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Prediction models for a young Kawayan tinik (*Bambusa spinosa* Roxb.) plantation in Nueva Ecija, Philippines

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ABSTRACT. The objective of this study is to generate prediction models for different characteristics (clump and culm variables, aboveground dry biomass, chemical properties, and gross calorific values) of Kawayan tinik (*Bambusa spinosa* Roxb.) as a function of clump age. Biomass yield models were developed over a three-year-period that can serve as basis for making decisions in the planning and design of bamboo energy plantations. Linear and non-linear models best fit the data. Models considered were linear regression (double log model) and non-linear regression specifically exponential, logarithmic, and Gompertz. Prediction models with high coefficient of determination (R^2) values, adjusted R^2, low root mean square error (RMSE), and significant coefficients were generated for all tested dependent variables except for culm dry biomass. Of all the models used, the exponential model fitted best with the data, specifically the exp2, followed by exp2a, and then the linear regression model. In terms of dry biomass, multiple linear regression model in double natural logarithmic form showed that culm number per clump and culm diameter are important variables in estimating culm dry biomass. Branches+leaves dry biomass can be predicted by culm number per clump, culm diameter, and clump age. These prediction models can be used to estimate the bamboo characteristics included in the study given the same clump age and site conditions.

Keywords: bioenergy, linear regression analysis, non-linear regression analysis

INTRODUCTION

Bamboo species are highly renewable biomass because these are fast growing. Compared with tree plantations, a bamboo plantation can be harvested within a much shorter period (Razal & Palijon, 2009). According to Liese (1999), bamboo in general has the potential of an energy cash crop in a sustainable agricultural farming system. Widenoja (2007) said that bamboo can be converted to charcoal to become a more efficient fuel. Lobovikov *et al.* (2007) stated further that charcoal from bamboo could compete in the charcoal market because of several reasons: a) bamboo grows faster and its rotation cycle is shorter compared to trees, b) the calorific and absorption properties of bamboo charcoal are similar to or better than wood charcoal, and c) it is easier and cheaper to produce. He added that bamboo contains 57% bio-oil, 22% charcoal, and 21% gas.

Kawayan tinik (*Bambusa spinosa* Roxb.) holds promise as an alternative biomass crop not only in the Philippines but also in other countries where this species grows. Studies of Rosario (2011) and Evangelista (2012) reported the potential of Kawayan tinik for bioenergy production, reporting a calorific value of 3,972 Kcal/kg up to 6,283 Kcal/kg. Kawayan tinik is one of the most important bamboo species in the Philippines and is well-distributed geographically in the country. Among its uses are as raw materials for construction, furniture, parquet, concrete reinforcements, kitchen utensils, chopsticks, hats, toys, papermaking, basketry, and farming implements (Mendoza *et al.* 2019). As cited by Virtucio & Roxas (2003), INBAR in 993 listed the top priority species for research and development through consultation with national experts from different countries.

Yield prediction modeling for tree species is well-explored (Zeng *et al.* 2017; Ubuy *et al.* 2018; Tetemke *et al.* 2019.), and models have already been established for several tree species. In the case of bamboo, most of the biomass determination studies conducted were for mature natural or artificial bamboo stands (Yen 2016). Huy *et al.* (2019) developed and validated a modeling system to estimate the aboveground biomass of

Bambusa procera A. Chev. & A. Camus in Vietnam using culm diameter at breast height and height as predictors. Li *et al.* (2016) also used these two predictors to estimate the aboveground biomass of *Bambusa stenostachya* Hack. Meanwhile, Xayalath *et al.* (2019) concluded that culm diameter at breast height is a practical explanatory variable that can be used to estimate the aboveground biomass of 11 commonly used bamboo species in Laos PDR. The same conclusion was also made by Yuen *et al.* (2017) in predicting the biomass of *Bambusa nutans* Wall. ex Munro in Thailand.

While vegetative growth of clumping bamboo has been documented (Banik 2015; Virtucio & Roxas 2003), there is little information about yield prediction models for young bamboo plantations, specifically for Kawayan tinik. Colis (1996) developed equations that could be used in predicting culm diameter, culm height, number of shoots, number of culms, clump diameter, and culm dry weight of mature Kawayan tinik plantation in Dumanjug, Cebu. Physiographic and edaphic variables were used to come up with the equations. Rosario (2011) also tried to develop yield prediction models for the natural stands of Kawayan tinik located in four different physiographic locations in Ilocos Norte. He concluded that clump diameter is an important factor in predicting the shoot, culm, and biomass yields of these stands. Furthermore, the edaphic and physiographic factors improved the equations developed for estimating the yields of the stands.

The main contribution of this study to the bamboo industry is the development of prediction models for different properties (clump and culm variables, aboveground dry biomass, chemical properties, and gross calorific values) of Kawayan tinik as a function of clump age. Kawayan tinik being a "multi-purpose" bamboo species would require appropriate plantation development and harvesting system. Biomass yield prediction studies will be very helpful in improving the harvesting system of Kawayan tinik. An idea of how much Kawayan tinik poles will be available for bioenergy production given a specific size of plantation after a certain period is essential in its sustainable utilization. In addition, studies looking into the properties of Kawayan tinik as affected by clump age and how it affects performance as an energy crop are still lacking. In order to use Kawayan tinik as raw material for energy production efficiently, it is essential to carry out a detailed characterization of its biomass. This can help promote Kawayan tinik plantations as bioenergy sources.

METHODOLOGY

Data gathering

The sample collection site was a Kawayan tinik plantation jointly established by the Ecosystems Research and Development Bureau (ERDB) of the Department of Environment and Natural Resources (DENR) and Fort Magsaysay Military Reservation (FMMR) in 2013. Six-month-old branch cuttings with two nodes were used as propagules in the plantation establishment. From the time of establishment until the completion of this study, no other harvesting of shoots and culms was conducted in the site. Shoot or culm mortality was not observed or recorded. Nine clumps were harvested over a three-year period, or three clumps per year. The age of the clump was based from the time of plantation establishment. Whole clump harvesting of one-year-old clumps was done in 2014, two-year-old clumps in 2015, and three-year-old clumps in 2016. After each harvest, the basal clump diameter, number of culms per clump, culm height, and culm diameter were measured for all sample clumps harvested for that year. Individual and total aboveground dry biomass of culms and branches+leaves samples were also determined and summarized. Culm and branches+leaves 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 gross calorific values (GCVs) were obtained using a Shimadzu bomb calorimeter following ASTM D 2015-96.

Data analysis and generation of prediction models

Analysis of variance and Kruskal-Wallis tests were done to determine if clump age has a significant effect on all the variables that were measured. Regression analysis with clump age as the independent variable was done to generate equations that can be used to predict the values of the following variables: clump diameter, culm number, culm height, culm diameter, culm, and branches+leaves dry biomass, fixed carbon, volatile matter, ash contents, and gross calorific values of culms and branches+leaves samples. Several functional forms of both independent and dependent variables were tested such as natural logarithmic, standardized, and untransformed values. Regression model that had the highest coefficient of determination (R^2), adjusted R^2 and low root mean square error (RMSE), and significant coefficients, was selected as the best fitting model for the prediction of each dependent variable.

Linear and non-linear regression models were tested to find the best model that fits the data. Models used were simple and multiple linear regression models and non-linear regression models specifically exponential (exp2, exp2a, exp3), logarithmic (log3, log4), and Gompertz (gom3, gom4). **Table 1** lists all the models tested in the study. Stata 15 software package was used in all the analyses conducted.

RESULTS AND DISCUSSION

Sample characteristics

Mendoza *et al.* (2019) characterized the aboveground biomass of Kawayan tinik clumps collected in the study site and its potential as a source of bioenergy. The paper also discussed the implications of the results and compared the data with other related studies. Different factors can affect the growth variability of bamboo. Overall, the clump's productivity is determined by site conditions (Tiongco 1997; Virtucio & Roxas 2003; Thapa & Aryal 2012), planting stocks quality (Thapa & Aryal 2012), and silvicultural treatments (Decipulo *et al*. 2009; Malab *et al.* 2009). Anthropogenic disturbances such as massive shoot harvesting (Razal *et al.* 2019) and other external factors like attack of pests and wild boars (Thapa & Aryal 2012) can also hinder the productive capacity of bamboo. Growth competition among culms within the same clump also affects the vigor of the culm and the mother clump as a whole (Darabant *et al.* 2016).

Based on the study conducted by Tiongco (1997), where he evaluated the performance of an eight-year-old Kawayan tinik plantation as affected by clump age and site productivity, the values gathered in this study were closer to the values collected in

Table 1. Regression models used in the study and its equation forms.

Regression Model	Equation
LINEAR	
Simple in double natural log form	$lny = ln\mathrm{a} + \mathrm{b}lnx$
(ln = transformed to natural log values) Multiple	$y = \mathrm{a} + \mathrm{b}_1\mathrm{x}_1 + \mathrm{b}_2\mathrm{x}_2$ $y = \mathrm{a} + \mathrm{b}_1\mathrm{x}_1 + \mathrm{b}_2\mathrm{x}_2 + \mathrm{b}_3\mathrm{x}_3$
Multiple in double natural log form (ln = transformed to natural log values)	$lny = ln\mathrm{a} + \mathrm{b}_1lnx_1 + \mathrm{b}_2lnx_2$ $lny = ln\mathrm{a} + \mathrm{b}_1lnx_1 + \mathrm{b}_2lnx_2 + \mathrm{b}_3lnx_3$
Multiple in standardized form (z = transformed to standardized values)	$zy = \mathrm{a} + \mathrm{b}_1zx_1 + \mathrm{b}_2zx_2 + \mathrm{b}_3zx_3$
NON-LINEAR	
Exponential	
exp2	$y = \mathrm{b}_1 * \mathrm{b}_2^x$
exp2a	$y = \mathrm{b}_1 * (1 - \mathrm{b}_2^x)$
exp3	$y = \mathrm{b}_0 + \mathrm{b}_1 * \mathrm{b}_2^x$
Logarithmic	
log3	$y = \dfrac{\mathrm{b}_1}{1+exp(-\mathrm{b}_2 * (x - \mathrm{b}_3))}$
log4	$y = \dfrac{\mathrm{b}_0 + \mathrm{b}_1}{1+ exp(-\mathrm{b}_2 * (x - \mathrm{b}_3))}$
Gompertz	
gom3	$y = \mathrm{b}_1 * exp(-\exp(-\mathrm{b}_2 * (x - \mathrm{b}_3)))$
gom4	$y = \mathrm{b}_0 + \mathrm{b}_1 * exp(-\exp(-\mathrm{b}_2 * (x - \mathrm{b}_3)))$

a marginally productive site in Bukidnon. Nevertheless, total comparison was not feasible since the study sites differed in age and in other factors that could affect Kawayan tinik's growth.

Table 2 lists the mean values of the different clump and culm variables measured for each sample clump. As expected, average basal clump diameter was smallest in one-year-old clumps (20.18 ± 2.11 cm) and largest in three-year-old clumps (52.51 ± 9.43 cm), as the differences were statistically significant. Mean culm number per clump is lowest in two-year-old clumps (8 ± 1.00 culms) and highest in three-year-old clumps (16 ± 3.51 culms). As bamboo grows older, more culms are produced until a certain age where the clump no longer bears new shoots, depending on the site conditions and clump management (Virtucio & Roxas 2003). Shoot or culm mortality also influences the number of culms in a clump, but this was not recorded during the yearly visits because of the difficulty in ascertaining the evidence for such, especially for shoots that perish during emergence. Culm height followed the trend of basal clump diameter, significantly increasing from one-year-old (1.79 ± 0.22 m) to three-year-old clumps (4.97 ± 0.60 m). Culm diameter values of one-, two-, and three-year-old clumps followed the trend observed in basal clump diameter and culm height. Lowest mean culm diameter was recorded for one-year-old clumps (1.62 ± 0.31 cm) and highest mean was from three-year-old clumps (2.44 ± 0.17 cm).

Bamboo in general is known to have high carbon sequestration ability (Lobovikov *et al.* 2012; Nath *et al.* 2015; Yuen *et al.* 2017). Because it is a fast-growing species, it needs a large volume of carbon to support its rapid development. Yen (2016) stated that the growth of bamboo has two distinct phases. Abrupt culm height growth constitutes the first phase while the second phase is all about increase in culm strength and biomass accumulation. Table 1 summarizes the mean individual culm and the corresponding branches+leaves dry biomass per clump and the total aboveground dry biomass of one-, two-, and three-year-old clumps. Lowest average culm (0.18 ± 0.07 kg) and branches+leaves (0.21 ± 0.08 kg) dry weights were recorded for one-year-old clumps. On the average, total aboveground dry biomass of one-year-old clumps was composed of 1.31 ± 0.36 kg culms and 1.56 ± 0.36 kg branches+leaves. Individual culms of three-year-old clumps and the corresponding branches+leaves were found to have the highest dry biomass. Mean dry biomass of each culm weighed 4.53 ± 1.19 kg while its corresponding branches+leaves weighed 1.29 ± 0.13 kg. Total aboveground dry biomass of three-year-old clumps consisted of 80.75 ± 66.99 kg of culms and 20.90 ± 9.29 kg of branches+leaves. Widjaja (2020) reported that one-year old bamboo plantations are already suitable for biomass for energy production.

Table 3 shows the chemical properties of the samples. Scurlock *et al.* (2000) reported that as bamboo grows older, fixed carbon content decreases. On average, fixed carbon content of culm samples was smallest in two-year-old clumps (17.99 ± 0.05 %) and largest in one-year-old clumps (27.08 ± 0.50 %). Lowest fixed carbon content was recorded for branches+leaves samples from three-year-old clumps (17.13 ± 0.43 %) while highest fixed carbon content was recorded for branches+leaves samples from one-year-old clumps (26.86 ± 0.68 %). Ganesh (2003) gathered

Table 2. Mean clump and culm variables and dry biomass of culms and branches+leaves samples of one-, two-, and three-year-old Kawayan tinik clumps.

Year of harvest	Clump age	Basal clump diameter (cm)	Culm number per clump (pc)	Culm height (m)	Culm diameter (cm)	Dry weight of individual culm (kg)	Dry weight of corresponding branches+ leaves per culm (kg)	Total above-ground dry culm biomass per clump (kg)	Total above-ground dry branches + leaves biomass per clump (kg)
2014	1	$20.18^{a} \pm 3.65$	$8.67^{ns} \pm 3.21$	$1.79^{a} \pm 0.39$	$1.62^{ns} \pm 0.54$	$0.18^{a} \pm 0.07$	$0.21^{a} \pm 0.08$	$1.31^{a} \pm 0.36$	$1.56^{a} \pm 0.36$
2015	2	$24.80^{a} \pm 0.75$	$8.00^{ns} \pm 1.73$	$4.51^{b} \pm 1.59$	$2.39^{ns} \pm 0.57$	$2.15^{b} \pm 1.01$	$1.17^{b} \pm 0.31$	$16.3^{b} \pm 11.49$	$9.00^{b} \pm 3.20$
2016	3	$52.51^{b} \pm 16.34$	$16^{ns} \pm 6.08$	$4.97^{b} \pm 1.04$	$2.44^{ns} \pm 0.29$	$4.53^{c} \pm 1.19$	$1.29^{b} \pm 0.13$	$80.75^{c} \pm 66.99$	$20.90^{c} \pm 9.29$

Table 3. Mean fixed carbon, volatile matter, ash content percentages (dry weight basis), and gross calorific values of culms and branches+leaves samples of one-, two-, and three-year-old Kawayan tinik clumps.

Year of harvest	Clump age	Fixed carbon of culms (%)	Fixed carbon of branches+ leaves (%)	Volatile matter of culms (%)	Volatile matter of branches+ leaves (%)	Ash content of culms (%)	Ash content of branches+ leaves (%)	Gross calorific value of culms (kcal/kg)	Gross calorific value of branches+leaves (kcal/kg)
2014	1	$27.08^{a} \pm 0.87$	$26.86^{a} \pm 1.17$	$71.48^{a} \pm 1.34$	$66.31^{a} \pm 1.25$	$1.44^{ns} \pm 0.57$	$9.09^{a} \pm 0.96$	$4{,}166.67^{a} \pm 10.71$	$3{,}945.67^{ns} \pm 7.22$
2015	2	$17.99^{b} \pm 0.08$	$21.30^{b} \pm 0.92$	$79.89^{b} \pm 0.55$	$69.62^{ab} \pm 1.84$	$2.12^{ns} \pm 0.49$	$6.84^{ab} \pm 1.88$	$4{,}032.00^{b} \pm 16.80$	$3{,}979.33^{ns} \pm 7.36$
2016	3	$19.80^{b} \pm 0.90$	$17.13^{c} \pm 0.74$	$77.73^{b} \pm 1.23$	$70.30^{b} \pm 0.95$	$2.47^{ns} \pm 0.37$	$12.57^{b} \pm 1.37$	$4{,}377.33^{a} \pm 12.99$	$4{,}031.00^{ns} \pm 15.01$

lower values of fixed carbon for several bamboo culm species compared to the results of this study. Volatile matter of culms was lowest in one-year-old clumps (71.48 ± 0.77 %) and highest in two-year-old clumps (79.89 ± 0.32 %). Similar to the trend observed for culms, volatile matter of branches+leaves samples was also lowest in one-year-old clumps (66.31 ± 0.72 %) while branches+leaves samples of three-year-old clumps had the highest volatile matter (70.30 ± 0.55 %). Culms appeared to have higher volatile matter than its combined branches and leaves. Ganesh (2003) reported slightly higher values for the volatile matter of several bamboo culms, while Sadiku *et al.* (2016) reported higher values for the volatile matter of *Bambusa vulgaris* Schrad. culms. Lowest mean for ash content percentages of culms (1.44 ± 0.33 %) and branches+leaves samples (6.84 ± 1.09 %) were recorded for one-year-old clumps while culms (2.47 ± 0.21 %) and branches+leaves samples (12.57 ± 0.79 %) from three-year-old clumps were found to have the highest ash content percentages. It was evident that the ash content of Kawayan tinik's branches+leaves was higher than the ash content of its culms. Bamboo leaves have high silica content (17-23%) according to Silviana & Bayu (2018).

Table 3 also shows the gross calorific values of the culms and branches+leaves samples of the three clump ages. Gross calorific values of branches+leaves samples increased from one-year-old (3,945.67 ± 7.22 kcal/kg) to three-year-old clumps (4,031± 15.01 kcal/kg). Culm samples exhibited a different trend since lowest GCV was recorded for two-year-old clumps (4,032 ± 16.80 kcal/kg) and highest mean value was obtained from three-year-old clumps (4,377.33 ± 12.99 kcal/kg). Several factors might have influenced these results, as mentioned earlier. The different culm ages sampled in two- and three-year-old clumps can also be one of the reasons for the variability of GCVs (Mendoza *et al.* 2019). Dransfield & Widjaja (1995) reported that the energy value of Kawayan tinik is 120 kJ/100g. Evangelista (2012) observed that the internodes of Kawayan tinik has higher GCV (4,161 Kcal/kg) compared to its nodes (3,972 Kcal/kg). In comparison to *B. vulgaris*, the values reported in this study were still higher than the results of the study of Sadiku *et al.* (2016).

Generation of prediction models

Proper management of Kawayan tinik plantations helps in minimizing operational costs and maximizes the derived benefits. Tools like prediction models are important to managers to ensure the sustainability of the plantations. Models are helpful in culm selection and yield estimation of a stand without harvesting the culms. In this study, linear and non-linear models (exponential, logarithmic, and Gompertz) were tested to generate the best model that can predict the variables important in making management decision. All variables were also transformed to two different forms (standardized, double natural logarithmic) to improve the fit of the tested equations. Most of the studies that tried to develop prediction equations for several bamboo parameters used a linear form (Rosario (2011), Muchiri & Muga (2013), Singnar *et al.* (2015). However, Paine *et al.* (2011) cited that the best way to accommodate temporal variation in growth rates is with nonlinear growth models, since linear models have limiting utility by assuming constant absolute growth rate.

Table 4 presents the summary of generated equations for predicting all the variables included in the study with clump age as the independent variable. During the conduct of regression analysis, it was observed that running gom3 and log3 models takes a long time before converging, thus, these were eliminated from the list of models that were tested. It should be pointed out that these models apply only to Kawayan tinik plantations established using branch cuttings, with same age and similar growing conditions. It is also important to note that only few studies dealt with the prediction of the properties of Kawayan tinik as a function of clump age, hence, limited comparisons were made in this part of discussion.

Clump and culm variables. For the prediction of basal clump diameter in one-, two-, and three-year-old Kawayan tinik clumps, the best fit model turned out to be the exp2 equation, with an R^2 of 0.944 and adjusted R^2 value of 0.929. The coefficients b1 and b2 also appeared to be significant with p-values 0.04 and 0.00, respectively. Root mean square error is also acceptable. Result of the analysis of variance also showed the goodness of fit of the model for predicting the basal clump diameter of Kawayan tinik clumps (p-value = 0.0000).

Similar to basal clump diameter, the best fit equation to predict culm number per clump was the exp2 equation, since the R^2 value was high (0.901) as well as the adjusted R^2 (0.873). The p-values of the coefficients were also within acceptable significance range. Root mean square error was also small. Result of the analysis of variance also showed the goodness of fit of the model for predicting culm number per clump of Kawayan tinik (p-value = 0.003). Rosario (2011) also developed a linear prediction model for total number of culms per clump of naturally growing Kawayan tinik in Ilocos Norte, Philippines. He cited that basal clump diameter, physiographic (slope, aspect), and edaphic (phosphorus, organic matter) factors influenced the total number of culms in Kawayan tinik clumps. Kumar *et al.* (2005) also developed a linear model to predict the total number of culms per clump of *Bambusa bambos* (L.) Voss in India. He used clump diameter at breast height to predict this variable.

Table 4. Summary of generated equations for predicting all the variables included in the study with clump age as the independent variable.

Variable	Equation	R^2	RMSE
Basal clump diameter (cm)	$clumpdia = 9.303 * 1.767^{clump\ age}$	0.9444	9.725
Culm number per clump	$culmno = 4.714 * 1.478^{clump\ age}$	0.9285	4.259
Culm height (m)	$culmht = 1.677 * 1.466^{clump\ age}$	0.924	1.150
Culm diameter (cm)	$culmdia = 1.483 * 1.197^{clump\ age}$	0.924	0.456
Culm fixed carbon (%)	$culmfc = 19.928 * 1.334^{clump\ age}$	0.998	1.014
Culm volatile matter (%)	$culmvm = 79.066 * 0.907^{clump\ age}$	0.999	1.713
Culm ash content (%)	$culmash = 2.781 * 0.516^{clump\ age}$	0.962	0.466
Branches+leaves fixed carbon (%)	$branchfc = 33.611 * 0.798^{clump\ age}$	0.9987	0.894
Branches+leaves volatile matter (%)	$branchvm = 70.079 * 0.946^{clump\ age}$	0.9997	1.311
Branches+leaves ash content (%)	$branchash = 4.965 * 1.361^{clump\ age}$	0.9855	1.348
Culm GCV (Kcal/kg)	$culmgcv = 3981.755 * 1.026^{clump\ age}$	0.993	129.452
Branches+leaves GCV (Kcal/kg)	$branchfc = 3781.606 * 1.011^{clump\ age}$	0.9996	378.883

Regression analysis for culm height tested the six models mentioned above, and all these models converged. All the R^2 and adjusted R^2 were within acceptable range, however, some coefficients have p-values that were not significant, hence these models were not considered as the best fit model in predicting culm height. The exponential form exp2 appeared to be the best fit model, since its R^2 was high (0.924) as well as its adjusted R^2 (0.902), and the p-values of the coefficients (b1 = 0.038, b2 = 0.00) were also significant at $\alpha = 0.05$. Root mean square error was also small. Result of the analysis of variance also showed the goodness of fit of the model for predicting the culm height of Kawayan tinik clumps with p = 0.0001. The study of Rosario (2011) generated equation for average culm height prediction of culms from naturally growing Kawayan tinik clumps. He stated that clump diameter, elevation, slope, and soil organic matter affect the height of the culms. Singnar *et al.* (2015) also developed a model to predict culm height of *Meloccana baccifera* (Roxb.) Kurz bamboo species in India, with culm diameter at breast height influencing the height of the culms. Das *et al.* (2015) also reported the same variable affecting the culm height of *Schizostachyum dullooa* (Gamble) R.B. Majumdar. Yen (2016) also had the same findings for *Phyllostachys pubescens* J. Houz.

The best fit model in predicting culm diameter was still the exp2 model since its R^2 is high (0.961) as well as its adjusted R^2 (0.950), and the p-values of the coefficients (b1 = 0.00, b2 = 0.003) were significant at $\alpha = 0.05$. Root mean square error was also acceptable. Result of the analysis of variance also showed the goodness of fit of the model for predicting the culm diameter of Kawayan tinik clumps with p = 0.0000. Most of the studies used culm diameter as a predictor in the generation of models, not as a dependent variable. Only few studies predicted the culm diameter of bamboo. Rosario (2011) stated that the factors that can be used to predict the average diameter of Kawayan tinik culms from natural stands are clump diameter, slope, elevation, and soil pH.

Chemical properties. Regression model runs to predict the fixed carbon content of the culms from one-, two-, and three-year old clumps results to convergence of all models except exp3. However, not all the models that fitted the data can be considered in the prediction of the fixed carbon present in the culms since only two of the models that converged yielded high R^2 and adjusted R^2 values, with low root mean square error and significant p-values of the coefficients. Both exp2 and exp2a models can be used to predict fixed carbon, but exp2a was better since it has higher high R^2 and adjusted R^2 values and lower root mean square error compared to exp2 model. Result of the analysis of variance also showed the goodness of fit of the model for predicting the fixed carbon content of Kawayan tinik culms with p = 0.0000.

Similar to the regression analysis for fixed carbon, all the models converged in the prediction of culm volatile matter except for exp3. Both exp2 and exp2a models can be used to predict culm volatile matter, since these two models yielded high R^2 and adjusted R^2 values, low root mean square error, and significant p-values of the coefficients, but exp2a was better because it has a lower root mean square error. Result of the analysis of variance also showed the goodness of fit of the model for predicting the volatile matter of Kawayan tinik culms with p = 0.0000.

For ash content, all six models converged but exp2a was considered to be the best fit model since it has the highest R^2 and adjusted R^2 values, lowest root mean square error, and significant p-values of the coefficients. Result of the analysis of variance also showed the goodness of fit of the model for predicting the ash content of Kawayan tinik culms with p = 0.0000.

Regression model runs to predict the fixed carbon of the branches+leaves samples from one-, two-, and three-year old clumps resulted to convergence of all models with high R^2 and adjusted R^2 values. However, only the coefficients of the exp2, exp2a, and double log models were significant at $\alpha = 0.05$. From these three models, exp2 yielded the highest R^2 and adjusted R^2 values and a relatively lower root mean square; thus, it was considered to be the best model to predict the fixed carbon of the branches+leaves samples of one-, two-, and three-year old clumps. Result of the analysis of variance also showed the goodness of fit of the model for predicting the fixed carbon content of combined Kawayan tinik branches and leaves with p = 0.0000.

Similar to the regression analysis for branches+leaves' fixed carbon, all the models used to predict the volatile matter of branches+leaves converged and resulted to acceptable R^2 and adjusted R^2 values, but only the coefficients of the exp2, exp2a, and double log models were significant at $\alpha = 0.05$. Root mean square error of the double log model was relatively lower compared to the exponential models, but its R^2 and adjusted R^2 values were also smaller. Both exp2 and exp2a models can be used to predict the volatile matter of branches and leaves, since these two models yielded high R^2 and adjusted R^2 values, low root mean square error, and significant p-values of the coefficients, but exp2a was better because of its lower root mean square error and slightly higher R^2 and adjusted R^2 values. Result of the analysis of variance also showed the goodness of fit of the model for predicting the volatile matter of combined Kawayan tinik branches and leaves with p = 0.0000.

Regression model runs to predict the ash content of the branches+leaves samples from one-, two-, and three-year old clumps resulted to convergence of all six models, but exp2 is considered to be the best fit model since it has the highest R^2 and adjusted R^2 values, low root mean square error, and significant p-values of the coefficients. The double log model had the lowest root mean square error, but its R^2 and adjusted R^2 values were lower than the exp2 model. Result of the analysis of variance also showed the goodness of fit of the model for predicting the ash content of combined Kawayan tinik branches and leaves with p = 0.0000.

Gross calorific value. Results of the regression model runs to generate the best fit model in predicting culm and branches+leaves gross calorific values showed that only exp2 and exp2a models resulted to high R^2 and adjusted R^2 values; hence, it can be considered as probable models to predict the gross calorific value of culms and branches from one-, two-, and three-year-old clumps. Between these two models, exp2 got higher R^2 and adjusted R^2 values, lower root mean square error, and yielded significant coefficients, hence, it was the best fit model to predict culm and branches+leaves gross calorific values. Result of the analysis of variance also showed the goodness of fit of the model for predicting the gross calorific values of Kawayan tinik culms and branches+leaves with p = 0.0000.

Aboveground dry biomass yield prediction models

Most of the prediction models developed for estimating aboveground biomass in general use culm diameter at breast height as a predictor, just like the allometric equations in predicting the biomass of trees. However, unlike tree biomass, the height variable is not commonly used in the prediction of bamboo biomass since according to Huy *et al.* (2019), height is difficult to apply since height is difficult to measure because of culm density. Culm dry weight of *B. bambos* was predicted by Kumar *et al.* (2005) using linear regression with the log transformed culm diameter at breast height as the predictor. Muchiri & Muga (2013) also cited that culm merchantable oven-dry weight of *Yushania alpina* (K. Schum.) W.C. Lin can be predicted by using culm diameter at breast height and culm green weight as predictors. Rosario (2011) reported that clump diameter and soil pH affect the total culm biomass of a Kawayan tinik clump. Yen (2016) stated that culm biomass can also be predicted using its culm diameter at breast height. Only a few studies dealt with predicting biomass yield of bamboo branches and leaves. Huy *et al.* (2019) stated that biomass of these bamboo plant parts is very hard to predict using empirical models. Values of the coefficient of determination usually range between 0.5–0.6 only (Huy *et al.* 2019, Yen *et al.* (2010). Still, they developed a model to predict the biomass of the branches and leaves of *B. procera* using culm diameter at breast height.

Multiple regression analysis using double natural logarithmic, standardized, and untransformed values of the variables was conducted to generate dry biomass yield prediction models for the plantation. The variables tested to predict culm and branches+leaves dry biomass were clump age, culm number per clump, culm height, and culm diameter. However, not all of these variables were included in the equation since its p-values were not significant, and the variance inflation factor of the variables were high that it denotes multicollinearity. These variables should be eliminated to generate a sound model. As discussed in the previous sections, most of the models developed to predict bamboo biomass used culm diameter at breast height as the sole predictor. **Table 5** shows the summary of the regression analysis done for culm and branches+leaves dry biomass.

Culm dry biomass appeared to be significantly affected by culm diameter and culm number per clump, with culm diameter having a higher influence over culm number per clump. All the three runs of multiple regression analysis models for the prediction of culm biomass have high R^2. However, regression analysis of standardized values (z variables) resulted to insignificant p-value for the constant coefficient; thus, this was not considered as the best model for the prediction of culm biomass. Both untransformed and double natural logarithmic values yielded significant results for the p-values of the three coefficients, high R^2 and adjusted R^2, and mean variance inflation factor that was near or almost equal to 1. On the other hand, root mean square

Table 5. Summary of the best fit model for the prediction of Kawayan tinik culm and branches+leaves dry biomass.

Variable	Coefficients	p-VALUE	95% Confidence Interval
Culm dry biomass (kg)			
Equation form: $lny = lna + b_1lnx_1 + b_2lnx_2$			
lnculmno	2.245	0.002	1.215 – 3.279
lnculmdia	4.715	0.000	3.171 – 6.259
Constant	-6.255	0.001	-8.854 – -3.656
Mean VIF = 1.00	R^2 = 0.937	Adj. R^2 = 0.916	Root MSE = 0.522
Branches+leaves dry biomass (kg)			
Equation form: $lny = lna + b_1lnx_1 + b_2lnx_2 + b_3lnx_3$			
lnclumpage	1.426	0.002	0.826 – 2.025
lnculmno	0.490	0.046	0.012 – 0.969
lnculmdia	1.596	0.004	0.773 – 2.419
Constant	-1.291	0.043	-2.524 – -0.058
Mean VIF =2.78	R^2 = 0.988	Adj. R^2 = 0.980	Root MSE = 0.164

error of the natural double logarithmic values were much lower compared to that of the untransformed values. Consequently, coefficients generated from the regression analysis of the double natural logarithmic values appeared to be the best fit model for the prediction of culm dry biomass.

Results of the multiple regression analysis suggest that clump age, culm number per clump, and culm diameter significantly affect branches+leaves dry biomass. Double natural logarithmic and untransformed values were also used to generate prediction models using multiple regression analysis. All the three runs of the values used gave high R^2 and adjusted R^2values, but similar to the prediction of culm biomass, the constant coefficient generated using z variables resulted to insignificant p-value; hence, generated equation using these values was not considered as the best fitting model to predict branches+leaves dry biomass.

Both untransformed and double natural logarithmic values yielded significant results for the p-value of the four coefficients, high R^2, and adjusted R^2 and mean variance inflation factor that was slightly higher than 1. On the other hand, root mean square error of the double natural logarithmic values were much lower compared to that of the untransformed values. Also, using the untransformed values, the generated p-value of the clump age coefficient was 0.059, which was higher than the traditional 0.05. This makes the regression coefficients of the double natural logarithmic values regression analysis a better fit than the analysis of untransformed values.

CONCLUSION

Prediction models with high R^2, adjusted R^2, low root mean square error, and coefficients that have significant values were generated for all variables. This implies that these prediction models can be used to estimate the variables included in the study given the same clump age and conditions in the site. In general, all the variables appeared to be positively correlated with clump age. Among the models used, the exponential model fitted most of the data, specifically the exp2 model, followed by exp2a, and then the linear regression model. Basal clump diameter, culm number per clump, culm height, culm diameter, fixed carbon and ash content, culm and branches+leaves gross calorific values fitted best with the exp2 model. Fixed carbon, volatile matter and ash content of Kawayan tinik culms, and volatile matter of branches+leaves can be predicted by the exp2a model.

In terms of dry biomass, multiple linear regression model in double natural logarithmic form showed that culm number per clump and culm diameter are important variables in estimating culm dry biomass. Branches+leaves dry biomass can be predicted by culm number per clump, culm diameter, and clump age.

For greater accuracy and precision, it is highly recommended to increase the sampling size in conducting similar activities in the future. Preliminary information about the planting stocks used, culm mortality rate, and more accurate climatic and edaphic data should also be reported. Tagging should also be done to identify the different ages of the culms present in the clump. Models generated can be used in estimating the different variables measured in this study, provided that similar clump age, planting stocks used, and site conditions prevail in the plantation where the models will be applied. Models to be generated should be validated to test the accuracy of the equations developed.

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