

# Response surface methodology to simplify calculation of wood energy potency from tropical short rotation coppice species

M T Haqiqi, Yuliansyah, W Suwinarti and R Amirta\*

Faculty of Forestry, Mulawarman University. Jl. Ki Hajar Dewantara, Samarinda, East Kalimantan, Indonesia

\*Corresponding Author: r\_amirta@yahoo.com

**Abstract.** Short Rotation Coppice (SRC) system is an option to provide renewable and sustainable feedstock in generating electricity for rural area. Here in this study, we focussed on application of Response Surface Methodology (RSM) to simplify calculation protocols to point out wood chip production and energy potency from some tropical SRC species identified as *Bauhinia purpurea*, *Bridelia tomentosa*, *Calliandra calothyrsus*, *Fagraea racemosa*, *Gliricidia sepium*, *Melastoma malabathricum*, *Piper aduncum*, *Vernonia amygdalina*, *Vernonia arborea* and *Vitex pinnata*. The result showed that the highest calorific value was obtained from *V. pinnata* wood ( $19.97 \text{ MJ kg}^{-1}$ ) due to its high lignin content (29.84 %, w/w). Our findings also indicated that the use of RSM for estimating energy-electricity of SRC wood had significant term regarding to the quadratic model ( $R^2 = 0.953$ ), whereas the solid-chip ratio prediction was accurate ( $R^2 = 1.000$ ). In the near future, the simple formula will be promising to calculate energy production easily from woody biomass, especially from SRC species.

## 1. Introduction

Nowadays, the worldwide energy consumption is constantly growing and the utilization of primary fossil energy sources is already approaching their natural limits however mostly fossil-fuel based energy generation is linked with emissions of large quantities of pollutants, causing serious negative environmental effects [1]. Every year, the combustion of fossil fuels produces around 21.3 billion tonnes of  $\text{CO}_2$  [2]. Bioenergy, a promising alternative to substitute fossil fuel, is the largest contributor in the world to the renewable and sustainable energy sector, and it plays a significant role in various energy industries, such as heating and cooling, electricity and power, and transportation fuel [3].

Biomass is one of the most important sources to increase the production of energy based on renewable energy sources [4]. Biomass is largely developed, by representing 10.4 % of the world's total primary energy supply or 77.4 % of global renewable energy supply [5]. As a country which is located on the equator, Indonesia has big opportunity in the forest biomass resources utilization. Forest also contains biomass diversity richness associated in various community forest and is potential for energy feedstock. Moreover, Yuliansyah [6] explained that wood of waste biomass from the logging activities and other residues are also potential for generating electricity. According to the previous report [7], power generation using short rotation coppice (SRC) species as energy feedstock was suggested. Its sustainable system can support the government policies to increase bioenergy sector for prosperities in the remote area. Some SRC species such as poplar (*Populus* spp), willow (*Salix* spp), *Acacia* spp and *Eucalyptus* spp have been grown and developed in many countries in the World



[8]. However, there is no list about SRC species implementation in forest plantation for energy production in Indonesia as far.

Many techniques and formulas to determine the energy potency from wood biomass were previously introduced [9,10]. However, the simple formula is more promising for searching and establishing the potential feedstock for short rotation coppice cultivation. The aim of this study is to promote a new alternative method for calculating energy-electricity from quadratic model of response surface methodology. Further, we also analyzed their wood chemical composition. We suggest that using new methods will be able to give a great option for easy calculation for wood electricity generation application in the near future.

## 2. Materials and Method

### 2.1. Short rotation coppice wood biomass

Some tropical short rotation coppice species which were potentially to be utilized for feedstock of electricity production particularly in remote area including *Bauhinia purpurea* var. *corneri* de Wit., *Bridelia tomentosa* Blume, *Calliandra calothyrsus* Meissner, *Fagraea racemosa* Jack ex Wall., *Gliricidia sepium* (Jacq.) Kunth ex Walp., *Melastoma malabathricum* L., *Piper aduncum* L., *Vernonia amygdalina* Delile, *Vernonia arborea* Buch.-Ham., and *Vitex pinnata* (L.) Kuntze were used in this study. The collected wood samples were debarked, chipped, air dried and powdered.

### 2.2. Wood chemical properties and energy analysis

The TAPPI standard method [11] was used to determine the klason lignin content from the wood. The holocellulose and  $\alpha$ -cellulose content were also determined according to Wise's chlorite method [12] and the TAPPI standard method [13]. In addition, the wood moisture content and their calorific value were analyzed using ASTM [14] D 7582-12 and ASTM D 5865-123, respectively. The equation proposed by Francescato [10] was used to calculate energy potency and wood chip production.

### 2.3. Experimental design

Response surface methodology (RSM) was used to modify and simplify the formula of energy potency, especially for the simple measurement from short rotation coppice wood species. The wood density (A) and moisture content (B) were chosen as potential factors with two levels (-1, +1). The experimental design with the total of 16 trials was generated by D-optimal design on Design expert® 7.0.0 software. The calculation technically used adding random calorific value from each wood coppice species. The interaction of two factors was investigated and displayed by Analysis of Variance (ANOVA).

## 3. Results and Discussion

### 3.1. Wood Chemical properties and calorific value

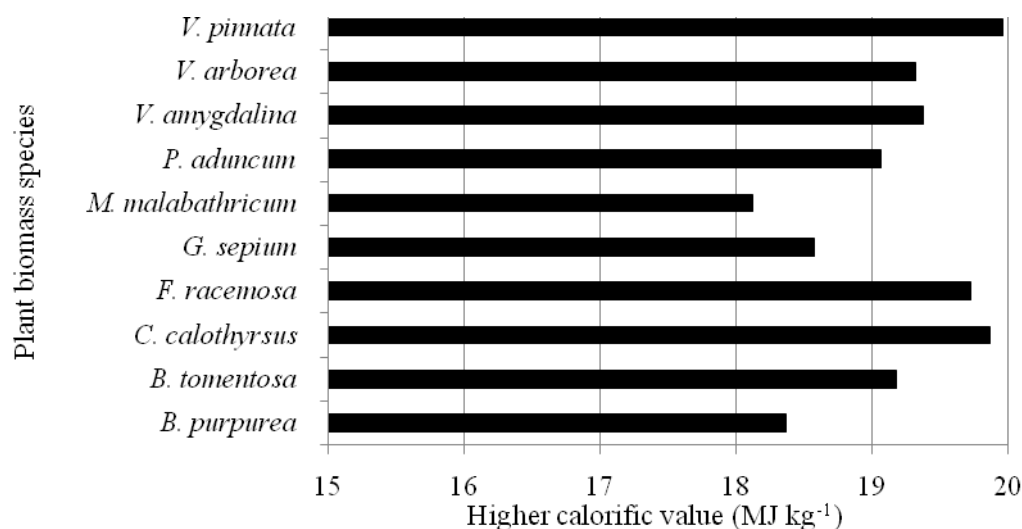
The preliminary analysis on suitability of 10 selected Short Rotation Coppice (SRC) species as materials for green electricity production was done by evaluation of their wood chemical composition. The amount of holocellulose, cellulose and lignin were discussed. We found that the highest holocellulose content was obtained from *B. tomentosa* (78.99 %) followed by *M. malabathricum* (78.04 %), *C. calothyrsus* (76.94 %), *F. racemosa* (76.22 %) and *V. amygdalina* (74.91 %). On the other hands, we also found that the lowest cellulose content was obtained from *P. aduncum* (41.69 %). According to the value, the other tropical woody SRC species contained cellulose content higher than some clones of willow SRC planted in Japan [15]. Moreover, we also found that the highest proportion of lignin content was obtained from *V. pinnata* (29.84 %) followed by *V. arborea* (29.64 %), *B. purpurea* (28.89 %), *G. sepium* (26.17 %) and *C. calothyrsus* (25.09 %). The examined wood chemical compositions have similar result with other tropical fast growing woody species previously

studied [16]. The wood biomass composition depends on various factors such as plant species, soil conditions, climate and competition [17,18].

**Tabel 1.** Chemical component of wood from some tropical short rotation coppice species.

No	Plant biomass species		Holocellulose (%)	Cellulose (%)	Lignin (%)
	Latin name	Local name			
1	<i>B. purpurea</i>	Daun kupu-kupu	73.40 ± 0.35	51.51 ± 0.12	28.89 ± 0.86
2	<i>B. tomentosa</i>	Berduri	78.99 ± 0.86	53.83 ± 1.16	21.49 ± 0.52
3	<i>C. calothyrsus</i>	Kaliandra	76.94 ± 0.27	50.74 ± 0.10	25.09 ± 0.01
4	<i>F. racemosa</i>	Kopi-kopian	76.22 ± 1.03	52.25 ± 1.67	23.55 ± 0.09
5	<i>G. sepium</i>	Gamal	73.91 ± 1.30	44.07 ± 1.83	26.17 ± 0.01
6	<i>M. malabathricum</i>	Karamunting	78.04 ± 0.69	45.56 ± 0.92	20.79 ± 0.62
7	<i>P. aduncum</i>	Sirih hutan	72.82 ± 0.33	41.69 ± 0.71	23.77 ± 0.17
8	<i>V. amygdalina</i>	Sambung nyawa	74.94 ± 0.71	44.19 ± 0.23	24.17 ± 1.50
9	<i>V. arborea</i>	Hamirung	71.98 ± 1.57	49.37 ± 1.79	29.64 ± 0.09
10	<i>V. pinnata</i>	Laban	72.15 ± 0.72	44.87 ± 0.30	29.84 ± 0.11

The gross calorific value among 10 SRC species had been published at the previous paper [7]. In this paper, we analyzed the Higher Calorific Value (HCV) produced during their wood combustion process of each biomass plant species. The highest HVC was obtained from *V. pinnata* wood (19.96 MJ kg<sup>-1</sup>), whereas the lowest HCV was obtained from *M. malabathricum* wood (18.12 MJ kg<sup>-1</sup>). Generally, lignin content influences the obtaining calorific value from combustion of woody biomass. The highest lignin content strongly contributed to the higher calorific value of *V. pinnata* while *M. malabathricum* was the lowest from those plant species. These findings were also in line with the previous report [19,20].



**Figure 1.** Higher calorific value of wood from some tropical short rotation coppice species

### 3.2. Experimental design

The wood density and moisture content of 10 SRC plant species was analyzed on our previous report [7]. However, the results of wood density and moisture content measurement were used as variables in this study to simplify common calculation of energy potency and wood chip production using

Response Surface Methodology (RSM). Response surface plot was displayed (Figure 2) with the generated formula as follows:

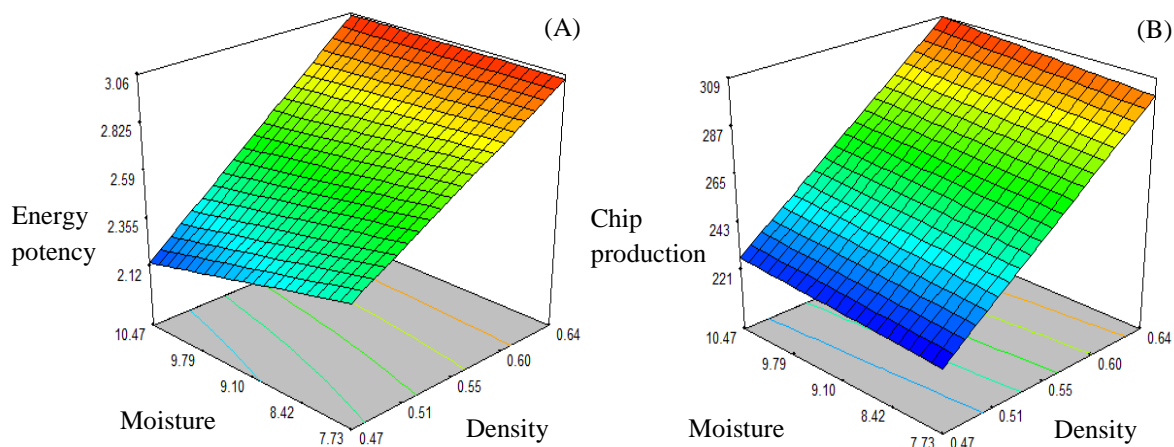
$$Y_A = 3.647 - 1.032 A - 0.386 B + 0.614 AB \quad (1)$$

$$Y_B = 436.719 A + 4.36719 AB \quad (2)$$

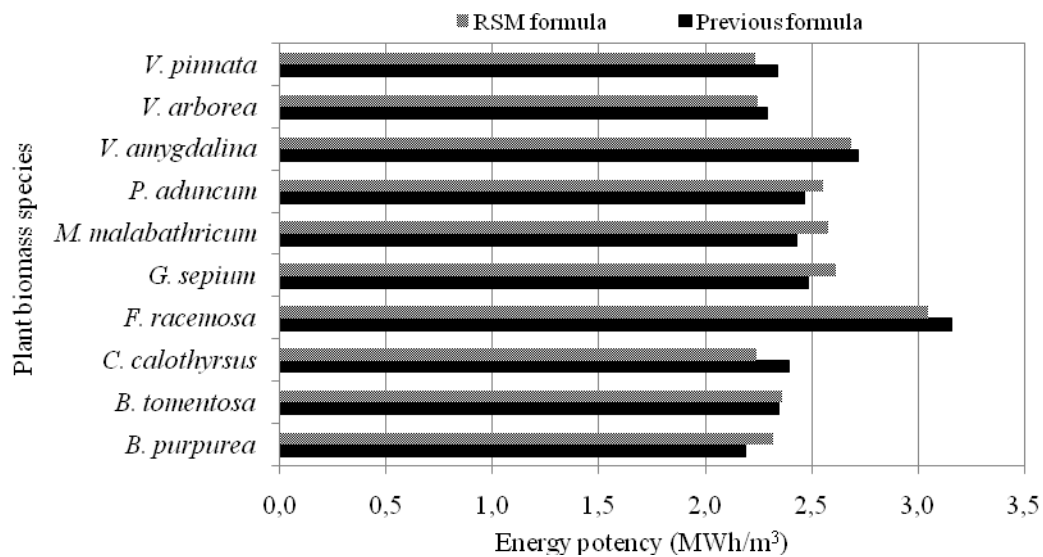
Where  $Y_A$  is wood energy potency (MWh/m<sup>3</sup>),  $Y_B$  is wood chip production (kg/m<sup>3</sup>),  $A$  is wood density (g/cm<sup>3</sup>), and  $B$  is wood moisture content (%).

This model fitted the data with  $R^2$  value equal to 0.962 and 1.000 for the response of energy potency and wood chip production, and the predicted  $R^2$  value for the same response were 0.953 and 1.000, respectively. In this case, interaction of  $A$  and  $B$  was in significant terms. The quadratic model was evaluated using ANOVA for analyzing the effects of the factors on the response. The  $p$ -values which was lower than an  $\alpha$ -level of 0.05 indicated that the quadratic model was also significant. The linear terms were significant for model and it was mean that the variables had an important influence on the energy potency and wood chip production.

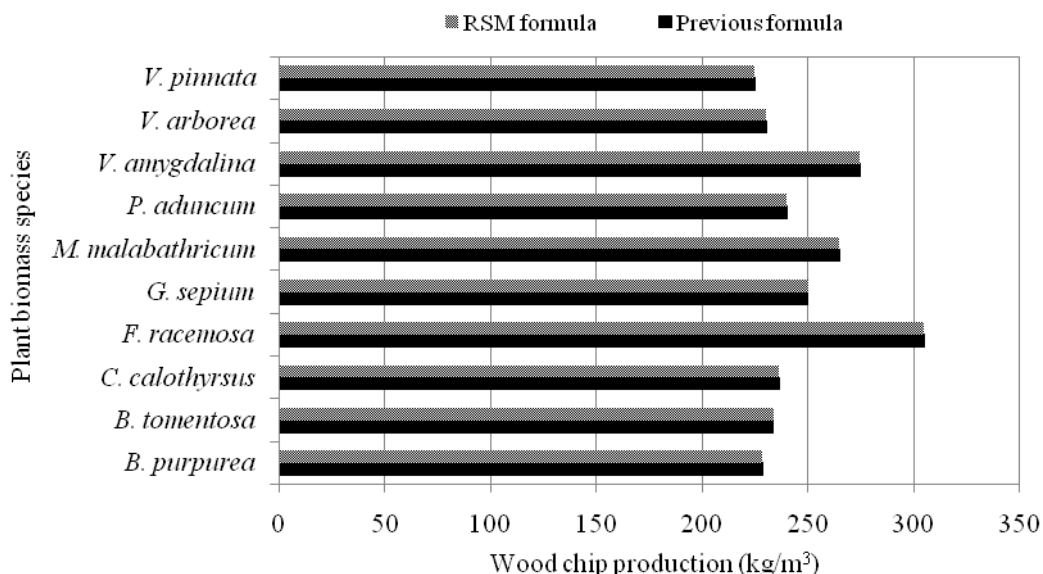
The formula was used to estimate the energy potency and wood chip production from tropical SRC which  $R^2$  was 0.953 and 1.000, respectively. In our approach, we eliminated the use of calorific value, an important factor on energy assesment to calculate energy electricity from woody biomass. RSM formula was also compared to common formula used for wood energy calculation [9]. Our findings proved that calculation using RSM formula had high similarity result from common formula used. It was desribed that RSM had an ability to simplify calculation from long formula to the short and easy formula. In this study, we investigated that among 10 SRC species, the highest energy potency was obtained from *F. racemosa* with the value of 3.16 MWh/m<sup>3</sup> while the wood chip production from its plant species was 304.91 kg/m<sup>3</sup>. We suggest that the formula generated by RSM was useful for simple calculation of energy electricity from SRC species or other woody biomass species in tropical area.



**Figure 2.** Response surface plot of wood energy potency (A) and wood chip production (B) from some short rotation coppice plant species



**Figure 3.** The high similarity results of wood energy potency between calculations using common formula and prediction using RSM formula



**Figure 4.** The high similarity results of wood chip production between calculations using common formula and prediction using RSM formula

#### 4. Conclusion

In conclusion, we found that the use of response surface methodology quadratic model resulted in simple formula of potency energy and wood chip production calculation from short rotation coppice plant species with the significant interaction between wood density and wood moisture content. Based on wood chemical component characteristics, the high lignin content also gave the high wood calorific value production from those SRC species.

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