Modern Applied Science; Vol. 7, No. 3; 2013
ISSN 1913-1844 E-ISSN 1913-1852
Published by Canadian Center of Science and Education

Carbon Dioxide Absorption of Common Trees in Chulalongkorn University

Chanon Suwanmontri[1], Charnwit Kositanont[2] & Noppaporn Panich[3]

[1] Inter-department of Environmental Science, Graduate School, Chulalongkorn University, Bangkok, Thailand

[2] Department of Microbiology, Faculty of Science, Chulalongkorn University, Bangkok, Thailand

[3] Environmental Research Institute, Chulalongkorn University, Bangkok, Thailand

Correspondence: Charnwit Kositanont, Department of Microbiology, Faculty of Science, Chulalongkorn University, Phayathai Road, Bangkok 10330, Thailand. Tel: 66-2-218-7667. E-mail: charnwit_k@yahoo.com

Received: January 13, 2013 Accepted: January 31, 2013 Online Published: February 7, 2013

doi:10.5539/mas.v7n3p1 URL: http://dx.doi.org/10.5539/mas.v7n3p1

Abstract

This paper studies the relevance between carbon dioxide (CO_2) absorption rates of common trees in Chulalongkorn University (Thailand), and environmental factors -- light intensity, air temperature, leaf temperature, and CO_2 concentration in air -- by forming non-linear models. The common tree species are *Pterocarpus indicus, Samanea saman, Peltophorum pterocarpum,* and *Terminalia catappa*. Measuring CO_2 absorption was done by chamber analysis approach. The experiment was carried out by gauging 10 leaves, 7 hours per day, and 2 days per species. According to the models, it is obvious that light intensity is the most influential factor to CO_2 absorption for all studied species. *Peltophorum pterocarpum* and *Samanea saman* reach their maximum CO_2 uptake rates of 24.5 and 20.9 CO_2 $\mu mol \cdot m^{-2}s^{-1}$, when photosynthetically active radiation is 1100 and 1500 $\mu mol \cdot m^{-2}s^{-1}$ respectively. The other two do not reach their maximum rate within model data range. The regressions were best fitted with Gaussian function and Sigmoidal function. It is also suggested that *Peltophorum pterocarpum* and *Samanea saman* are good carbon sink and they should be planted more in the city for optimal CO_2 absorption.

Keywords: carbon dioxide absorption, non-linear regression, photosynthetically active radiation

1. Introduction

Environmental problems are such a threat that people all over the world should have concerned. While high technology keeps on in a fast pace, the nature has been contaminated seriously in past decades. Environmental scientists have classified carbon dioxide (CO_2) as the most significant anthropogenic greenhouse gases (Stangeland, 2007; Smith et al., 2003). It has been risen by 39 percent (from 280 parts per million: ppm, to 388 ppm) since the beginning of Industrial Revolution (Wright & Boorse, 2011). There is a possibility of CO_2 effecting on human health if inhaling air with carbon dioxide 426 ppm or more for a long term; and the body may immediately effects from 600 ppm (Robertson, 2006). Carbon dioxide concentration in urban area is likely to be more than 426 ppm because of dense population and human activities (Janagkakan, Chavalparit, & Kanchanapiya, 2012). In order to impede the increase of ambient CO_2 concentration, CO_2-causing activities must be decreased. Or else, trees must be grown more as trees have capacity in carbon dioxide absorption (McPherson, 1998). For the utmost benefit, it is necessary to do research in many tree species to find suitable ones for absorbing CO_2 in standardized and reliable way.

Chulalongkorn University is located on the heart of Bangkok, the most crowded urban area of Thailand. The trees grown in the campus, especially abundant ones, are proved to survive well (Anitha, Joseph, Chandran, Ramasamy, & Prasad, 2010) in polluted air. Therefore, the campus is chosen as the study area. The specific objectives of this research are to find the most influential environmental factor on CO_2 absorption of common tree species in Chulalongkorn University; and to compare the CO_2 absorption capacity among the common species.

2. Methods

2.1 Carbon Dioxide Absorption Experiment

This research uses Li-6400 Portable Photosynthesis System (LI-COR Inc., USA) to measure the CO_2 assimilation. The four most common species in the campus based on abundance, are *Pterocarpus indicus* (generally called Burmese rosewood), *Samanea saman* (Rain tree), *Peltophorum pterocarpum* (Copper pod), and *Terminalia catappa* (Indian almond). As preliminary to the experiment, measuring CO_2 absorption from one leaf was conducted from 8 a.m. to 5 p.m. per species. Respectively for the main experiment, carbon dioxide absorption rates of each common species were measured from 10 leaves of different trees for 7 hours a day, 2 days for one species. Apart from carbon dioxide absorption (CO_2 $\mu mol \cdot m^{-2}s^{-1}$), the instrument also simultaneously measures the actual environmental conditions considered in this research -- photosynthetically active radiation or PAR (photon $\mu mol \cdot m^{-2}s^{-1}$), ambient air temperature (^oC), leaf temperature (^oC), and CO_2 concentration in air (ppm). To be representative of a species, the selected leaves must meet 4 qualifications:

a) The leaves are at canopy level.

b) The leaves directly get the sunlight without any shadow.

c) The leaves are in good shape and perfect, no hole on the leaves.

d) The leaf age is mature; besides, they should be of the same size on average to others.

2.2 Analyzing Experiment Result

In accordance with plant physiological theory (Taiz & Zeiger, 1991), relations between environmental factors, especially PAR, and CO_2 absorption are not likely to be linear (Baligar, Bunce, Elson, & Fageria, 2012; Utsugi, Okuda, Luna, & Gascon, 2009). In this paper, non-linear regressions are formed to find a one-way relation between the environmental variables, and the net carbon assimilation of each species. The followings are 5 choices of regression functions:

(Given $\hat{Y}$ = estimated net CO_2 exchange rates, X = the chosen external factors, α, β = estimated coefficients, X_0 = estimated X-intercept)

a) 3-parameter hill: $$\hat{Y} = [\alpha X^{\beta}] / [\gamma^{\beta} + X^{\beta}] \quad (1)$$

b) 3-parameter Logistic: $$\hat{Y} = [\alpha] / [\,1 + (X/X_0)^{\beta}\,] \quad (2)$$

c) 3-parameter Sigmoidal: $$\hat{Y} = [\alpha] / [\,1 + \exp\{-(X-X_0)/\beta\}\,] \quad (3)$$

d) 2-parameter Exponential Rise to Max: $$\hat{Y} = \alpha\,(\,1 - e^{-\beta X}) \quad (4)$$

e) 3-parameter Gaussian: $$\hat{Y} = [\alpha]\,\exp[-0.5\{(X-X_0)/\beta\}^2] \quad (5)$$

The rise-to-max exponential, Logistic, and Sigmoidal function shows a level-off maximum, that is the CO_2 absorption saturation point to the external factors; while hill and Gaussian function shows a peak, which means increasing external factors after peak negatively affect the absorption.

Coefficients of 5 choice forms subject to each external factor per species are estimated. Regression analysis techniques such as Analysis of Variance (ANOVA), Coefficient of Determination (R^2) are used to explain the best correlation between each variable and the CO_2 absorption of a species. Then, rank influential factors of each species by F value and determine the most suitable regression form for every factor. The soundest regression subject to the most influential external factor is determined as the carbon dioxide absorption model of each species. Combined in one graph, models of all species are compared how much different trends they have.

3. Results and Discussion

3.1 Preliminary Results

The diurnal carbon dioxide absorption of the 4 species is shown in Table 1. As can be seen from Table 1, the CO_2 assimilation of all species was fluctuated all day differently. That was due to unstable weather in the rainy season and measuring in different days. Light intensity (PAR) fluctuated dramatically that were not the same shape as in the research of Sunakorn and Kasemsap (2010), or of Dou, Zhang, Feng, and Liu (2005). It shows that PAR was very low from 8 to 10 a.m. on the day that *Pterocarpus indicus* and *Terminalia catappa* were collected, whereas there were much lighter on the day of *Peltophorum pterocarpum* and *Samanea saman*. Very low PAR data, below 200 photon $\mu mol \cdot m^{-2}s^{-1}$, refers to overcast sky (McDonald & Norton, 1992). It is suggested that comparing CO_2 absorption capacity among species needs many more observations with wider range of data from various trees. The main experiment can deal with this comparison.

Table 1. Diurnal CO_2 absorption and photosynthetically active radiation in preliminary measurement

Time	Pterocarpus indicus		Samanea saman		Peltophorum pterocarpum		Terminalia catappa	
	CO_2 absorption (CO_2 $\mu mol \cdot m^{-2}s^{-1}$)	PAR (photon $\mu mol \cdot m^{-2}s^{-1}$)	CO_2 absorption (CO_2 $\mu mol \cdot m^{-2}s^{-1}$)	PAR (photon $\mu mol \cdot m^{-2}s^{-1}$)	CO_2 absorption (CO_2 $\mu mol \cdot m^{-2}s^{-1}$)	PAR (photon $\mu mol \cdot m^{-2}s^{-1}$)	CO_2 absorption (CO_2 $\mu mol \cdot m^{-2}s^{-1}$)	PAR (photon $\mu mol \cdot m^{-2}s^{-1}$)
8 a.m.	0.83	37	16.45	1381	19.8	1111	2.83	16
9 a.m.	2.73	42	19.05	1464	24.25	877.5	2.62	32.5
10 a.m.	5.48	322.5	11.85	370	10.75	241	6.01	101
11 a.m.	12.35	1691.5	14.7	1610	20.35	1304.5	5.92	135
12 a.m.	9.73	1365	6.4	72	4.58	42	11.55	387.5
1 p.m.	3.22	100	6.23	103.5	4.2	46	4.94	77
2 p.m.	8.1	1364.5	6.74	198.5	11.85	174	3.38	96.5
3 p.m.	3.91	61	11.35	281	11.4	148.6	4.94	79
4 p.m.	2.71	45	4.81	115	5.85	33.5	3.82	45
5 p.m.	1.79	33	3.9	52.5	2.62	33	5.116	345

3.2 Forming Models Using Data from the Main Experiment

Five different non-linear regression functions were applied to each independent variable, and the most suitable function for that variable, one with highest R^2, was selected for each species. Table 2 shows that among 5 choice functions, only 3-parameter Gaussian function and 3-parameter Sigmoidal function were the most appropriate regression forms.

Table 2. Regression forms of CO_2 absorption subject to external factors with best R^2 in ( ), and F value in [ ]

Species	Independent Variable			
	PAR	Leaf temperature	Air temperature	Ambient CO_2 concentration
Pterocarpus indicus	Guassian (0.832) [597.7]	Gaussian (0.203) [30.6]	Gaussian (0.178) [25.9]	N/A*
Samanea saman	Sigmoidal (0.848) [600.9]	Sigmoidal (0.559) [136.5]	Sigmoidal (0.528) [120.3]	Gaussian (0.358) [59.9]
Peltophorum pterocarpum	Gaussian (0.892) [1084.8]	Sigmoidal (0.283) [51.5]	Sigmoidal (0.283) [51.7]	N/A
Terminalia catappa	Gaussian (0.794) [482.8]	Sigmoidal (0.692) [281.7]	Sigmoidal (0.537) [145.0]	N/A

*N/A = not applicable with any function.

Testing Analysis of Variance, all of the regressions were tested as follows:

H_0: $\alpha = \beta = X_0 = 0$ (null hypothesis)

H_A: not all parameters are zero (alternative hypothesis)

Given Significant level (α) = 0.001, critical $F_{0.001}$ value is 11.6 when residual degree of freedom is around 200; therefore, the null hypothesis is rejected if calculated F value outnumber the critical $F_{0.001}$. All calculated F value of the regressions shown in the table (except those not applicable) passed the critical F value and accepted the alternative hypothesis.

Taking F values into account, light intensity (PAR variable) was the most influential factor for all plant species.

The R^2 values, 0.79 to 0.89, were very high despite the experiment with uncontrolled environment. Ambient CO_2 concentration, in opposite, was little related to carbon dioxide absorption rate. The CO_2 concentration data of *Pterocarpus indicus, Peltophorum pterocarpum* and *Terminalia catappa* cannot be regressed by any function due to their extremely scattering data. Only the data of *Samanea saman* had a relation in some level to absorption rate (R^2 was 0.358). According to F and R^2 value, another factor affecting CO_2 assimilation next to PAR is leaf temperature. Air temperature was also an explainable factor at some level, but less than leaf temperature. It is suggested that temperature at the leaf surface directly affects photosynthetic enzyme activities (Hikosaka, Ishikawa, Borjigidai, Muller, & Onoda, 2006; Sage & Kubien, 2007), while air temperature does not. Determined that photosynthetically active radiation was the most important environmental factors affecting CO_2 absorption, the results of estimating regression coefficients of each species with highest R^2 are shown in Table 3.

Table 3. Estimated CO_2 uptake regressions subject to light intensity (X)

Species (function)	Regression	
Pterocarpus indicus (Gaussian)	$\hat{Y} = [24.1045] \exp[-0.5\{(X - 4284.7937)/2133.7638\}2]$	(6)
Samanea saman (Sigmoid)	$\hat{Y} = 21.4604 / [\ 1 + \exp\{- (X - 336.7547) / 274.2606\}]$	(7)
Peltophorum pterocarpum (Gaussian)	$\hat{Y} = [24.4406] \exp[-0.5\{(X - 1096.5999) / 623.951\}2]$	(8)
Terminalia catappa (Gaussian)	$\hat{Y} = [23.504] \exp[-0.5\{(X – 2767.4333) / 1477.9279\}2]$	(9)

It is commonly known that regression is able to predict the dependent variable only in data range used. The model of *Pterocarpus indicus*, *Samanea saman*, *Peltophorum pterocarpum*, and *Terminalia catappa* should be valid from PAR 30 to 1700 $\mu mol \cdot m^{-2}s^{-1}$, 80 to 1700 $\mu mol \cdot m^{-2}s^{-1}$, 30 to 1700 $\mu mol \cdot m^{-2}s^{-1}$, and from PAR 15 to 1500 $\mu mol \cdot m^{-2}s^{-1}$ respectively. Nevertheless, Janjai and Wattan (2011) found that light intensities higher than 1650 $\mu mol \cdot m^{-2}s^{-1}$ should occur in Bangkok only around 11 a.m. to 1 p.m. in March and April, typically warmest months of the year. These carbon dioxide assimilation models should be feasible in most of the time.

3.3 Comparing Carbon Dioxide Absorption Capacity

Figure 1 presents photosynthetic response graphs of 4 common trees plotted from models in Table 3. According to the graph, *Samanea saman* and *Peltophorum pterocarpum* have higher CO_2 assimilation than *Pterocarpus indicus* and *Terminalia catappa* through the photosynthetically active radiation range from 100 to 1800 $\mu mol \cdot m^{-2}s^{-1}$. In the range of 300 to 1400 $\mu mol \cdot m^{-2}s^{-1}$ of light intensity, *Peltophorum pterocarpum*'s CO_2 assimilation is higher than *Samanea saman*. *Peltophorum pterocarpum* shows maximum CO_2 assimilation of 24.5 CO_2 $\mu mol \cdot m^{-2}s^{-1}$ at light intensity of 1100 $\mu mol \cdot m^{-2}s^{-1}$, while *Samanea saman* reaches its CO_2 assimilation plateau of 20.9 CO_2 $\mu mol \cdot m^{-2}s^{-1}$ at 1500 $\mu mol \cdot m^{-2}s^{-1}$ light intensity.

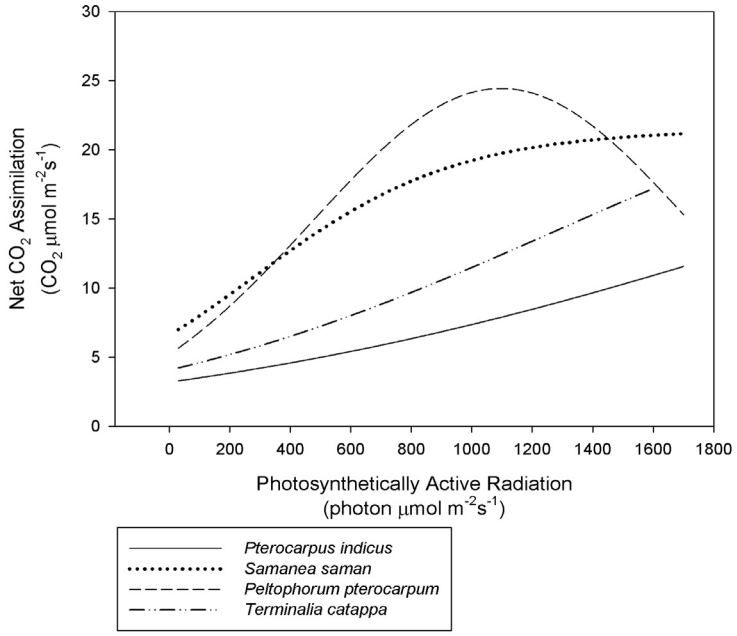

Figure 1. CO_2 photosynthetic response curves of common species to light intensity

Light-response net CO_2 absorption curve in gaussian function is hardly found in other studies. The reason is that this research measures the absorption in real environmental condition, without any control, to explain the actual responses. The decreasing absorption rates of *Peltophorum pterocarpum* after the peak included effects of other factors in residual error such as leaf temperature and ambient air CO_2 concentration. However, most of the studies, using the Li-6400 instrument, controlled external factors other than those being considered. For instance, the study of Koike, Kitaoka, Ichie, Lei, and Kitao (2004) controlled ambient CO_2 concentration at 350 ppm to remove its effect on CO_2 absorption from light-response curve; hence, the curve leveled off like rise-to-max exponential form.

There are few other pieces of research conducted in Bangkok that gauge carbon dioxide absorption of the 4 studied species. Table 4 presents maximum CO_2 absorption of *Pterocarpus indicus* from 2 previous studies compared with this paper's estimation.

Table 4. Comparing CO_2 absorption of *Pterocarpus indicus* from other studies and this paper

Previous study	PAR from the study (photon µmol·$m^{-2}s^{-1}$)	CO_2 absorption from the study (CO_2 µmol·m^{-2}s-1)	CO_2 absorption estimated by this paper's model (CO_2 µmol·$m^{-2}s^{-1}$)
By Puangchit & Royampaeng (1994)			
At Lumpini park	800	6.51	6.35
At Jatujak park	1050	9.46	7.51
By Samphantharak (2005)	800	4.1	6.35

It can be seen that at PAR 800 µmol·$m^{-2}s^{-1}$, the CO_2 absorption rate by Puangchit and Royampaeng (1994) was 6.51, while the absorption rate by Samphantharak (2005) was around 4.1. Applying the same PAR (800 µmol·$m^{-2}s^{-1}$) to the Gaussian model (6) of *Pterocarpus indicus* in this study, the estimated absorption rate was 6.35 µmol·$m^{-2}s^{-1}$. It can be seen that the estimated CO_2 absorption from this research were comparable to the other studies.

4. Conclusion

According to the data, it can be concluded that the carbon dioxide absorption rate in the same environmental condition depends on the species of trees. Photosynthetically active radiation (PAR) clearly affects the CO_2 absorption of trees. The non-linear models derived in this study are well fitted and useful to compare carbon dioxide absorption with other plants. It is implied that carbon dioxide absorption characteristics of these plant species are general to the city. In addition, it is recommended that *Samanea saman* and *Peltophorum pterocarpum* should be planted more in the city in order to reduce ambient CO_2 during day time. Good management of green area in the campus could make better air quality not only for students and staffs, but also for city people.

Acknowledgement

This research is a part of thesis for Master of Science in Environmental Science program accomplishment (Chulalongkorn University), which has been funded by the Graduate School, Chulalongkorn University (H.M. King Bhumibol Adulyadej's 72nd Birthday Anniversary Scholarship).

References

Anitha, K., Joseph, S., Chandran, R. J., Ramasamy, E. V., & Prasad, S. N. (2010). Tree species diversity and community composition in a human-dominated tropical forest of Western Ghats biodiversity hotspot, India. *Ecological Complexity, 7*, 217-224. http://dx.doi.org/10.1016/j.ecocom.2010.02.005

Baligar, V. C., Bunce, J. A., Elson, M. K., & Fageria, N. K. (2012). Photosynthetic Photon Flux Density, carbon dioxide concentration and temperature influence photosynthesis in *Crotalaria* species. *The Open Plant Science Journal, 6*, 1-7. http://dx.doi.org/10.2174/1874294701206010001

Dou, J., Zhang, Y., Feng, Z., & Liu, W. (2005). Variation in photosynthetic photon flux density within a tropical seasonal rain forest of Xishuangbanna, south-western China. *Journal of Environmental Sciences, 17*(6), 966-969. Retrieved from http://www.environmental-expert.com/Files/6620/articles/11704/28-2-4.pdf

Hikosaka, K., Ishikawa, K., Borjigidai, A., Muller, O., & Onoda, Y. (2006). Temperature acclimation of photosynthesis: mechanisms involved in the changes in temperature dependence of photosynthetic rate. *Journal of Experimental Botany, 57*(2), 291-302. http://dx.doi.org/10.1093/jxb/erj049

Janangkakan, B., Chavalparit, O., & Kanchanapiya, P. (2012). Carbon footprint of an academic organization: a case study of the Department of Environmental Engineering, Chulalongkorn University. *Journal of Environmental Research, 34*(1). Retrieved from http://www.eric.chula.ac.th/jer-en/download/v34y2555/v34n1y2555/v34n1a1.pdf

Janjai, S., & Wattan, R. (2011). Development of a model for the estimation of photosynthetically active radiation from geostationary satellite data in a tropical environment. *Remote Sensing of Environment, 115*, 1680-1693. http://dx.doi.org/10.1016/j.rse.2011.02.026

Koike, T., Kitaoka, S., Ichie, T., Lei, T. T., & Kitao, M. (2004). Photosynthetic characteristics of mixed deciduous-broadleaf forests from leaf to stand. *Global Environmental Change in the Ocean and on Land,* 453-472. Retrieved from http://www.terrapub.co.jp/e-library/kawahata/pdf/453.pdf

McDonald, D., & Norton, D. A. (1992). Light environments in temperate New Zealand podocarp rainforests. *New Zealand Journal of Ecology, 16*(1), 15-22. Retrieved from http://www.newzealandecology.org.nz/nzje/free_issues/NZJEcol16_1_15.pdf

McPherson, E. G. (1998). Atmospheric carbon dioxide reduction by Sacramento's urban forest. *Journal of Arboriculture, 24*(4), 215-223. Retrieved from http://www.fs.fed.us/psw/programs/uesd/uep/products/cufr_26_EM98_9.pdf

Puangchit, L., & Royampaeng, S. (1994). Leaf structure and gas exchange characteristics of *Pterocarpus indicus* planted in the city. *Thai Journal of Forestry, 13*, 135-149. Retrieved from http://www.thaiscience.info/journals/Article/Leaf%20structure%20and%20gas%20exchange%20characteristics%20of%20pterocarpus%20indicus%20planted%20in%20the%20city.pdf

Robertson, D. S. (2006). Health effects of increase in concentration of carbon dioxide in the atmosphere. *Current Science, 90*, 1607-1609. Retrieved from http://www.alfaintek.com/assets/files/D_S_Robertson.pdf

Sage, R. F. & Kubien, D. S. (2007). The temperature response of C_3 and C_4 photosynthesis. *Plant, Cell and Environment, 30*, 1086-1106. http://dx.doi.org/10.1111/j.1365-3040.2007.01682.x

Samphantharak, T. (2005). *Leaf CO_2 exchange characteristics of some tree species planted in urban area*.

Bangkok, Thailand: Kasetsart University. Retrieved from http://www.lib.ku.ac.th/KUthesis/2548/ThatsawanSAM/ThatsawanSAMAll.pdf

Smith, K. A., Ball, T., Conen, F., Dobbie, K. E., Massheder, J., & Rey, A. (2003). Exchange of greenhouse gases between soil and atmosphere: interactions of soil physical factors and biological processes. *European Journal of Soil Science, 54*, 779-791. http://dx.doi.org/10.1046/j.1365-2389.2003.00567.x

Stangeland, A. (2007). A model for CO_2 capture potential. *International Journal of Greenhouse Gas Control, 1*(4), 418-429. http://dx.doi.org/10.1016/S1750-5836(07)00087-4

Sunakorn, P., & Kasemsap, P. (2010). CO_2 uptake performance of climbing plant wall. *Journal of Architectural/Planning Research and Studies, 7*, 175-190. Retrieved from http://www.ap.tu.ac.th/jars/download/jars/v7-2/11%20CO2%20Uptake%20Performance_Pasinee%20040811.pdf

Taiz, L., & Zeiger, E. (1991). *Plant physiology*. Redwood, CA: The Benjamin/Cummings Publishing.

Utsugi, H., Okuda, S., Luna, A. C., & Gascon, A. F. (2009). Differences in growth and photosynthesis performance of two dipterocarp species planted in Laguna, the Philippines. *The Japan Agricultural Research Quarterly, 43*(1), 43-53. http://dx.doi.org/10.6090/jarq.43.45

Wright, R. T., & Boorse, D. (2011). *Environmental science: toward a sustainable future* (11th ed.). Upper Saddle River, NJ: Prentice Hall.