Parameterization of 3PGS model for aboveground biomass estimation in *Eucalyptus camadulensis* and *Acacia mangium* plantation

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Abstract

Within the framework of Kyoto protocol, carbon sink concept is a major topic for the global climate change. There is an urgent need to collect vital data on forest plantations. Therefore, there is an obvious need to develop methods for estimating the biomass at diverse sites with non-destructive methods. Modeling is one of the effective approaches and Process Based Models (PBMs) that can provide a better understanding of stand growth and dynamics. A simplified model of PBMs is 3PG (Physiological Principles Predicting Growth) [1] and modified version is 3PGS model (Physiological Principles Predicting Growth with Satellite data) [2]. The model enables to use parameters derived from satellite data (NDVI : Normalized Difference Vegetation Index and FPAR : The Fraction of Photosynthetically Active Radiation) as well as meteorological data. The objective of this study is to estimate aboveground biomass (W_{abv}) by using 3PGS model. W_{abv} were validated with field-measured values. The Field measurements were conducted in *Eucalyptus camaldulensis* and *Acacia mangium* plantation that is the first time to apply 3PGS model for these 2 species. Sensitivity analysis was done and found 4 sensitive parameters that need to be accurately determined are NDVI_FPAR_Constant, NDVI_FPAR_Intercept, Canopy Quantum Efficiency (Alpha) and Specific Leaf Area (SLA). The sensitive parameters were simulated to calculate W_{abv} thus accurately sensitive parameters are required. Sensitive parameters are Alpha and SLA. We found suitable Alpha are 0.07 and 0.13 molC/mol PAR and SLA are 22.5 and 35 (m^2/kg)for *E. camaldulensis* and *A. mangium* respectively. Relationship between NDVI and FPAR values, Logarithm is the best for achieving NDVI_FPAR_Intercept, NDVI_FPAR_Constant values. NDVI were derived from satellite data (LANDSAT ETM＋ and MODIS) and FPAR were obtained from MODIS FPAR product (Moderate Resolution Imaging Spectroradiometer ;

8-day composite) and field data. Result showed 3PGS model provided better W_{abv} of *E. camadulensis* than *A. mangium*. Moreover, in my study area LANDSAT ETM＋ and FPAR from field data are suitable to derived NDVI and FPAR respectively. In future for *E. camaldulensis* and *A. mangium*'s aboveground biomass (W_{abv}) estimation by using 3 PGS model, Alpha and SLA values from this research can be apply in other plantation as well.

Key words : Carbon sinks, Plantation, Process-Based Model (PBMs), 3PGS, NDVI, FPAR, Biomass

1. INTRODUCTION

In line with the international discussion on the global climate change that includes carbon sink concept in "Kyoto protocol", there an urgent need to collect some necessary data on forest plantations. FAO, 2006 said there was a very rapid expansion of plantation in Asia-pacific region and one of the largest plantation areas is Thailand. Eucalyptus and other fast-growing species such as Acacia were planted for paper mill, fuel wood and construction, ect. Plantation and Plants may be viewed as "Carbon sinks" removing CO_2 from atmosphere and oceans by convert it into organic chemicals (biomass ; stem, root and foliages). Biomass is assimilation and accumulation of carbon into organic matter determined by carbon fixation and carbon release, therefore, biomass can be estimated by modeling carbon dynamics.[3] Estimating biomass by allometric equations may be time-consuming and laborious, because of the need to cut sample trees at the target research site, and the cutting may adversely affect the site. Therefore, there is clearly need to develop methods for estimating the biomass of managed plantations at diverse sites simply with non-destructive methods. Process-based models (PBMs) attempt to the processes of growth model without tree destruction by taking as input the light, temperature and soil nutrient levels, and modeling photosynthesis, respiration and the allocation of photosynthesis to roots, stems and leaves. These are also known as mechanistic of physiological models. These models help to provide a better understanding of growth and stand dynamics.[4]

One simplified model of PBMs is 3 PG model ; Physiological Processes Predicting Growth developed by Landsberg and Waring in 1997.[1] A modified version of 3 PG model is 3PGS ; Physiological Principles Predicting Growth with Satellite data.[2] 3PGS enables to use satellite-derived estimates of the FPAR, which is a measure of the amount of incident visible light absorbed by plant tissues. In 1997, Photosynthetically Active Radiation (PAR) estimation at the Earth's surface from satellite observations and current satellite algorithms to estimate PAR at the Earth's surface was reviewed. PAR can be obtained directly from top-of-atmosphere solar radiance, which is used to determine the transmissivity of the atmosphere. Many researchers found well correlate with NDVI, FPAR, Biomass and LAI by using the remote sensed data (i.e. NOAA 11 AVHRR/2, LANDSAT TM, MODIS, ect) and ecosystem model.[5] FPAR is more linearly related to NDVI than is LAI, so that retrieval using remote sensing is less problematical.[6] For MODIS FPAR has strong linear relation with NDVI but MODIS tendency to overestimate FPAR[7] In the other hand, using of an empirical linear relationship between FPAR and NDVI can also bring about probable errors particularly in area with low NDVI. Derived NDVI for forest stands has been related to LAI, FPAR and to carbon sink. Because light absorption drives the photosynthetic process, FPAR is directly related to photosynthesis and the rate of carbon sink. FPAR is often used to drive models of biomass estimation or net annual carbon sink.

3PGS model have been applied to single species plantations and even-aged throughout the world. Mostly are *E. globulus*, *E. obliquia*, *E. grandis*, Pinus spp., Douglas fir, etc. (N. C. Coops, 1998, 2001 ; Waring, 2000 ; Dye, 2001 ; Landberg, 1997, 2002). This research is the first application for 3PGS model to estimate W_{abv} in this 2 species *E. camaldulensis* and *A. mangium* in Thailand plantation. The objective of this study is to estimate aboveground biomass (W_{abv}) by using 3PGS model. W_{abv} were validated with field-measured values. The Field measurements were conducted in *E. camaldulensis* and *A. mangium* plantation. Our focus is parameterization of sensitive parameters for best fit between W_{abv} from model and field data.

2. STUDY AREA

Field measurements were conducted in even-aged five plots of *E. camaldulensis* and *A. mangium* plantation within year 1998 to 2003 in Lat Kra Ting, Sanam Chaikhet district, Chachoeng-sao Province, Thailand. Plantation in the study area is shown in figure 1 (13 o 42’ N., 101 o 06’E.) with the

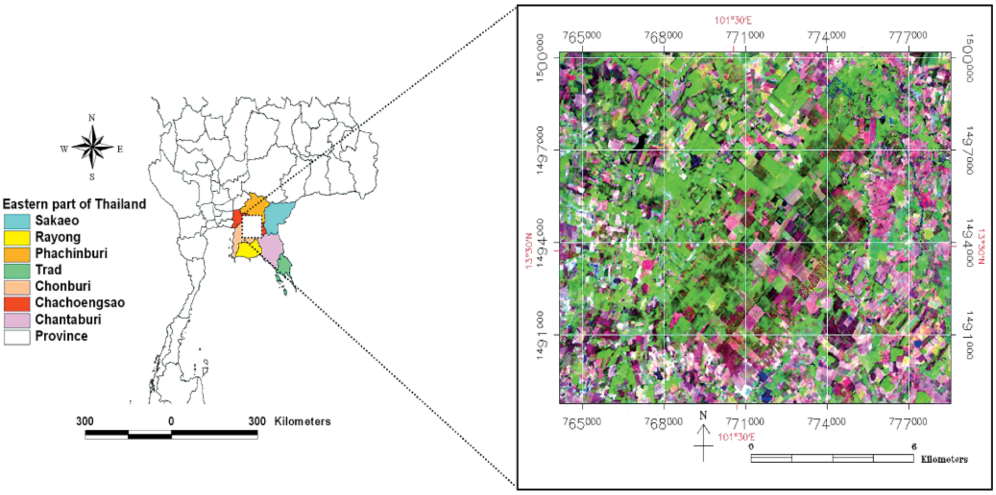

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Figure 1　Study area in Lad Kra Ting plantation, Sanam Chai Ket District area around 32.68 square kilometers, each plots are and the altitude is approximately 70 meters from MSL. Soil consisted sand, silt and clay around 48%, 26% and 26% respectively.

E. camaldulensis or river red gum is one if the most widely used tree species in plantation forestry world wide. It is a native tree of Australia and has a wide natural distribution range in Australian mainland[8]. This is important for tropical and subtropical countries in which there is a need to rehabilitate degraded land. Considering the wide range of its wood utilization and its high yield per unit land area, this species seems to exhibit great potential as a plantation species. Presently, the total plantation area of all *Eucalyptus* spp. in the whole world is estimated at 13 million ha. Rapid spread of *E. camaldulensis* as a plantation forestry species in Thailand alone indicates the potential of this particular species in rural development and integrated land use. *A. mangium* is one of the major fast growing species used in plantation forestry programs throughout Asia and the Pacific[9]. This species has been cultivated in various places as a forestry tree and has escaped from plantings due to its rapid growth and tolerance of very poor soils. *A. mangium* is playing an increasingly important role in efforts to sustain commercial supply of tree products while reducing pressure on natural forest ecosystems. *A. mangium* apparently tolerates annual precipitation of 10 to 45 dm or more mean maximum temperature of 31 –34°C in summer, mean minimum temperature of 12–25°C in winter, and pH of 4.2 –7.5.

3. METHODOLOGY

3PGS model require 3 groups of inputs. First are Inventory data and field data such as physiological data, biomass and site data. Second is meteorological data and the last one is Satellite data

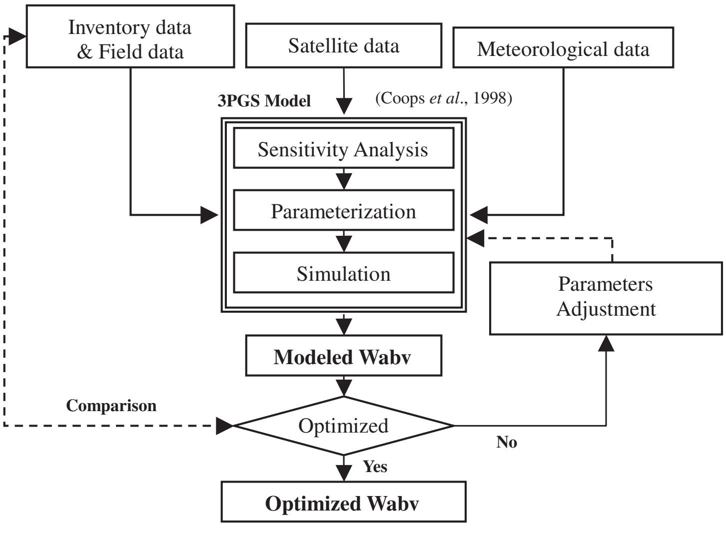

Figure 2 Framework of the study (W_{abv} : aboveground biomass)

(MODIS and Landsat ETM＋). Sensitivity analysis and parameterization then model simulation were done. Modeled W_{abv} (output) was compared with Field W_{abv} then parameter adjustment or iterative process will do for fitting Modeled W_{abv} with Field data. Framework of this study is shown in figure 2.

4. 3PGS MODEL

3PGS model is a simple, process-based, stand-level model of forest growth developed by Landsberg and Waring.[1] It is a deliberate attempt to bridge the gap between mensuration-based growth and yield models, and process-based, carbon-balance models. In 3PGS, the The Fraction of Photosynthetically Active Radiation absorbed by the forest canopy (FPAR) is estimated from a satellite-derived NDVI. This spectral vegetation index has been shown, both empirically and theoretically, to be related to the FPAR absorbed by vegetation canopy.[10] It requires only readily available site and climatic data as inputs and predicts the time course of stand development on a monthly basis in a form familiar to the forest manager, as well as various biomass pools, water use and available soil water. For this research NDVI and FPAR relationship was needed. NDVI related to the FPAR as nearly linear relationship. However, the relationship between NDVI and FPAR in some researches may not be valid for another. The relationship in other cases (logarithm and natural logarithm) was considered.

3PGS model can be applied to plantations or to even-aged, relatively homogeneous forests. It is a generic stand model since its structure is neither site nor species-specific, but it must be parameterized for individual species. Recently,[21] use 3PGS model to simulated forest growth dynamics of tropical rainforests. The results indicate that the simple, process based models are effective at capturing the

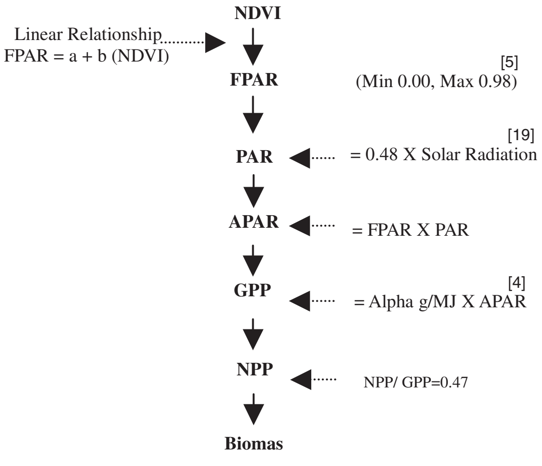

Figure 3　Biomass calculation flowchart by 3PGS model

growth dynamics of structurally complex old growth, restoration and plantation rainforests. Flowchart of the model calculates stand biomass process shown in Figure 3. Radiation intercepted by the canopy is determined from total incoming solar radiation and LAI through Beer's law. Gross primary production (GPP) is proportional to intercepted photosynthetically active radiation (PAR). The proportionality factor, called canopy quantum efficiency (Alpha), takes into account environmental effects through multiplicative modifiers based on atmospheric VPD, available soil water, mean air temperature, frost days per month, site nutrition, and stand age. Net Primary Production (NPP) is a constant fraction of GPP.[16]

5. DATA

5. 1 INVENTORY DATA

Actual biomass was not available then empirical equations were used to estimate above ground biomass from field data such as Diameter at Breast Height (DBH) and height. Above ground biomass estimated from 3PGS was validated with these above ground biomass from field data. (Table 1).

From plantation database, Empirical equations were used for calculating above ground biomass of *E. camaldulensis* and *A. mangium*. Stem biomass as equation (1) and (4), Branch biomass as equation (2) and (5) and Leaf biomass as equation (3) and (6).

Eucalyptus camaldulensis[11]

$$\text{Stem biomass (kg)} = 0.0807\ \text{DBH}^{2.5016} \qquad (1)$$

$$\text{Branch biomass (kg)} = 0.0172\ \text{DBH}^{2.3247} \qquad (2)$$

Table 1 Inventory Data of A 1 (*A. mangium.*), E 2 (*E. camadulensis*) Study sites, in 1998–2003

Year	Site	Planting Year	Age (yrs)	Lat-Long		MSL (mm)	Area (rai)	Total Trees in Plot	Volume (m3/rai)	Stand Stocking (trees/ha)	DBH (cm)	Height (m)
				N	E							
1999	A 1	1998	1	13.5245	101.5120	56.6	206.9	47504	3.54	1434.72	5.24	4.46
2000	A 1	1998	2	13.5245	101.5120	56.6	206.9	47504	7.32	1434.72	9.25	6.87
2001	A 1	1998	3	13.5245	101.5120	56.6	206.9	47504	12.29	1434.72	10.76	10.48
2002	A 1	1998	4	13.5245	101.5120	56.6	206.9	40469	13.33	1222.24	12.06	11.66
2003	A 1	1998	5	13.5245	101.5120	56.6	206.9	38133	13.54	1151.69	12.35	12.25
1999	E 2	1998	1	13.4916	101.5269	55.5	319.6	63912	2.46	1249.73	4.35	5.31
2000	E 2	1998	2	13.4916	101.5269	55.5	319.6	63912	4.13	1249.73	6.23	6.19
2001	E 2	1998	3	13.4916	101.5269	55.5	319.6	63912	4.16	1249.73	6.68	7.57
2002	E 2	1998	4	13.4916	101.5269	55.5	319.6	81972	7.56	1602.87	8.54	8.58

Leaf biomass (kg) $= 0.0178\ \mathrm{DBH}^{1.6815}$ (3)

Where : DBH = Diameter at breath Height (cm.)

Acacia mangium[12]

Stem biomass (kg) $= 0.0283\ X^{0.9473}$ (4)

Branch biomass (kg) $= 0.0027\ X^{1.0074}$ (5)

Leaf biomass (kg) $= 0.0115\ X^{0.7242}$ (6)

Where : $X = \mathrm{DBH}^2 * H$, $(\mathrm{cm}^2\mathrm{m})$

5. 2　METEOROLOGICAL DATA

The weather in this area is characterized with average temperature of 28℃ and annual rainfall of 1312 millimeters with the total of 100 rainy days/year.[11] Figure 4 shows climatic databases[11] in 19982003 (Average 5 years)

5. 3　SATELLITE DATA

This study used two different dates of Landsat 7 Enhanced Thematic Mapper-Plus (ETM＋) level 1 G (path 128 row 51) images observed on 30 November 2001 and 5 February 2003 to derived NDVI. Landsat ETM＋ images were atmospherically corrected by implementing 6 S.[13] 6 S is used to calculate

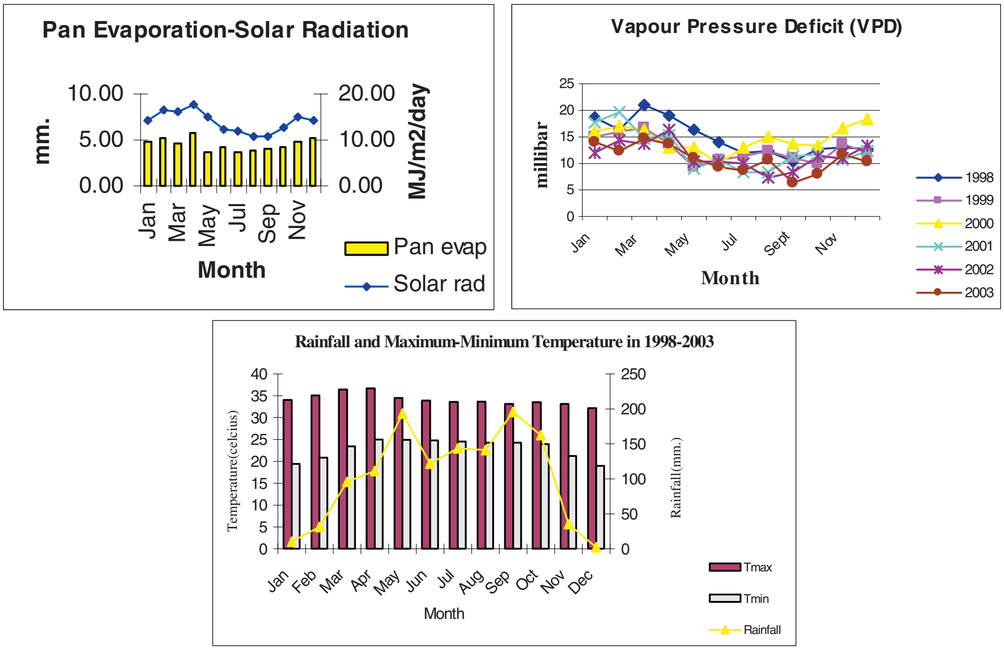

Figure 4　**Pan Evapotranspiration ; mm., Solar Radiation ; MJ/m 2/day, VPD ; millibar, Total Monthly Rainfall ; mm. and Maximum-Minimum Temperature ; Celsius in 1998–2003 (Average 5 years)**

the incident radiative fluxes using information on the optical properties of atmosphere. As an original source code of 6 S cannot be applied for ETM+ data, spectral response functions of ETM+ (bands 1 to 5, 7) were defined, and then implemented. MODIS ; Moderate Resolution Imaging Spectroradiometer from Leaf Area Index/FPAR 8 Day L 4 Global 1 km (MOD 15) for obtaining FPAR values and Vegetation Indices 16-Day L 3 Global 250 m (MOD 13) for NDVI values in year 2000 to 2004 were used.

6. FIELD SURVEY

For this research NDVI and FPAR relationship was needed. The relationship is independent of pixel heterogeneity, parameterized with ground cover, plant leaf area and variations in leaf orientation and optical properties. On the other hand, the relationship is sensitive to background, atmosphere and bidirectional effects.[14] We collected FPAR in *E. camaldulensis* and *A. mangium* plots at different age (age 1–5 years). Measurement was conducted 2 times in July and December 2006. Firstly, we used plant canopy analyzers (LAI-2000,Licor) with LI-190 (Licor) to measure PAR (Photosynthetically Active Radiation) value as two simultaneously-measured PAR using multi-PAR sensors ; above (PARblw) and below canopy (PARabv). Secondly, FPAR was calculated using following expression :

$$\mathrm{FPAR} = 1 - \mathrm{PAR}_{\mathrm{blw}} / \mathrm{PAR}_{\mathrm{abv}} \qquad (7)$$

The LI-190 sensor was placed in an open area and the other one under the canopy. Measurements were made under conditions of diffuse skylight.[15] Locations of plots were recorded. Inside each plots, 2 sets of equipments were used to measure $\mathrm{PAR}_{\mathrm{blw}}$. Six trees on 2 transect line in every 100 m interval were measured. For $\mathrm{PAR}_{\mathrm{abv}}$ was measured outside plot in open space area.

7. RESULTS

7. 1 SENSITIVITY ANALYSIS

Sensitivity analysis of a model helps understand individual parameters and how processes are modeled, identifies the parameters to be that need accurately determined provides insight into the limitations of model and most importantly builds confidence in use of a model. Parameters with low sensitivity level could be assigned default generic values whilst parameters with high sensitivity that affected the majority of model outputs required specific attention.[21] Some parameters in growth model mostly were estimated from an experimental base. The consequences of inaccuracy in these estimates often remain undefined.[16] In this paper we conducted sensitivity analysis to examine the effect of all sensitive parameters on W_{abv}. Table 2 shows the 3PGS model sensitivity analysis parameters and Relative sensitivity of variable (σ). The data used in the sensitivity analyses are from literature reviews of *Eucalyptus sp*. and *Acaia sp*. Two physiological parameters of 3PGS model were examined. We increased and decreased the Specific leaf area at age 0 ; SLA 0 and Canopy quantum efficiency ; Alpha for every plot in both species. W_{abv} of each parameter was computed and used to assess the sensitivity of 3PGS model to changes in its parameter values. The relative sensitivity σ (X ; p) of an output variable X with respect to a parameter p is the change X in X produced by a change Δp in p relative to the original values of X and P (Brylinsky, 1972 cited in[17])

$$\sigma\ (\mathrm{X}\ ;\ p)=\frac{\Delta X}{\mathrm{X}}\ \frac{p}{\Delta p} \tag{8}$$

Relative sensitivity of unity indicates that a percentage change in the value of a parameter will result in the same percentage change in the variable. Table 2 show canopy quantum efficiency ($\sigma=1.0$) have effect to above ground biomass (W_{abv}) more than Specific leaf area ($\sigma=0.03$)

7. 2 PARAMETERIZATION

The present study is based on 3PGS model parameterized for *E. calmadulensis* and *A. mangium*. The model was validated against data from 2 plots in Chacheongsao province, Thailand. The parameterization in table 3 was based on published data (Literature) or the results of direct measurements (Estimated) but normal procedure used standard default or the best available empirical data for as many as possible. Some sensitive parameters such as Specific leaf area at age 0 (SLA 0) and Canopy

Table 2 Sensitivity analysis and Relative sensitivity of variable

% Perturbed	Symbol	Description	Units	−20%	−10%	Std Value.	10%	20%
Parameter (p)	SLA 0	Specific leaf area at age 0	m^2/kg	13.6	15.3	17	18.7	20.4
	alpha	Canopy quantum efficiency	molC/molPAR	0.06	0.06	0.06	0.06	0.06
Variable (X)	Wabv	Above ground biomass (plotE 2)	tonDM/ha	13.44	13.49	13.53	13.57	13.61
Relative sensitivity (σ (X ; p))				0.032	0.031		0.030	0.030
%Perturbed	Symbol	Description	Units	−20%	−10%	Std Value.	10%	20%
	SLA 0	Specific leaf area at age 0	m^2/kg	17	17	17	17	17
Parameter (p)	alpha	Canopy quantum efficiency	molC/molPAR	0.048	0.054	0.06	0.066	0.072
Variable (X)	Wabv	Above ground biomass (plotE 2)	tonDM/ha	10.82	12.18	13.53	14.88	16.23
Relative sensitivity (σ (X ; p))				1.00	1.00		0.99	1.00

Table 3 Value description and source of species specific input parameters used in calibration of the 3 PG model for *E. camadulensis* (E.) and *A. mangium* (A.). Data classes (Literature, Fitted and Estimated)

Parameters	Value		Units	Data Class	Source
	E.	A.			
Foliage : stem partitioning ratio@D=2 cm (pFS 2)	1	1	−	E	Inventory data
Foliage : stem partitioning ratio@D=20 cm (pFS 20)	0.5	0.5	−	E	Inventory data
Constant in the stem mass v. diam. Relationship (StemConst)	0.08	0.08	−	E	Inventory data
Power in the stem mass v. diam. Relationship (StemPower)	2.5	2.5	−	E	Inventory data
Maximum fraction of NPP to (rootspRx)	0.8	0.8	−	L	[1]
Minimum fraction of NPP to (rootspRn)	0.11	0.11	−	L	[1]
Maximum litterfall (rategammaFx)	0.03	0.03	1/month	L	[1]
Litterfall rate at t=0 (gammaF 0)	0	0	1/month	L	[1]
Age at which litterfall rate has median value (tgammaF)	12	12	months	L	[1]
Average monthly root turnover rate (Rttover)	0.02	0.02	1/month	L	[18]
Minimum temperature for growth (Tmin)	10	10	deg. C	L	[12]
Optimum temperature for growth (Topt)	25	25	deg. C	L	[12]
Maximum temperature for growth (Tmax)	40	40	deg. C	L	[12]
Moisture ratio deficit for fq=0.5 (Swconst)	0.7	0.7	−	L	[18]
Power of moisture ratio deficit (Swpower)	9	9	−	L	[18]
Fraction mean single–tree foliage biomass lost per dead tree (mF)	0	0	−	L	[18]
Fraction mean single–tree root biomass lost per dead tree (mR)	0.2	0.2	−	L	[18]
Fraction mean single–tree stem biomass lost per dead tree (mS)	0.2	0.2	−	L	[18]
Specific leaf area at age 0 (SLA 0)	17	17	m^2/kg	F	*sensitive parameter
Specific leaf area for mature leaves (SLA 1)	4	6	m^2/kg	L	[1]
Age at which specific leaf area = (SLA 0+SLA 1)/2 (tSLA)	2.5	2.5	years	L	[1]
Extinction coefficient for absorption of PAR by canopy (k)	0.5	0.5	−	L	[18]
Age at canopy cover (depend on tree space) (fullCanAge)	5	5	years	E	Inventory data
Maximum proportion of rainfall evaporated from canopy	0.15	0.15	−	L	[18]
LAI for maximum rainfall interception (LAImaxIntcptn)	0	0	−	L	[18]
Canopy quantum efficiency (alpha)	0.06	0.06	molC/molPAR	F	*sensitive parameter
Ratio NPP/GPP (Y)	0.47	0.47	−	L	[19]
Maximum canopy conductance (MaxCond)	0.02	0.02	m/s	L	[18]
LAI for maximum canopy conductance (LAIgcx)	3.33	3.33	−	L	[4]
Defines stomatal response to VPD (CoeffCond)	0.05	0.05	1/mBar	L	[18]
Canopy boundary layer conductance (Blcond)	0.2	0.2	m/s	L	[18]
Branch and bark fraction at age 0 (fracBB 0)	0.75	0.75	−	L	[4]
Branch and bark fraction for mature stands (fracBB 1)	0.15	0.15	−	L	[4]
Age at which fracBB= (fracBB 0+fracBB 1)/2 (tBB)	2	2	years	L	[4]
Minimum basic density–for young trees (rhoMin)	1.1	1.1	t/m 3	E	Inventory data
Maximum basic density–for older trees (rhoMax)	1.1	1.1	t/m 3	E	Inventory data
Age at which rho= (rhoMin+rhoMax)/2 (tRho)	4	4	years	E	Inventory data
Intercept of net v. solar radiation relationship (Qa)	–90	–90	W/m 2	L	[18]
Slope of net v. solar radiation relationship (Qb)	0.8	0.8	−	L	[18]
Molecular weight of dry matter (gDM_mol)	24	24	g DM/mol	L	[18]
Conversion of solar radiation to PAR (molPAR_MJ)	2.3	2.3	mol/MJ	L	[18]

quantum efficiency (Alpha) had to tune with measured data (Fitted). We did iterative process to optimize parameter values (SLA 0 and Alpha) and match modeled W_{abv} to measured W_{abv} data.

NDVI can be estimated from remote sensing data. Regarding model simulation, 3PGS model used other parameters (table 6) such as NDVI_FPAR_intercept (a), NDVI_FPAR_constant (b) and NDVI average values. In 3PGS model, FPAR is estimated from a satellite derived-NDVI. Some researchers found this spectral vegetation index related to the FPAR as nearly linear relationship equation (9). However, the relationship between NDVI and FPAR in some research may not be valid for another because the relationship is sensitive to soil background, irradiance quality, canopy structure and leaf

[21] optics.

$$\mathrm{FPAR} = b_1\ \mathrm{NDVI} + a_1 \tag{9}$$

$$\mathrm{FPAR} = b_2 \log(\mathrm{NDVI}) + a_2 \tag{10}$$

$$\mathrm{FPAR} = b_3 \ln(\mathrm{NDVI}) + a_3 \tag{11}$$

The relationship in other cases (logarithm and natural logarithm) was considered as equation (10) and (11) respectively. We used MODIS ; Moderate Resolution Imaging Spectroradiometer from Leaf Area Index/FPAR 8-Day L 4 Global 1 km (MOD 15) for obtaining FPAR values and Vegetation Indices 16-Day L 3 Global 250 m (MOD 13) for NDVI values, then FPAR and NDVI relationship was calculated by the following equation :

$$\mathrm{FPAR} = \frac{\mathrm{NDVI} - \mathrm{NDVI}_{\mathrm{min}}}{\mathrm{NDVI}_{\mathrm{max}} - \mathrm{NDVI}_{\mathrm{min}}} \cdot (\mathrm{FPAR}_{\mathrm{max}} - \mathrm{FPAR}_{\mathrm{min}}) + \mathrm{FPAR}_{\mathrm{min}} \tag{12}$$

$$\mathrm{FPAR}_{\mathrm{max}} = b \log(\mathrm{NDVI}_{\mathrm{max}} - \mathrm{NDVI}_{\mathrm{min}} + 1) + \mathrm{FPAR}_{\mathrm{min}} \tag{13}$$

$$\mathrm{FPAR}_{\mathrm{max}} = b \ln(\mathrm{NDVI}_{\mathrm{max}} - \mathrm{NDVI}_{\mathrm{min}} + 1) + \mathrm{FPAR}_{\mathrm{min}} \tag{14}$$

Table 4. NDVIs in 2003 were mostly lower than NDVIs in 2001 because some leaves in 5 year old fell before 2003. For plot A 1, NDVI was a little higher than others because of *Acacia sp.*'s characteristic that its leaf has area wider than *Eucalyptus sp*. Because of limitation of available high-spatial resolution satellite data (Landsat ETM+), low-spatial resolution satellite data (MODIS Vegetation Indices 16-Day L 3 Global 250 m ; MOD 13) be utilized for achieving temporal NDVI data as well (Table 5).

Simulated (modeled) values of W_{abv} from 3PGS were calculated (Table 7). Estimation of *E. camaldulensis*'s W_{abv} by 3PGS model are 6.72, 12.31, 17.38 and 22.36 tonDM/ha/year of 1 to 4 years old, respectively. *A. mangium*' W_{abv} estimated by 3PGS model are 7.96, 13.92, 19.56, 25.20 and

Table 4 NDVI and NDVI_FPAR constant values in year 2001 and 2003 ("6 S" represents the values obtained from atmospherically corrected Landsat ETM+ data while "__" represents the values obtained from data without atmospheric correction)

Plot		2001	2003
		NDVI	NDVI
A 1	6 s	0.88	0.65
	—	0.68	0.50
E 2	6 s	0.69	0.50
	—	0.52	0.38

Table 5 Average, maximum and minimum of FPAR and NDVI data of Acacia sp., Eucalyptus sp. study sites, in 1998–2003 (FPAR from MODIS FPAR and FPAR field, NDVI from LANDSAT NDVI and MODIS NDVI)

Age (Yrs)	Planting year	FPAR				NDVI			
		MODIS		Field data		Landsat ETM＋		MODIS	
		Acacia	Eucalyptus	Acacia	Eucalyptus	Acacia	Eucalyptus	Acacia	Eucalyptus
1	1999	0.720	0.670	0.835	N/A	N/A	N/A	N/A	N/A
2	2000	0.740	0.900	0.942	0.822	N/A	N/A	0.751	0.731
3	2001	0.940	0.850	0.942	0.711	0.880	0.690	0.748	0.637
4	2002	0.940	0.630	0.845	0.882	N/A	N/A	0.695	0.630
5	2003	0.630	0.740	0.908	0.873	0.650	0.500	0.627	0.602
	MAX	0.940	0.900	0.942	0.882	0.940	0.900	0.890	0.840
	MIN	0.630	0.630	0.835	0.711	0.340	0.330	0.530	0.390

Table 6 3PGS model parameters values； NDVI_FPAR_const (b) and NDVI_FPAR_inct(a) in 3 cases of relationship of FPAR (from MODIS and Field data) and NDVI(from LANDSAT and MODIS)

Relationship	Plot	*A. Mangium*				*E. Camadulensis*			
	NDVI	Landsat ETM＋		MODIS		Landsat ETM＋		MODIS	
	FPAR	MODIS	Field	MODIS	Field	MODIS	Field	MODIS	Field
Linear	b_1	0.579	0.184	0.944	0.305	0.480	0.184	0.670	0.330
	a_1	0.378	0.778	0.136	0.687	0.490	0.683	0.350	0.601
Log	b_2	1.55	0.535	0.231	0.820	0.196	0.872	1.678	1.070
	a_2	0.63	0.835	0.63	0.835	0.630	0.711	0.630	0.711
ln	b_3	0.316	0.109	0.663	0.215	0.277	0.106	0.377	0.197
	a_3	0.919	0.953	1.042	0.980	0.938	0.854	0.954	0.907

28.20 tonDM/ha/year of 1 to 5 years old, respectively.

In my study area in case of *E. Camadulensis* the best relationship between NDVI and FPAR is Logarithm. NDVI derived from LANDSAT is better than MODIS NDVI. FPAR obtained from field data show better results than MOD_FPAR. The best fitted SLA 0 is 22.5 m^2/kg and Alpha is 0.07 molC/molPAR. In case of *A. Mangium* the best relationship between NDVI and FPAR is Logarithm. NDVI derived from LANDSAT is better than MODIS NDVI. FPAR obtained from MOD_FPAR show better results than field data. The best-fitted SLA is 35 m^2/kg and Alpha is 0.136 molC/molPAR. Root mean square errors (RMSE) and relative RMSE are shown in Table 7 as well. All RMSE of Eucalyptus plot were less than RMSE in Acaia plots. That mean 3PGS model is suitable for Eucalytus sp. more than *Acacia sp*. as show in figure 5.

Table 7　The best fitted values of Specific Leaf Area (SLA) and Canopy Quantum Efficiency (Alpha), Root Mean Square Error and relative RMSE between Modeled (Modeled_Wabv) and Field above ground biomass (Field_Wabv) of *Eucalyptus Camadulensis* (above panel) and *Acacia Mangium* (below panel)

FPAR	Rel	NDVI	SLA 0	Alpha	Age (yrs)	Aboveground Biomass		RMSE	Relative RMSE
						Modeled (tonDM/ha)	Field (tonDM/ha)		
Field data	log	LANDSAT	22.5	0.07	1	6.7174	4.91		
					2	12.3066	11.97		
					3	17.3773	13.99		
					4	22.3568	25.53		
								2.3268	0.3623

FPAR	Rel	NDVI	SLA 0	Alpha	Age (yrs)	Aboveground Biomass		RMSE	Relative RMSE
						Modeled (tonDM/ha)	Field (tonDM/ha)		
MODIS	log	LANDSAT	35	0.13	1	13.53	4.4		
					2	23.66	18.7		
					3	33.25	36.75		
					4	42.84	48.62		
					5	47.95	50.18		
								5.6320	0.7290

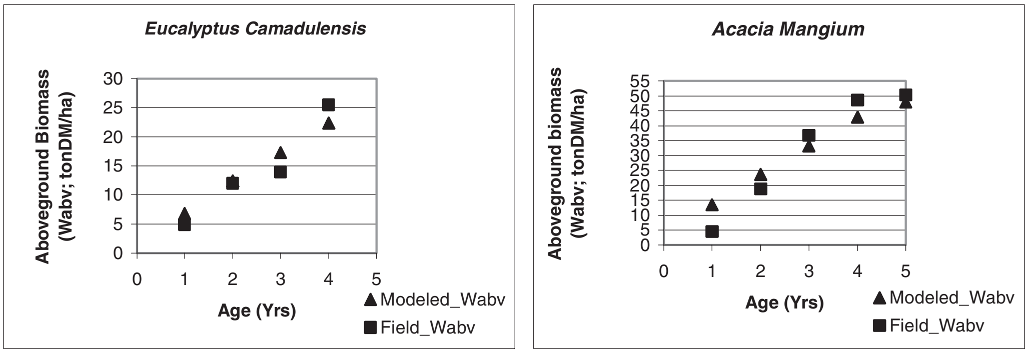

Figure 5　Modeled (Modeled_W_{abv}) and Field above ground biomass (Field_W_{abv}) of Eucalyptus Camadulensis(left) and Acacia Mangium (right)

8. DISCUSSION

Vegetation Index and The Fraction of Photosynthetically Active Radiation ; FPAR

3PGS model calculates APAR from remote sensing derived data NDVI and FPAR that reduce the cost to collect the field data in order to estimate such W_{abv}. Another advantage is that 3PGS model can input some parameters as grid mode (spatial data) such as NDVI, temperature, rainfall and LAI. This means for biomass estimation, 3PGS model is applicable for wide area from local scale to regional scale. Additionally, spatial resolution of satellite images that have effect to NDVI should be considered in term of study area characteristics such as size of forest area, homogenous and even-age stands and area topographic. In case of our study area, tree planting space were 2 m×3 m and 2 m×4 m which has some effect to low NDVI because of the reflectance come from understorey plant or land. Fine spatial resolution images seem to give higher potential on biomass estimation in tropi[20] cs. We agreed that high spatial resolution such as Landsat is better to accurately derive NDVI. Before applying 3PGS model one should consider vegetation index and constraints whether suitable for that study area and tree species or not. For model simulation improvements corrected NDVI (NDVIc) that consider mid-infrared band maybe more appropriate. As a rule of thumb parameter values should be always assigned by direct measurement (observed data). Obtaining all parameters through field measurement is better approach for initial model simulation. Temporal satellite data should be used for NDVI and FPAR relationship in long-term assessment. Their relationship also varies from site to site. Nevertheless, 3PGS model has some limitations of the using of NDVI and FPAR relationship cause from inaccurate NDVI value and availability of satellite data. FPAR can obtain from any sources such as field survey and MODIS FPAR product because result showed not so difference between field data and MODIS product. Due to biomass estimation, NDVI effective in estimating green biomass but it has been found to be very poor indicator of forest biomass since the majority of the forest biomass is non green[22]. In case of *A. Mangium*, W_{abv} from field data is higher than modeled W_{abv} because of *A. Mangium* have many branches and some branches have no green leaves. In future research should consider other vegetation index to use in 3PGS model such as Enhanced Vegetation Index ; EVI, Soil Adjusted Vegetation Index ; SAVI, ect.

Specific Leaf Area (SLA) and Canopy Quantum Efficiency (Alpha)

All sensitive parameters were examined by the relative sensitivity () the results have identified parameters that need to be accurately determined. In this study high sensitive parameters are Canopy quantum efficiency (Alpha) and Specific Leaf Area (SLA) respectively. An analysis should be performed with understanding of biological reality. The important parameters for photosynthetic rate are Alpha and SLA. SLA can be sensitive parameter because they represent key leaf structural and chemical properties be related to leaf and canopy gas exchange rates[7] that depends on age and species (species specific parameter). In further study, SLA should be compared with the actual SLA obtained by field measurement. Because of lacking of SLA from field data then the iterative process was used to find suitable value in our study. Alpha depends on environmental effects such as temperature, vapor pressure deficit, available soil water, site nutrition and stand age[19]. Alpha describe the yield of photochemical reactions in regard to oxygen production or carbon fixation, as a result of the amount and quality of light absorbed by the canopy Alpha also can calculate from W_{abv} field data, solar radiation and FPAR. We found that this Alpha have the same value with Alpha from model's iterative process. Therefore, Alpha value can be used with confidence in 3PGS model for my study area. Lansberg and Warring, 1997 applied Alpha in priori study's assumption is 0.03 and 0.04 molC/molPAR for coniferous forest. In 2001, N. C. Coops et al found Alpha is 0.05 molC/molPAR for *Pinus radiata* plantation. And P. J. Sands et al, 2002 study in *E. globulus* fitting Alpha value is 0.07 molC/molPAR. This value shows same as our result in *E. camadulensis*. Due to Alpha for *A. magium* had not been study yet then here we propose 0.13 molC/molPAR is reference value for future research. This research showed that 3PGS model has species-specific parameters. Site-specific parameters, it is required to calibrate all parameters for each site in future research. Normal procedure is to use standard default or the best available empirical values for as many parameters as possible.

9. CONCLUSION

In this research, we estimated *E. camaldulensis* and *A. mangium*'s W_{abv} in plantation by 3PGS model. We did sensitivity analysis and parameterization. Sensitive parameters are Alpha and SLA. Iterative process was done to optimize Alpha and SLA for matching modeled and field W_{abv}. Alpha are 0.07 and 0.13 molC/mol PAR for *E. camaldulensis* and *A. mangium* respectively. 3PGS model need satellite derived parameters such as NDVI_FPAR_intercept, NDVI_FPAR_const and NDVI average values. Therefore, We have to know the relationship between NDVI and FPAR. NDVI and FPAR can obtain from satellite data, and we found that logarithm relationship is the best for calculating *E. camaldulensis* and *A. mangium*'s W_{abv}. It was revealed that model simulation should consider species-specific parameters. In future our Alpha values can suitable apply for *E. camaldulensis* and *A. mangium*'s W_{abv} estimation. If you have Satellite NDVI and FPAR data, minimum meteorological data and interested species's physiological data, the 3PGS model can widely apply for W_{abv} calculation in other plantations as well.

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