100 ppm of potassium should be present in the soil for optimum kawayan tinik growth. Virtucio and Roxas (2003) also reported a significant increase in the number of culms per clump with the application of fertilizer in unmanaged plantations. M'dimore (2009) cited that the supply of water before and during the shooting season has been recognized as an enhancing factor to initiate and promote shoot production. Irrigation increased the number of shoots, with the effect being greatest if combined with fertilizer application.

Results of the soil analysis revealed that the soil in the site contains low organic matter, nitrogen, phosphorus, and potassium. Only the soil pH (5.6–6.2) recorded an acceptable range for bamboo growth. Average soil organic matter (2.6%), nitrogen (0.11), phosphorus (5.13 ppm), and potassium (0.15me/100g soil) are all in the low range. Tiongco (1997) evaluated the eight-year growth of kawayan tinik plantations in Malaybalay, Bukidnon, Philippines – as a function of clump age and productivity on sites classified as either highly, fairly, and marginally productive – based on the soil chemical and physical properties. Generally, highly productive site has a more desirable soil physical properties and higher levels of soil nutrients compared to the fairly and marginally productive sites. Comparison of the soil analysis of the FMMR site and the three productivity classes of the kawayan tinik plantations stratified by Tiongco (1997) in Bukidnon revealed that the FMMR site is closer to the soil properties of the marginally productive site. However, total comparison of the clump and culm variables gathered in FMMR with the results gathered by Tiongco (1997) in Bukidnon is not feasible since Bukidnon plantations were established using culm cuttings while FMMR plantation was established using branch cuttings. Different climatic and physiographic conditions also complicate the total comparison of these two studies. Other factors had contributed to the performance of the clumps aside from soil properties. Nonetheless, performance of the sample clumps used in this study was definitely affected by the poor soil condition of the site.

Aboveground Dry Biomass
Rhizomes are the underground stems of bamboo plants, providing stability to the whole clump in the absence of a central trunk (Virtucio and Roxas 2003). Dransfield and Widjaja (1995) cited that new rhizomes are produced from older rhizomes and, mostly, culms developed from the apices of these younger rhizomes. Bamboo clump formation follows after several closely positioned shoots emerged from the sympodial rhizome system. A aboveground biomass production in bamboo is therefore
highly dependent on the vigor of its rhizome system. A more vigorous rhizome system allows the bamboo clump to take advantage of the limited soil and water resources compared to the other clumps.

Banik (2015) stated that branching in culms starts after it reached its maximum height. Numerous thin branches start sprouting from each culm bud. It is followed by leaf development after two to four weeks. During the first year of harvest, when the sample clumps were only one year old, the biomass of combined branches and leaves appeared to be higher than the culm biomass, meaning the growth of leaves and branches is prioritized than increasing the cellular makeup of the culms. This is supported by the study of Thokchom and Yadava (2017), which observed lower values of belowground biomass in one-year-old Schizostachyum pergracile clumps compared to older clumps. Their results indicate that at the early stages of growth, the plant depends completely upon the leaf area to build the carbon chains and metabolites that allow the growth of each organ (Düking et al. 2011, as cited by Thokchom and Yadav 2017). Other studies supporting the trend observed in this study are those reported by Shanmughavel and co-authors (2001) and Panda (2011), who noticed increasing branch and leaf biomass of one-, two- and three-year-old B. bambos clumps. Kozlowski and co-authors (1991) reported that in young trees, a very high proportion of photosynthate is used in leaf production. Opposing these results are the studies of Banik (2000) and Banik and Islam (2005), where they recorded that one-year-old culms have fewer leaves than two- and three-year-old bamboo culms. Banik (2015) further stated that, generally, one-year-old bamboo culms have smaller leaf biomass than older ones. It should be noted that contrasting trend might be due to the fact that previously cited studies only reported leaf biomass, while observed values in this experiment involved the dry weight of branches and leaves in the sampled clumps.

For all clumps, the highest culm dry biomass value recorded was 157.68 kg - five times higher than its corresponding B+L biomass, which was 30.86 kg. These values were relatively lower compared to the reported dry weight of several fast-growing fuelwood species. Pleguezuelo and co-authors (2015) reported that several Eucalyptus plantations in the European Union countries can have a yield ranging from 10–20 t/ha/yr. Furthermore, Acacia mangium and Leucaena leucocephala plantations in the humid countries can have a biomass yield of 8–40+ t/ha/yr (FAO 2001).

**Chemical Properties**

Yen and Lee (2011) contended that bamboo has higher potential for fixing carbon dioxide from the atmosphere. Carbon is the major constituent of biomass, and its combustion increases the heating value; therefore, high carbon content is desirable in biofuels (Sadiku et al. 2016). Ganesh (2003) reported lower values of fixed carbon in various bamboo culm species compared to the results of this study. Sadiku and co-authors (2016) also observed much lower fixed carbon values in two- to four-year-old B. vulgaris culms (3.96–4.69%). They also observed a slight decrease in the fixed carbon content in two-year-old culms, and then a slight increase in three-year-old culms. Scurlock and co-authors (2000) also reported a decreasing trend in the fixed carbon content of Phyllostachys species with age, but their values were slightly lower compared to the fixed carbon of kawayan tinik culms measured in this study. In L. leucocephala, Rasat and co-authors (2016) reported much lower fixed carbon values (6.51–10.31%). No other study was found that reported on the fixed carbon of kawayan tinik branches and leaves, hence, no comparison was made.

Sadiku and co-authors (2016) observed higher volatile matter content ranging from 93% to 95.30% in 2- to 4-year-old B. vulgaris culms. Ganesh (2003) also reported slightly higher values of fixed carbon in his proximate analysis of several bamboo culms. Rasat and co-authors (2016) also observed volatile matter of L. leucocephala ranging from 81.46 to 84.72%, while Scurlock and co-authors (2000) observed lower volatile matter percentages in comparison to the results of this study. Mitchual and co-authors (2014) found out that the volatile matter of several fuelwood species ranges from 75 to 83%. Volatile matter of kawayan tinik culms measured in this study is within the range reported by Mitchual and co-authors (2014).

In general, biomass with lower ash content is preferred in bioenergy production since ash deposit on heat transfer surfaces in boilers and internal surfaces in gasifiers accelerate corrosion of hot heat exchanging tubes and also reduce their efficiency (Grover and Mishra 1996). Similar to the results of this study, Sadiku and co-authors (2016) also observed that the ash content of B. vulgaris increased as culm age increased. However, higher amount of ash was
observed in B+L than in the culms of kawayan tinik. This is mainly because large amount of silica is present in the leaves of bamboo. Bamboo leaves have a silica content of 17–23% by weight, higher than the silica content in rice husk (Silviana and Bayu 2018).

Kawayan tinik culm ash content reported by Semana (1967) and Espiloy (1996) were slightly higher while result of the study of Razal (2013) was lower compared to the results gathered in this study. Researchers who conducted proximate analysis of several fuelwood species all reported lower ash content compared to the results of this study (Yokohama and Matsuura 2008, Mitchual et al. 2014, Rasat et al. 2016).

GCVs
The standard measure of the energy content of a fuel is its heating value or calorific value. The GCV gives an indication of the amount of heat and the potential value of electricity that can be produced by the biomass (Sadiku et al. 2016). These values are higher compared to the GCVs of rice straws and aquatic plants listed by Yokohama and Matsuura (2008). In comparison to some fuelwood species, GCVs reported in this study are lower. Yokohama and Matsuura (2008) cited that Eucalyptus, a woody plant, has a GCV equivalent to 4466 kcal/kg. M. alnoo and A. ppiiah (1996) also reported higher values for some fuelwood species like L. leucocephala (4703 kcal/kg), Gliricidia sepium (4569 kcal/kg), and Senna siamea (4480 kcal/kg). Mitchual and co-authors (2014) reported that the GCV of six tropical species in has a range of 4815–5307 kcal/kg.

Scurlock and co-authors (2000) observed that the GCVs of Phyllostachys species did not significantly vary with culm age when they acquired almost similar values. They also noted that GCV is positively correlated with fixed carbon, but this relationship did not surface in their study. Similarly, this correlation was not exhibited in this study. The highest fixed carbon percentage was recorded in one-year-old samples but the highest GCVs were observed in three-year-old clumps. Volatile matter, on the other hand, is negatively correlated with GCV. This held true in the case of the culm samples from two-year-old clumps, which was reported to have the lowest fixed carbon yet highest volatile matter.

Ideally, as the clumps mature, more carbon is being assimilated and stored in its biomass, which will positively affect its GCV. This is apparently the trend in the B+L samples tested in this study. As reported in the previous sections, dry biomass increased from one-year-old to three-year-old clumps. However, in the case of culm samples, there was a decrease in the GCV of two-year-old clumps and then it increased again in the three-year-old clumps. Several factors might have influenced these results, as mentioned earlier. Heterogeneous culm samples with varying ages used in this study can be one of the reasons for the lower GCVs obtained for two-year-old clumps.

RECOMMENDATIONS
While the measured and computed properties of the sample clumps appear to be lower than the properties of several species used for bioenergy production, the results of the study suggest that the FMMR kawayan tinik plantation is a potential source of raw materials for bioenergy production. Should there be continuing interest in the assessment of bamboo plantations as bioenergy source, the following are recommended:

1. application and full documentation of silvicultural treatments that are likely to increase the productivity of the clumps and improve the properties and suitability for bioenergy production;
2. increasing the planting stock density by lowering the planting spacing from 10 m x 10 m to a much closer stock density subject to trial runs; and
3. utilizing one-year-old clumps for bioenergy purposes, which appears to be a viable option since results showed acceptable fuel property values even at such an early age of the plantation.

ACKNOWLEDGMENTS
The authors would like to acknowledge the Commission on Higher Education – Faculty Development Program for the thesis grant. The same gratitude is due to the following persons who greatly contributed to the realization of the study: Dr. Portia Lapitan, Forester Gregorio Santos, Jr. and M Gen. Angela De Leon. Thank you very much for giving the authors the permission to conduct the study at FMMR and for all the assistance accorded to the authors. Similarly, to all the staff of ERDB-DENR, FMMR, and DFPPS-CFNR who helped the authors during the conduct of the study, thank you for your kind assistance.

REFERENCES


COLIS JC. 1996. Evaluation of site quality preferences of kawayan tinik (Bambusa blumeana Schultes) at Dumanjug bamboo plantation project, Dumanjug, Cebu [MS Thesis]. University of the Philippines Los Baños. 91p. (Available at the UPLB Main Library)


EVANGELISTA AA. 2012. Production and characterization of fuel pellets from kawayan tinik (Bambusa blumeana Bl. ex Schult. f.) and bikal [Schizostachyum diffusum (Blco.) Merr.] [MS Thesis]. College of Forestry and Natural Resources, University of the Philippines Los Baños. 75p. (Available at CFNR Library)


SILVIANA S, BAYU W J. 2018. Silicon conversion from bamboo leaf silica by magnesiothermic reduction for development of li-ion battery anode. MATEC Web of Conferences 156: 1–5.


TIONGCO L E. 1997. Edaphic factors are related to productivity and nutrient uptake of kawayan tinik (Bambusa blumeana Schultes F.) in Bukidnon [M S Thesis]. University of the Philippines Los Baños. 91p. (Available at the UPLB Main Library)


