Kasetsart J. (Nat. Sci.) 38 : 419 - 424 (2004)

Daily and Annual CO_2 Uptake of *Pterocarpus macrocarpus* and *Azadirachta siamensis* under Field Condition

Sureeporn Kerdkankaew[1], Jesada Luangjame[2] and Pojanie Khummongkol[3]

ABSTRACT

The green areas are generally taken into account for building projects and the city planning. Annual CO_2 uptake obtained by the field measurement, followed by the mathematical model can be used to calculate the green area. Hence, this study investigated values of daily and annual CO_2 uptake by two plant species, *Pterocarpus macrocarpus* and *Azadirachta siamensis*. The experimental results showed that average daytime CO_2 uptake rates were significantly higher for *A. siamensis* than *P. macrocarpus* in August and December. The monthly daytime CO_2 uptake showed the highest value in December of 69.05 gC m^{-2} for *P. macrocarpus* and 89.27 gC m^{-2} for *A. siamensis*. For the monthly nighttime CO_2 release, the highest value was in March of 24.40 gC m^{-2} for *P. macrocarpus* and 26.66 gC m^{-2} for *A. siamensis*. The annual estimations in daytime CO_2 uptake, nighttime CO_2 release and net CO_2 uptake for *P. macrocarpus* were 641.69 gC m^{-2}, 259.06 gC m^{-2} and 382.63 gC m^{-2}, respectively. For *A. siamensis*, the annual estimations in daytime CO_2 uptake, nighttime CO_2 release and net CO_2 uptake were 773.66 gC m^{-2}, 286.43 gC m^{-2} and 487.23 gC m^{-2}, respectively.

Key words: carbon sequester, fast-growing tree, green area, plantation, slow-growing tree

INTRODUCTION

The ambient CO_2 has been on an increasing rate because of the human activities which include fuel combustion, deforestation and agriculture. These effects could be linked to an average higher temperature during a summer time in some explicit European countries. However, to mitigate and control this problem, afforestation is considered as a method for CO_2 reduction. In a large city, green land is also an important area for reducing air pollution and CO_2 and producing the essential gas for living of animals i.e. O_2. Therefore, the green area is generally included in the building project and city planning.

To determine the quantity of the green area, annual CO_2 uptake obtained by the field measurement followed by the mathematical model is applied. The field measurements determine a value of net photosynthesis or the net CO_2 flux. Hollinger *et al.* (1994) showed that leaf-level responses of photosynthesis to irradiance, temperature and air saturation deficit were very similar to responses obtained from measurements of net CO_2 flux over a range of environmental conditions using eddy covariance (EC). EC which

1 The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, Bangkok 10140, Thailand. e-mail: sureekaew@hotmail.com

2 Department of National Park, Wildlife and Plant Conservation. Phaholyothin Rd., Chatuchak, Bangkok 10900, Thailand.

3 Division of Environmental Technology, School of Energy and Materials, King Mongkut's University of Technology, Thonburi, Thailand.

Received date : 21/04/04 Accepted date : 18/06/04

is a practical method, therefore has currently been used to estimate daily and annual CO_2 uptake. Barcza (2001) also evaluated the CO_2 storage using the EC technique. His study reported the absorbed quantity of 134 gC m^{-2} in 1997, 146 gC m^{-2} in 1998, and only 92 gC m^{-2} in 1999 over the agricultural region. In addition, Rannik *et al.* (2002) measured CO_2 uptake of the forest ecosystem using the shoot scale gas exchange measurement in combination with process-based modeling. As a result, the average daily CO_2 uptake by the forest was found to be 2.4 g m^{-2} d^{-1} in July-August and 1.7 g m^{-2} d^{-1} in September.

Although the rates of daily or annual CO_2 uptake are important values for estimating the CO_2 reduction quantity and consequently determining the land area, they are impractical for measuring in a field by a portable photosynthesis system throughout a year. This study, instead, calculated daily and annual CO_2 uptake using the leaf-scale CO_2 uptake measurements and the mathematical equation. Furthermore, the study focused on *Pterocarpus macrocarpus* (praduu pa), the slow-growing tree, and *Azadirachta siamensis* (sadao Thai), the fast-growing tree since they had been widely planted throughout the country.

MATERIALS AND METHODS

The study site was located at the Silvicultural Research Center No.3, Tha Muang district, Kanchanaburi province (14°01′ N latitude, 99°45′ E longitude, 60 msl altitude). The soil type was a sandy loam. *P. macrocarpus* and *A. siamensis* were planted in June 1989 at 4 × 4 m spacing. They were grown into two separated plots, covering a total area of 7,712 m^2. The diameter at breast height (DBH) of *P. macrocarpus* was in the range of 32-50 cm and *A. siamensis* was 38-78 cm.

For each measurement, four trees of *P. macrocarpus* and *A. siamensis* were randomly selected. Ten mature leaves facing east to west in each selected tree were chosen and CO_2 uptakes were measured by a portable photosynthesis system (Li-Cor 6200) at one-hour interval. All measurements were taken in February, June, August and December 2000 from 06:30 to 19:30 hr. Respiration rate was measured during 18:00-19:30 hr where PAR was less than 8 μmol m^{-2} s^{-1} (Koskela *et al.*, 1999; Rannik, 2002).

Calculation of daytime CO_2 uptake

To determine the daytime CO_2 uptake by both tree species, the hourly CO_2 uptake was integrated from 08:00 to 17:30 hr. During these hours CO_2 emission was excluded.

Calculation of daily CO_2 uptake

The daily CO_2 uptake was the summation of the daytime CO_2 uptake during 06:30-19:30 hr and the nighttime respiration rate between 19:30-06:30 hr (Rannik *et al.*, 2002), as shown in equation (1).

$$A = P_n - R \quad (1)$$

where A is net CO_2 uptake rate, P_n is daytime CO_2 uptake, R is nighttime CO_2 release or respiration rate. The daytime CO_2 uptake is the integration of hourly net CO_2 uptake rate (Roberts, 1992). The nighttime CO_2 release can be calculated by the respiration equation and the daily average air temperature from Kanchanaburi Meteorological Station. The respiration equation is:

$$R_{(Ta)} = R_0.2^{Ta/10} \quad (2)$$

where $R(Ta)$ is the measured respiration rate at air temperature (Ta) °C, R_0 is the respiration rate at air temperature 0 °C and Ta is the air temperature (°C). Parameter value of R_0 was estimated on fitting the measured respiration rates in Eq. (2) by the least square method (Koskela *et al.*, 1999). Subsequently, the daily nighttime respiration rate was evaluated by substitution the R_0 and daily average air temperature into Eq. (2).

Calculation of annual CO_2 uptake

Annual CO_2 uptake is the integration of monthly net CO_2 uptake rate in each plant (Barcza, 2001). The monthly CO_2 uptake is the summation of daily CO_2 uptake in each month. The annual was obtained by replacing missing daytime data with the light-response estimates (Griffis *et al*., 2003) and by interpolation.

Statistical analysis

Daytime CO_2 uptake and nighttime CO_2 release were calculated and presented in average value (±SD) for each tree species. The differences between measured periods were statistically analyzed by using the one-way analysis of variance (ANOVA) of statistical software with the Duncan's New Multiple Range Test at significant levels $P \leq 0.05$. The differences between tree species were analyzed by the Student's *t* test procedure at significant levels $P \leq 0.05$.

RESULTS AND DISCUSSION

Average daytime CO_2 uptake rates

Average daytime CO_2 uptake rates measured from 08:00 to 17:30 hr were found to be 59.94 (±8.92) and 101.59 (±3.03) $mgCO_2\ dm^{-2}\ d^{-1}$ for *A. siamensis* and 44.34 (±3.71) and 76.68 (±1.10) $mgCO_2\ dm^{-2}\ d^{-1}$ for *P. macrocarpus* in August and December 2000, respectively. This shows a significant higher CO_2 uptake rate of *A. siamensis* than *P. macrocarpus* in August (P=0.035) and December (P=0.002) but not significant in February (P=0.253) and June (P=0.151), as shown in Figure 1. It was believed that *P. macrocarpus* had a higher resistance to water stress than *A. siamensis*. This observation agreed with the result of Man and Lieffers (1997). They found the significant differences in capacity of CO_2 uptake between white spruce (*Picea glauca*) and jack pine (*Pinus banksiana*) in June, September and October only because jack pine had a higher tolerance to drought. On the other hand, in February with the high temperature and water stress, the average daytime CO_2 uptake of *A. siamensis* and *P. macrocarpus* were only 57.12 (±1.97) $mgCO_2\ dm^{-2}\ d^{-1}$ and 55.15 (±4.11) $mgCO_2\ dm^{-2}\ d^{-1}$, respectively.

In February, June, August and December 2000, daytime CO_2 uptake of *A. siamensis* was higher than *P. macrocarpus* at 3.58, 6.71, 35.18 and 32.49 %, respectively. This result corresponded with the result of Kuo and Cheng (2001). Their

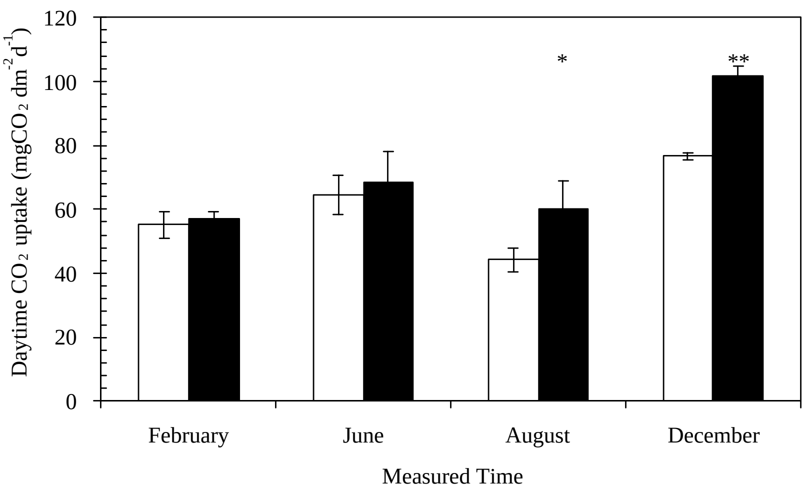

Figure 1 Average daytime CO_2 uptake (08:00-17.30 hr) of *P. macrocarpus* (the white column) and *A. siamensis* (the dark column) in the measured time in 2000 (n=40). Significant differences for tree species indicated by * $P \leq 0.05$; ** $P \leq 0.01$.

study found that the CO_2 uptake in *Laportea pterostigma* seedling was significantly lower than *Mallotus paniculatus*.

Calculation of daily and annual net CO_2 uptake

Table 1 shows the average calculated values of daytime CO_2 uptake, nighttime CO_2 release and net daily CO_2 uptake of *A. siamensis* and *P. macrocarpus* in 2000. The daytime CO_2 uptake and nighttime CO_2 release in both tree species were significantly different ($P=0.012$ and $P<0.001$, respectively). The daily net CO_2 uptake rate calculated ranged 2.8-21.4 gC m^{-2} d^{-1} for *A. siamensis* and 3.6-15.7 gC m^{-2} d^{-1} for *P. macrocarpus*. This result was similar with the report of Albrizio and Steduto (2003). They reported the different daily CO_2 uptake for four crops: the maximum daily CO_2 uptake were 26.45, 25.17 and 23.62 gC m^{-2} d^{-1} for sunflower (*Helianthus annuus*), sorghum (*Sorghum bicolor*) and chickpea (*Cicer arietinum*) respectively, but only 10.5 gC m^{-2} d^{-1} for wheat (*Triticum respectively, durum*). However, these values were different from the other reports because the study focused on the leaf CO_2 uptake and release whereas the others were studied in the ecosystem which included the soil respiration. For instance, Vorlitis *et al.* (2001) reported the daily net CO_2 uptake rate of 6.6-12.2 gC m^{-2} d^{-1} in Amazon forest (cerradão) whereas Rannik *et al.* (2002) reported 1.7-2.4 gC m^{-2} d^{-1}. Furthermore, the monthly daytime CO_2 uptake was at the lowest value in April for both tree species with the values of about 34.6 gC m^{-2} (Table 2). This correlated with the results of other study (Vourlitis *et al.*, 2001). The lowest CO_2 uptake was observed in summer with the drought stress. The highest values in both tree species, *P. macrocarpus* and *A. siamensis*, were also found in December at 69.1 and 89.3 gC m^{-2}, respectively. This result differed from the study of Barcza

Table 1 The average daytime CO_2 uptake, nighttime CO_2 release and net daily CO_2 uptake of *P. macrocarpus* and *A. siamensis* in 2000. Daytime from 06:30 to 19:30 hr and nighttime 19:30-06:30 hr.

Month	*P. macrocarpus* (g C m^{-2} d^{-1})1/			*A. siamensis* (g C m^{-2} d^{-1})1/		
	Daytime CO_2 uptake	Nighttime CO_2 release	Net CO_2 uptake	Daytime CO_2 uptake	Nighttime CO_2 release	Net CO_2 uptake
January	1.48 b2/	0.68	0.79 c	2.30 d	0.77	1.52 d
February	1.50 b	0.68	0.82 c	1.65 c	0.77	0.88 c
March	1.33 b	0.79	0.54 b	1.40 b	0.86	0.54 b
April	1.15 a	0.80	0.36 a	1.15 a	0.87	0.28 a
May	1.33 b	0.75	0.58 b	1.40 b	0.83	0.57 b
June	2.03 cd	0.71	1.32 de	2.40 de	0.77	1.63 d
July	1.96 c	0.69	1.27 de	2.31 d	0.75	1.56 d
August	1.89c	0.71	1.18 d	2.23 d	0.77	1.46 d
September	1.97 cd	0.73	1.24 de	2.39 de	0.81	1.58 de
October	2.06 cde	0.67	1.39 ef	2.55 ef	0.73	1.82 ef
November	2.14 de	0.62	1.52 f	2.72 fg	0.70	2.01 fg
December	2.23 e	0.66	1.57 f	2.88 g	0.74	2.13 g

1/ the CO_2 uptake and release were calculated per one unit of leaf area.
2/ the different letters in the same column are significant by different at $P < 0.05$ using Duncan's New Multiple Range Test.

(2001), which showed the highest value in wet season in Hungary forest. It might be due to the different climate. In tropical forest, cloud was commonly found in the rainy season (Man and Lieffers, 1997) hence decreasing the CO_2 uptake while the weather was related to lower temperature in the winter thus increasing the CO_2 uptake. On the contrary, the weather was cold and freezing in temperate forest therefore the CO_2 uptake is inhibited.

For the monthly nighttime CO_2 release in both tree species, the lowest and highest values occurred in the same month. The lowest CO_2 release was in November at 21.2 gC m^{-2} for *A. siamensis* and only 18.7 gC m^{-2} for *P. macrocarpus*. The highest values for *P. macrocarpus* and *A. siamensis* were found in March at 24.4 and 26.7 gC m^{-2}, respectively. In dry season, the CO_2 release rates were high but the CO_2 uptakes were low because of the higher temperature and the lesser water availability.

The annual daytime CO_2 uptake was 641.7 gC m^{-2} in *P. macrocarpus* and 773.7 gC m^{-2} in *A. siamensis* (Table 2). The annual nighttime CO_2 releases were 259.1 gC m^{-2} and 286.4 gC m^{-2} in *P. macrocarpus* and *A. siamensis*, respectively. The calculated annual net CO_2 uptakes were 382.7 gC m^{-2} in *P. macrocarpus* and 487.2 gC m^{-2} in *A. siamensis*, which were similar to the other results. For example, Barcza (2001) reported annual CO_2 uptake in the tropical forest ranged 100-590 gC m^{-2}. Whitehead *et al.* (2001) showed the ranged annual CO_2 uptake of 700-2300 gC m^{-2} for indigenous forests in New Zealand.

CONCLUSION

In a large city, green land is an inpostant

Table 2 The average monthly and annual values of daytime CO_2 uptake, nighttime CO_2 release and net CO_2 uptake of *P. macrocarpus* and *A. siamensis* in 2000.

Month	*P. macrocarpus* (g C m^{-2})1/			*A. siamensis* (g C m^{-2})1/		
	Daytime CO_2 uptake	Nighttime CO_2 release	Net CO_2 uptake	Daytime CO_2 uptake	Nighttime CO_2 release	Net CO_2 uptake
January	45.87 d2/	21.21 e	24.66 e	71.22 e	23.95 f	47.27 g
February	42.11 c	19.69 b	22.42 d	46.24 c	22.24 b	23.99 d
March	41.22 b	24.40 j	16.82 b	43.44 b	26.66 j	16.77 b
April	34.66 a	23.98 i	10.68 a	34.53 a	26.20 i	8.33 a
May	41.22 b	23.36 h	17.86 c	43.44 b	25.67 h	17.76 c
June	60.80 g	21.20 e	39.60 i	72.05 g	23.16 d	48.89 i
July	60.73 g	21.38 f	39.35 h	71.80 f	23.36 e	48.44 h
August	58.62 e	21.20 e	37.42 g	69.15 d	23.16 d	45.99 e
September	59.26 f	22.76 g	36.50 f	71.79 f	25.02 g	46.77 f
October	63.84 h	20.74 d	43.10 j	79.21 h	22.79 c	56.42 j
November	64.30 i	18.74 a	45.56 k	81.52 i	21.16 a	60.36 k
December	69.05 j	20.40 c	48.65 l	89.27 j	23.04 d	66.23 l
Annual	**641.69**	**259.06**	**382.63**	**773.66**	**286.43**	**487.23**

1/ the CO_2 uptake and release were calculated per one unit of leaf area.

2/ the different letters are statistically significant differences at $P < 0.05$ using Duncan's New Multiple Range Test.

area for reducing air pollution and producing the essential gas for living of animals. Therefore,the green areas are taken into account for building projects and the city planning. Consequently for city planning, a fast - growing tree (*A.siamensis*) should be planted in order to reduce air pollution and produce O_2.

ACKNOWLEDGEMENTS

The authors would like to thank the National Energy Policy Office (NEPO), Thailand for their financial support and the Department of National Parks, Wildlife and Plant Conservation for the study site instruments and facilities. Thanks are due to Prof. Dr. Kasem Chunkao and Dr. Damrong Pipatwattanakul for their guidance and comment.

LITERATURE CITED

Albrizio, R. and P. Steduto. 2003. Photosynthesis, respiration and conservative carbon use efficiency of four field grown crops. **Agric For Meteorol**. 16: 19-36.

Barcza, Z. 2001. **Long Term Atmosphere/ Biosphere Exchange of CO_2 in Hungary.** Ph.D. Dissertation, Eötvös Loŕand Univesity, Hungary.

Griffis, T.J., T.A. Black, K. Morgenstern, A.G. Barr, Z. Nesic, G.B. Drewitt, D. Gaumont-Guay and J.H. McCaughey. 2003. Ecophysiological controls on the carbon balances of three southern boreal forests. **Agric. For Meteorol.** 117: 53-71.

Hollinger, D.Y., F.M. Kelliher, J.N. Byers, J.E. Hunt, T.M. McSeveny and P.L. Weir. 1994. Carbon dioxide exchange between an undisturbed old-growth temperate forest and the atmosphere. **Ecology** 75: 134-150.

Koskela, J., P. Hari and D. Pipatwattanakul. 1999. Analyses of gas exchange of Merkus pine populations by the optimality. **Tree Physiol.** 19: 511-518.

Kuo, Y-L. and C-T. Cheng. 2001. High CO_2 levels near the forest floor may compensate for the light-limited rates of net photosynthesis in understory shade-tolerant seedlings, pp. 184-199. *In* C.T. Chien and R. Rose (eds.). **Proceedings of the Tropical Forestry Symposium: The Art and Practice of Conservation Planting.** Sep. 24-29, 2001. Taipei, Taiwan.

Man, R. and V.J. Lieffers. 1997. Seasonal variations of photosynthetic capacities of white spruce (*Picea glauca)* and jack pine *(Pinus banksiana)* Saplings. **Can. J. Bot.** 75: 1766-1771.

Rannik, Ü., N. Altimir, J. Raittla, T. Suni, A. Gaman, T. Hussein, T. Hölttä, H. Lassila, M. Latokartano, A. Lauri, A. Ntsheh, T. Petäjä, R. Sorjamaa, H. Ylä-Mella, P. Keronen, F. Berninger, T. Vesala, P. Hari and M. Kulmala. 2002. Fluxes of carbon dioxide and water vapour over Scots pine forest and clearing. **Agric. For Meteorol.** 111: 187-202.

Roberts, J.M., P.T.W. Rosier and K.V.S. Murthy. 1992. Physiological studies in young eucalyptus stands in southern India and their use in estimating forest transpiration, pp. 214-220. *In* I.R. Calder, R.L. Hall and P.G. Adlard (eds.). **Growth and water use of forest plantations.** John Wiley and Sons, UK.

Vourlitis, G.L., N.P. Filho, M.M.S. Hayashi, J.D.S. Nogueira, F.T. Caseiro and J.H. Campelo. 2001. Seasonal variations in the net ecosystem CO_2 exchange of a mature Amazonian transitional tropical forest. **Funct. Ecol.** 15: 388-395.

Whitehead, D., J.R. Leathwich and A.S. Walcroft. 2001. Modeling annual carbon uptake for the indigenous forests of New Zealand. **For. Sci.** 47(1): 9-20.