

## Simulation of Carbon Dynamics of *Acacia mangium* Forest at Parungpanjang, Bogor, West Java, Indonesia Using Century Model

Isni Nuraziza<sup>1</sup> and Endah Sulistyawati<sup>2\*</sup>

Master Program in Biomangement, School of Life Sciences and Technology,  
Institut Teknologi Bandung, Jl. Ganesha 10 Bandung 40132, Indonesia

### Abstract

Forest ecosystems play an important role in regulating atmospheric carbon through the photosynthesis process. Many studies have measured the carbon stocks of *Acacia mangium* but those studies only captured a static view without taking into account the role of other components of the ecosystem. Century is one of ecological models that can be used to simulate carbon dynamics and the effects of other components in ecosystems. This research has simulated the carbon dynamics of *Acacia mangium* in Parungpanjang, Bogor using Century model. The research stages included model parameterization, validation, and analysis of the pattern of carbon accumulation in an *Acacia mangium* stand grown in a reforestation setting. The parameterization was done by adjusting the model parameters to the characteristics of *Acacia mangium* and the environment condition of the study area. The validation was conducted by comparing the simulation results to empirical data from the field measurements of carbon stocks in *Acacia mangium* stands of 2<sup>nd</sup>, 4<sup>th</sup>, 6<sup>th</sup>, and 8<sup>th</sup> years old. The validation process demonstrated that the output of simulation approaches the empirical data. Pattern of the simulated dynamics in 50 years shows that the carbon accumulated in the forest system, *Acacia mangium* biomass, and necromass increase as the age of stand increases. However, the accumulation of soil carbon initially decreases until it reaches a relatively constant value.

*Key words:* *Acacia mangium*/ Century/ Carbon Dynamics

### 1. Introduction

Carbon content in different land use has become essential information. It is related to global warming issues as the implications of the increasing concentration of carbon dioxide (CO<sub>2</sub>). The existence of forest ecosystems as sequester and sink carbon plays major role. The forest provides its services to regulate the concentration of atmospheric carbon through plants photosynthesis.

*Acacia mangium* is one of the cultivated species in industrial timber estates (Hutan Tanaman Industri - HTI) in Indonesia. This growing fast species (Sanchez, 2006) is known as productive forest than its role in carbon sequestration. It can reach up to 30 m height and leaf size 25 cm x 30-10 cm (Sanchez, 2006). The measurement of carbon content in *Acacia mangium* has been widely applied in Indonesia.

However, the measurement only captured a static view without taking into account the role of other components of the ecosystem.

Century model developed by Parton et al. (1987, 1988 in Metherell et al. 1993) can be used to simulate the carbon dynamics in an ecosystem. The model can be applied to assess the effect of different environmental conditions on the pattern of dynamics of carbon accumulation. In this research, the simulation of carbon dynamics has been done to *Acacia mangium* plantations in the RPH Tenjo, region Parungpanjang, Bogor, Indonesia. The simulations carried out by using the Century model (version 4.0) that has been widely used in various ecosystems. However, it never been applied to *Acacia mangium* so it is necessarily parameterized and validated before. Therefore, this study will focus on the parameterization, model validation, and

\*Corresponding author

Email: endah@sith.itb.ac.id

analysis of carbon accumulation dynamics through simulations of *Acacia mangium* using Century model.

## 2. Methodology

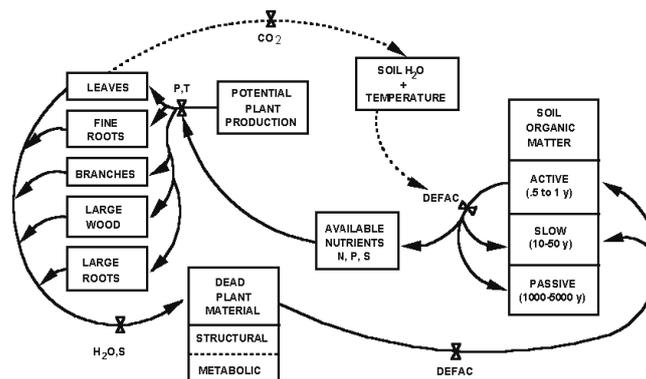
### 2.1 Study Site

The sample measurement had been taken in *Acacia mangium* plantation forest in (Resort Pemangkuan Hutan) Tenjo which organized by Perum Perhutani Unit III Jawa Barat dan Banten. This resort included to Bagian Kesatuan Pemangkuan Hutan (BKPH) Parungpanjang, Kesatuan Pemangkuan Hutan (KPH) Bogor, Jawa Barat. Its located at western region of Bogor, West Java, in the midst of 0 – 75 m dpl. The location has the average of

annual rainfall of 3.000 mm with maximum and minimum temperature of 25,5 °C and 18 °C respectively.

### 2.2. Century Model

Century model simulates key processes of nutrient cycling of an ecosystem. This model consists of several submodels i.e. plant production, climate, soil organic matters, dead plant materials. Those submodels represent pools that exist in real systems. Flows of nutrient between the pools are mainly regulated by functions of climate and plant nutrient/characteristics and parameters. Pools representation as submodels can be viewed in Figure 1.



**Figure 1** General description of Century Model (Metherell et al., 1993).

This model has been used to simulate ecosystem dynamics for most of the world's ecosystems, such as grasslands, agriculture, forests, and savanna (Metherell et al., 1993). It has been used to simulate the response of these ecosystems to changes in environmental variable (i.e temperature, rainfall, and atmospheric CO<sub>2</sub> levels). In this study, however, we only used the forest production submodel.

This model operates in monthly time step but the outputs can be presented in a monthly or yearly basis. Main model inputs are monthly precipitation, maximum and minimum air temperatures,

soil texture, and plant chemistry (Metherell et al., 1994). Those main inputs are subsequently used to derive other variables such as soil temperature, which is calculated as a function of air temperature and precipitation. More detailed description of the model can be seen in Metherell et al. (1993).

### 2.3 Model Parameterization

The parameterization was done by adjusting the model parameters of Century to the characteristics of *Acacia mangium* and the environment condition of the study area. Parameterization to

determine the input data needed for running the model. Input data were derived from field data and literature. Parameterizing was conducted by reviewing all the existing parameters, changing, and comparing the options parameters in the Century model (Metherell et al., 1993). The input data were processed using Century model to get the output extracted in graphical form.

Input of field data covering the value of C/N and lignin content of plants, and suitable annual climatic data within the location of the study in Bogor. The content of C/N and lignin samples were taken from each part stands of *Acacia mangium* (coarse roots, fine roots, stems, branches, and leaves) on the plant age 1<sup>st</sup> and 8<sup>th</sup> year. Climatic data included average rainfall monthly, average maximum temperature and minimum

temperature of each month at the study site (Parungpanjang, Bogor). These climatic data was obtained from Stasiun Klimatologi Bogor, Badan Meteorologi dan Geofisika (BMG), Jawa Barat.

## 2.4 Model Validation

The validation was conducted by comparing the simulation results to empirical data from the field measurements of carbon stocks in *Acacia mangium* stands of 2<sup>nd</sup>, 4<sup>th</sup>, 6<sup>th</sup>, and 8<sup>th</sup> years old. The field data was collected as much as three plots within size 30 x 20 m<sup>2</sup> (Heriansyah et al., 2003) at every stands (Figure 2). The data included Diameter at Breast Height (DBH - 1.3 m from aboveground) of trees, litter samples, soil samples, and soil pH.

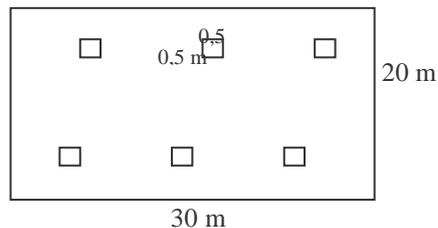


Figure 2 Plot of field sampling.

The carbon content was estimated 50% of standing biomass (Brown, 1997) which used allometric equation for calculating total biomass of *Acacia mangium* stands ( $y = 0.0533 x^{2.717}$  (Heriansyah, 2005)). Litter samples taken from six subplot size 0.5 x 0.5 m<sup>2</sup> for each plot. Soil sampling was taken twice each plot within core sampler for *bulk density* (the ratio between the mass of soil in the dry state with a constant volume in g/cm<sup>3</sup>) and the content of C/N soil within 4 cm in depth.

## 3. Result and discussion

### 3.1 Model Parameterization

Parameterizing was conducted by reviewing all the existing parameters, changing, and comparing the options parameters in the Century model (Metherell et al., 1993). Some parameters in the **site.100** and **tree.100** files were changed. The other parameters were set according to default values which describes the condition of ecosystems that similar to the simulated object (condition in tropical climates). For forest systems conducted in this study, parameterization is mainly done in the group parameters of **tree.100**. Several parameters (bold text)

that had been changed in this study can be seen in Table 1.

There are two parameters in this model, **prdx (3)** and **prdx (4)** (Table 1) which arrange the plant production. Parameter **prdx (3)** provides value of maximum gross primary production stated in biomass increment every month. The value of **prdx (3)** for *Acacia mangium* which simulated in this study was set maximum therefore the production was only controlled by **prdx (4)**. Parameter **prdx (4)** regulates the amount of maximum net primary production (NPP) expressed in the number of carbon added every month. Plant production is limited by temperature, rainfall, and light intensity, and the presence of nutrients (Campbell et al., 2004). The restrictions in this model is arranged by some

parameters as **ppdf** and **precip**, **tmn2m**, **tmx2m** in the **site.100** file.

The amount of total plant primary production will be allocated to each part of plant. In Century, the proportion of net primary production allocated into five components of stands (leaves, fine roots, branches, stems, and coarse roots). Some parameters that govern this allocation are **fcfrac**, **cerfor**, and **wdlig** (Table 1). Parameter **fcfrac** indicates value of carbon from net primary production allocated to parts of stands due to characteristics of the simulated species. Parameter **cerfor** shows the ratio of C to N, P, and S that contained in the components of stands. Parameter **cerfor** used in this study only for C/N ratio, while the value of P and S are not simulated (Table 1).

**Table 1** List of Parameters (only some parameters that had been changed in this study)

Parameter	Descriptions	Values	References
<b>prdx (3)</b>	Gross primary production (g biomass/m <sup>2</sup> /month)	9999,999	Metherell <i>et al.</i> , 1993
<b>prdx (4)</b>	Net primary production (g biomass/m <sup>2</sup> /month)	100,0000	Modified from Djumakking, 2003
<b>fcfrac(1,2)</b>	C allocation fraction of leaves for mature forest	0,0514	Djumakking, 2003
<b>fcfrac(2,2)</b>	C allocation fraction of fine roots for mature forest	0,0484	Djumakking, 2003; Strong & La Roi (1983a <i>in</i> Nalder & Wein, 2005); Ruark & Bockheim (1987 <i>in</i> Nalder & Wein, 2005); Peterson & Peterson (1992 <i>in</i> Nalder & Wein, 2005).
<b>fcfrac(3,2)</b>	C allocation fraction of fine branch for mature forest	0,1390	Djumakking, 2003
<b>fcfrac(4,2)</b>	C allocation fraction of large wood for mature forest	0,6643	Djumakking, 2003
<b>fcfrac(5,2)</b>	C allocation fraction of coarse root for mature forest	0,0969	Djumakking, 2003; Strong & La Roi (1983a <i>in</i> Nalder & Wein, 2005); Ruark & Bockheim (1987 <i>in</i> Nalder & Wein, 2005); Peterson & Peterson (1992 <i>in</i> Nalder & Wein, 2005).
<b>cerfor (1,1,1)</b>	minimum C/N ratio for leaves in forest system	18,0722	Sample test
<b>cerfor (1,2,1)</b>	minimum C/N ratio for fine root in forest system	38,2051	Sample test
<b>cerfor (1,3,1)</b>	minimum C/N ratio for branch in forest system	25,4757	Sample test.
<b>cerfor (1,4,1)</b>	minimum C/N ratio for large wood in forest system	50,3402	Sample test
<b>cerfor (1,5,1)</b>	minimum C/N ratio for coarse root in forest system	38,5748	Sample test
<b>cerfor (2,1,1)</b>	maximum C/N ratio for leaves in forest system	27,0183	Sample test
<b>cerfor (2,2,1)</b>	maximum C/N ratio for fine root in forest system	57,1026	Sample test
<b>cerfor (2,3,1)</b>	maximum C/N ratio for branch in forest system	86,4180	Sample test
<b>cerfor (2,4,1)</b>	maximum C/N ratio for large wood in forest system	426,3551	Hardiyanto et al., 2004
<b>cerfor</b>	maximum C/N ratio for coarse root in forest system	90,3208	Sample test

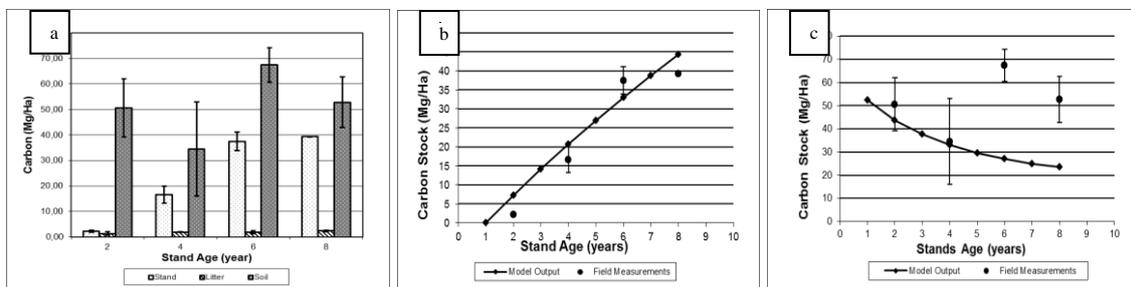
Parameter	Descriptions	Values	References
(2,5,1)			
<b>cerfor</b> (3,1,1)	Initial C/N ratio for leaves in forest system	24,9772	Sample test
<b>cerfor</b> (3,2,1)	Initial C/N ratio for fine root in forest system	45,7244	Sample test
<b>cerfor</b> (3,3,1)	Initial C/N ratio for branch in forest system	60,1603	Sample test
<b>cerfor</b> (3,4,1)	Initial C/N ratio for large wood in forest system	72,2836	Sample test
<b>cerfor</b> (3,5,1)	Initial C/N ratio for coarse root in forest system	78,3074	Sample test
<b>wdlig</b> (1)	lignin fraction for leaf production in forest system	0,2672	Sample test
<b>wdlig</b> (2)	lignin fraction for fine root production in forest system	0,0129	Sample test
<b>wdlig</b> (3)	lignin fraction for branch production in forest system	0,1128	Sample test
<b>wdlig</b> (4)	lignin fraction for large wood production in forest system	0,2978	Sample test
<b>wdlig</b> (5)	lignin fraction for coarse production in forest system	0,0934	Sample test
<b>leafdr</b>	monthly death rate fractions for leaves for month 1 (January) – month 12 (Desember)	0,3576	Modified from Saharjo & Watanabe, 2000 (assumed for rain tropical forest this value is same)

Lignin content determines the speed of decomposition rate for litter from each piece stands. The parameters used are **wdlig (1) - wdlig (5)** (Table 1) indicate the fraction of lignin in the components of stands. Century enter parameter **leafdr** (Table 1) as the rate of leaf death for each month from January to December. Indonesia is a tropical country so it was assumed that the death rate of leaves for each month is the same.

### 3.2 Model Validation

The results of carbon stocks measurement in stands, litter, and soil for

*Acacia mangium* plantation in the RPH Tenjo, Parungpanjang can be seen in Figure 3.a. From figure 3.a, can be viewed the carbon content of stands add at every age regionally. The smallest carbon stock can be found in 2<sup>nd</sup> years old of stands (2,21 Mg/Ha). The amount was increase and achieved 39,2977 Mg/Ha at 8<sup>th</sup> years old. However, the added carbon content between 6<sup>th</sup> years and 8<sup>th</sup> years is small. This small amount can be happened due to the growth of *Acacia mangium* at the age of 7<sup>th</sup> and 8<sup>th</sup> years dropped dramatically compared with the growth that occurred between ages 2<sup>nd</sup> and 6<sup>th</sup> years (ICRAF, 2008).



**Figure 3** a. Carbon Stock of *Acacia mangium* plantation forest system in RPH Tenjo; b. Comparison of carbon stock of *Acacia mangium* stand on the field measurement results with the simulation model c. Comparison of carbon stock in soil of *Acacia mangium* forest on the field measurement results with the simulation model.

The comparison shows the pattern of the simulation results approaches the results of carbon stock stand measurements (Figure 3.b). The amount of carbon stands grows in line within age of stands as the trend in nature. The thinning process on *Acacia mangium* plantation in the field was not simulated. It might causes this simulation results seem higher than actual measurements in the field. In the field, Perhutani party does the thinning in *Acacia mangium* plantation at age 3<sup>th</sup>, 5<sup>th</sup>, and 7<sup>th</sup> years. At 6<sup>th</sup> years, the simulation result is lower than field measurements because the thinning process has not been done.

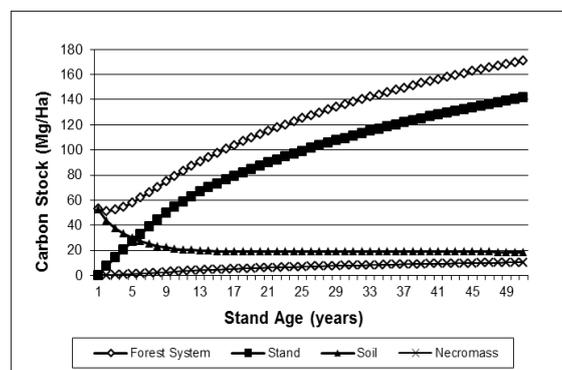
Results comparison of soil carbon accumulation of the simulation and field measurements can be seen in Figure 3.c. The simulation results show that the soil carbon decreases along with increasing stand age. The soil carbon declines from 52,5166 Mg/Ha (at 1<sup>st</sup> years old stands) to 23,4257 Mg C/Ha (at 8<sup>th</sup> years old stands).

The simulation results are different from the results of field measurements that do not indicate a pattern of decline. The simulation results of soil carbon in 2<sup>nd</sup> and 4<sup>th</sup> years age of stands approach the actual measurement. However, at 6<sup>th</sup> and 8<sup>th</sup> years of the stands age, soil carbon simulation results are much lower than the actual measurements. This can be due to inappropriate value of the input parameters used in the environmental factors.

The standard deviation on the results of soil carbon measurements for each age stand are big enough (Figure 3.a). It shows that the differences in soil carbon measurement for each repetition in each age stand is big. This indicates that although the age of the stands in the field is same, but if the different measurement locations, soil carbon stocks in these locations may vary. This difference can due to the fertilization and the differences in initial carbon matter prior to planting. The fertilization can increase biomass production and indirectly increase soil carbon sequestration (Siry et al., 2006).

### 3.3 Simulation of Carbon Dynamics in *Acacia mangium* Plantation Forest

The dynamics of the carbon stock was simulated for *Acacia mangium* for 50 years (Figure 4). The result shows the increasing carbon content of *Acacia mangium* forest system during the first 50 years growth. It achieve 170.96 Mg C/Ha and yet have a relatively constant value in 50<sup>th</sup> years. This carbon forest system is the sum of carbon in in the stands, the soil, dead wood and litter (necromass). The trendline was also seen in carbon dynamics of *Acacia mangium* stand if no thinning process. In nature, rare of *Acacia mangium* stands is more than 20<sup>th</sup> years old because this species is included as a pioneer species (ICRAF, 2008).



**Figure 4** Simulation result of carbon dynamic in *Acacia mangium* forest system.

The carbon content of necromass was also increased in line with the age of stands (Figure 4.) but smaller than the stand carbon. This situation often encountered in nature which occurred in the mature forest, depend on forest type and age of these forests (Brown, 1997). Soil carbon dynamics in soil carbon simulation results show decreased and began relatively constant at 20-years-old stands. This situation can be caused by high input of lignin content (**wdlig**) (Table 1). The high lignin content affects the rate for litter decomposition slows and

it is slowing the carbon transfer into soil. While the other influencing factors are climatic factors input (i.e. temperature and rainfall).

In simulation, amount of carbon accumulation in *Acacia mangium* stands is influenced by its several characteristics as input of the parameter. The carbon added each month in net primary production is one of its characteristics and it was set by **prdx (4)**. When the value **prdx (4)** is enlarged, then the standing stock of carbon accumulation will be greater (Figure 5.a.).

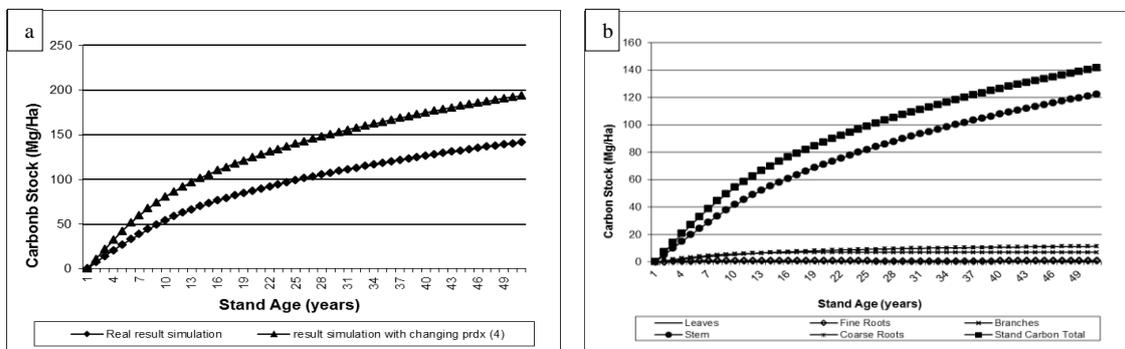


Figure 5 a. Comparative dynamics of carbon accumulation on stand simulation results with enlarged value of **prdx (4)**; b. Results simulation of carbon dynamics on stand parts of *Acacia mangium*.

Another characteristics is the proportion of net primary production allocation in stand components that affects the storing carbon on a stand. The proportion of the allocation into stand components in the model is arranged by **fcfrac**. Larger carbon allocation to the stem (**fcfrac 4.2**) than other parts contribute to enlarge the accumulation of carbon in the stands (Table 1, Figure 4, and Figure 5.b).

In nature, the large allocation of carbon in stem cause carbon would keep in greater stand and stored longer. It would make the decomposition process takes a long rod, especially comparing to the leaves (Saharjo and Watanabe, 2000; Mason, 1977). Therefore, the proportion of carbon allocation to each part stands determine the dynamics of carbon accumulation in a forest system.

#### 4. Conclusion

The simulation result by changing some parameters showed the accumulation of carbon in the stands of *Acacia mangium* output was approached the results of field measurements. The running model for 50 years showed the carbon dynamics in forest systems, in stands of *Acacia mangium*, and necromass continues to increase along with increasing age of stands and has not shown a relatively constant value. However, the simulation results for the carbon in the soil decline with stand age and showed a relatively constant value. Some factors which influence to simulation results are input values stand productivity, chemical plants, environmental and climatic factors such as temperature and rainfall.

## 5. Acknowledgements

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