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Carbon Dioxide Budget in *Phragmites communis* Stands

Ihm, Hyun-Bin[1], Byung-Sun Ihm[1*], Jeom-Sook Lee[2], Jong-Wook Kim[1] and Ha-Song Kim[3]

[1]*Department of Biology, Mokpo National University, Muan-Gun 534-729, Korea*

[2]*Department of Biology, Kunsan National University, Kunsan 573-701, Korea*

[3]*Department of Herbal Medicine Resources Development, Naju College, Naju 520-713, Korea*

ABSTRACT: The dynamic model was developed to simulate the photosynthetic rate of *Phragmites communis* stands in coastal ecosystem. The model was composed of the compartments of both climatic and biological variables. The former were photosynthetic photon flux density (PPFD), daily maximum- and minimum-temperature. The latter were combinations of the specific physiological responses of plant organs with the biomass of each organs. The PPFD and air temperature were calculated and using those values, gas exchange rate of each plant organ was calculated at every hour. The carbon budget was constructed using the modelled predictions. Analysis of annual productivity and fluxes showed that yearly gross population productivity, yearly population respiration and yearly net population productivity were 33.4, 21.3 and 12.1 CO^2 ton · ha^{-2} · yr^{-1}, respectively. The final result was tested over two stands, produced promising predictions with regards to the levels of production attained. The model can be used to determine production potential under given climatic conditions and could even be applied to plant canopies with analogous biological characteristics.

Key words: Carbon budget, Gross productivity, Net productivity *Phragmites communis*,

INTRODUCTION

Phragmites communis (common reed) is a C_3 carbon metabolism grass, is considered as highly productive, and has a wide global distribution, often present in wet regions as vast homogeneous expanses of reed bads (*Allirand and Gosse 1995*). *P. communis* community grows mostly in fresh but also in brackish and saline water (*Min and Kim 1983, Oh and Ihm 1983, Ihm et al. 2001*). They are broadly distributed in the western and southern coast in Korea (*Kim et al. 1982, Oh and Ihm 1983, Ihm and Lee 1998*). These reeds have been utilized to produce non-food commodities, such as paper pulp, roofing and building materials, and in waste water treatment plants (*Allirand and Gosse 1995*).

The stand development and biomass production of *P. communis* have been studied intensively in the field (*Haslam 1969a, 1969b, 1970, Dykyjova et al. 1970, Kvet 1971, Dykyjova and Pribil 1975, Fiala 1976, Ho 1979*). Such characteristics as CO_2 exchange and salt tolerence have been evaluted in the different locations (*Purer 1942, Walker and Waygood 1968, Sieghardt 1973, Gloser 1977, Matoh et al.* 1988, *Cizkova and Bauer 1998, Lissner et al. 1999*).

In Korea, *Kim* (*1971, 1975*) studied the process of plant community formation and standing crops in *P. communis* stands. The productivity of *P. communis* community was studied by *Kim et al.* (*1972*) in Yeongnam and Kyonggi regions, *Min and Kim* (1983) in Inchon, and *Oh and Ihm* (*1983*) in the Sumjin river estuary. *Chang and Oh* (*1977*) and *Chang et al.* (*1978*) studied the litter decomposition in *Phragmites* grassland in the delta of the Nakdong river.

Although many experiments have analyzed the growth dynamics of *P. communis*, few researchers have attempted to analyze the change of the primary production for *Phragmites* species using numerical simulation models (*Kim et al. 1972, Allirand and Gosse 1995, Asaeda and Karunaratne 2000.*).

The purpose of this paper is to analyze the effects of PPFD and air temperature on carbon dioxide budget of a well-established *P. communis* stands growing in coastal wetlands in Korea. Net annual photosynthesis is estimated by an empirical model developed on the basis of the measurements of both biometrical data and ecophysiological processes such as leaf photosynthesis and the respiration of leaves, stems and roots and rhizomes.

MATERIALS AND METHODS

The study site is located in Seoho-ri, cheongkye-myon, Muan-gun, Cheollanamdo Province (34° 58′ E, 126° 24′ N). The site is covered by a well-established *P. communis* stands, which are about 3.2 m in height in August. During the last 30 years the observations by Mokpo meterological station near Muan showed that the annual precipitation is around 1217 mm, 45-60 percent

*Author for correspondence; Phone: 82-61-450-2343, Fax: 82-61-454-0267, e-mail: ihmbs@chungkye.mokpo.ac.kr

of it comes in summer, and only 3-10 percent in winter.

The vertical light transmittance within the stand was measured on a ladder at 0.1 m intervals within the canopy at near noon on a fine day (11:00 to 14:00 solar time) in August. To measure horizontal light intensity was established by running string horizontally within a 5 × 5 m quadrat and the light intensity was measured at least 10 times at each intersecting point each height. The relative light intensity was determined using the method described by Kim (1985). Using above results the vertical and the horizontal light intensity within the canopy were calculated on the basis of the Lambert-Beer Law (Monsi and Saeki 1953, Ondok 1973). Gas exchange of leaves, stems and roots and rhizomes were measured using an infra-red gas analyzer (ADC, UK).

RESULTS AND DISCUSSION

Model structure

The model was composed of the compartments of both climatic and biological variables. The former were photosynthetic photon flux density (PPFD), daily maximum- and minimum-temperature. The latter were combinations of the specific physiological responses of plant organs with the biomass of the respective organs (Fig. 1).

The PPFD and air temperature were calculated and using their values the gas exchange rate of each plant organ was calculated at every hour. They were summed up as daily and annual outputs.

Diurnal pattern of climatic variables

The daily PPFD cycle was approximated by the method of Anderson (1971) and was corrected by cloud cover according to O'Rourke and Teijung (1981). The daily temperature cycle was approximated by sinusoidal equation using daily maximum- and minimum-values from a nearby meteorological station (Suh 1992, Kim and Kim 1997).

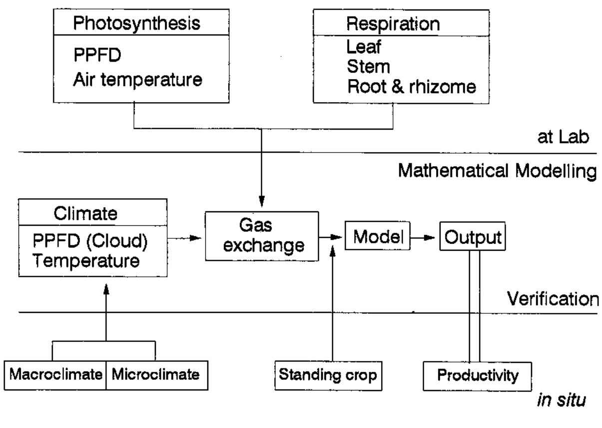

Fig. 1. Flow chart showing the experimental design in this study.

Seasonal change of leaf area

The empirical equation between leaf area (LA_t, m^2) and a given day (t) for growing season in a given year was determined by an logistic growth equation.

$$LA_t = \frac{K_{LA}}{1 + \exp(c - r\,t)} \quad (1)$$

where c and r are the integration coefficient and the growth coefficient of leaf area in a given year. K_{LA} = 4.409 m^2/m^2; c = 2.029; r = -0.0465.

Respiration of plant organs

The respiration rates of leaves (R_l) in mg CO_2 $dm^{-2}h^{-1}$, stems (R_s) in mg CO_2 $g^{-1}h^{-1}$ and roots and rhizomes (R_r) in mg CO_2 g^{-1} h_{-1} to temperature (T, ℃) were approximated by exponential equations (Fig. 2).

$$R_l = \exp(-2.096 + 0.043\,T) \quad (2)$$
(r = 0.963)

$$R_s = \exp(-2.742 + 0.044\,T) \quad (3)$$
(r = 0.965)

$$R_r = \exp(-3.765 + 0.055\,T) \quad (4)$$
(r = 0.974)

Net photosynthetic rate

The net photosynthetic rate $P(Q, T)$ in mg CO_2 $dm^{-2}h^{-1}$ at a given PPFD (Q, mmol quanta $m^{-1}s^{-1}$) and T (℃) can be calculated by Eq. (5), transforming the equation of Potvin *et al.* (1990). The constant f was given as -2.958 by the regression equation between net photosynthetic rate and PPFD at the optimum temperature (Fig. 3):

$$P(Q, T) = P_g\{1 - \exp(f \cdot Q)\} - Rl \quad (5)$$

where P_g is gross photosynthetic rate (mg CO_2 $dm^{-2}h^{-1}$).

Assuming that Q is very large or under saturation we may modify Eq. (5) to

$$P(\infty, T) = P_g - R_l = P_x \quad (6)$$

Under saturating PPFD the relation of photosynthetic rate (P_x, mg CO_2 $dm^{-2}h^{-1}$) to T was approximated by the quadratic function (Anderson 1982) (Fig. 3):

$$P_x = -7.646 + 1.710\,T - 0.030\,T^2 \quad (7)$$

Hourly CO_2 exchanges were calculated as changes of hourly environmental conditions and summed as daily and yearly amounts.

In sensitivity analyses to investigate the change of certain input data, net photosynthetic rate increases proportionally as PPFD increase with canopy. As variable multiplication factor

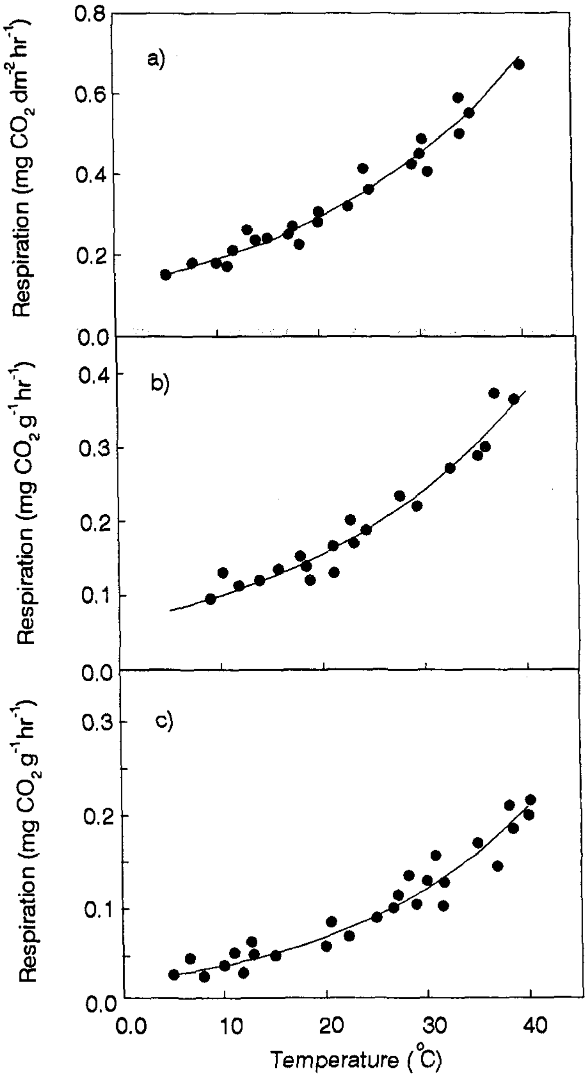

Fig. 2. Respiration rate of leaves (a), stems (b) and roots and rhizomes (c) dependent upon temperature in *P. communis*.

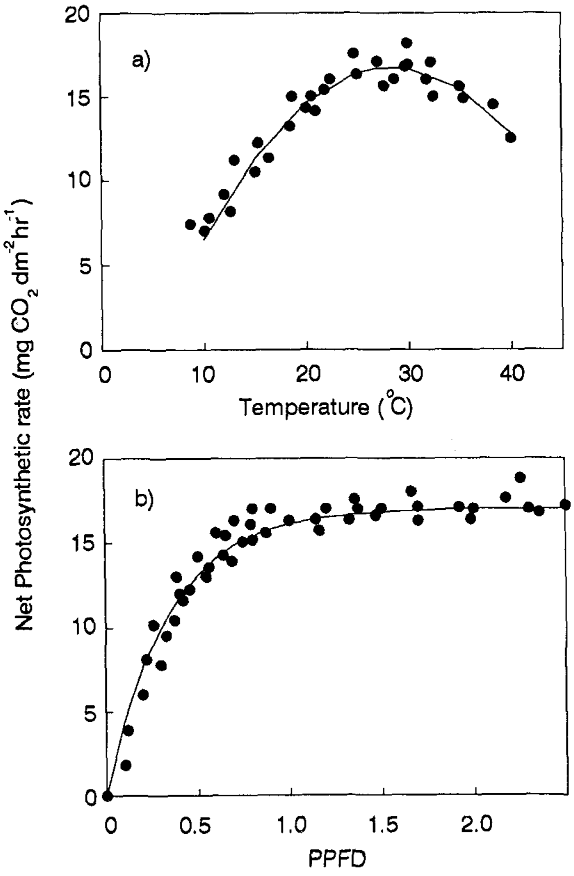

Fig. 3. Net photosynthetic rate dependent upon temperature (a) and PPFD (b) in *P. communis* leaves.

increases from 0.5 to 2.0, net photosynthetic rate inhibited by cloud cover decrease by as little as 10%. The sensitivity coefficients for gross photosynthetic rate and leaf area index contributed linearly to increase of net photosynthetic rate.

Analysis of annual productivity and fluxes showed that yearly gross population productivity, yearly population respiration and yearly net population productivity were 33.4, 21.3 and 12.1 ton CO_2 $ha^{-1}yr^{-1}$, respectively (Table 1). The dry matter net population productivity was 7.9 ton $ha^{-1}yr^{-1}$. The result was tested over two stands, produced 75 - 96% predictions of 8.4 and 10.5 ton $ha^{-1}yr^{-1}$ of tested stands. The model showed the annual carbon dioxide fluxes related to both above-ground and below-ground production that increased with increasing annual temperature. We observed that respiration of leaves and stems, as well as of

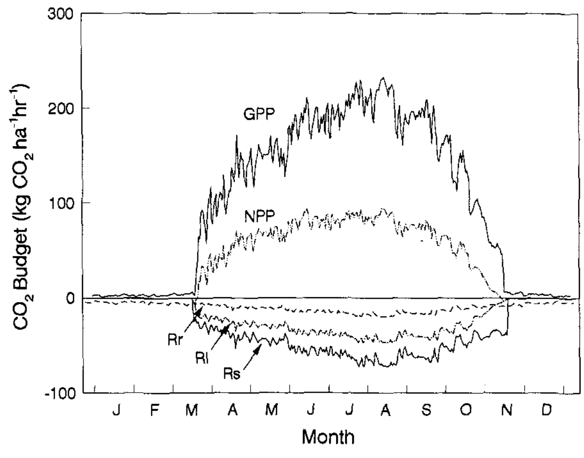

Fig. 4. Annual trends in population respiration of leaves (R_l), stems (R_s) and roots and rhizomes (R_r), gross population productivity (GPP) and net population productivity (NPP) of *P. communis* stands in the year.

Table 1. Annual carbon dioxide budgets in ton CO_2 $ha^{-1}yr^{-1}$ of *P. communis* population at the study site

Gross population productivity	33.4
Population respiration	
Leaf	6.0
Stem	11.6
Root and rhizome	3.7
Subtotal	21.3
Net population productivity	12.1
DM productivity (0.65 of NPP)	7.9

rhizomes and roots, consume a considerable amount of photosynthetic production.

Aboveground biomass of *P. communis* stands studied by *Kim et al. (1972), Kim (1975), Kim et al. (1982), Kim et al. (1986), Min and Kim (1983)* and *Oh and Ihm (1983)* at various sites in Korea was within a range from 4.1 ton/hr at Gunja which was flooded with the sea water at coast to 64.4 ton/ha at Eulsugdo which was flooded with brackish water at the estuary of the Nagdong river. The dry matter net population productivity of 7.9 ton $ha^{-1}yr^{-1}$ in this study was consistent with that of Muan peninsula by *Kim (1975)* and the Sumjin river estuary by Oh and Ihm (1983), which were located near this study site.

The model can be used to determine production potential under given climatic conditions and could even be applied to plant canopies with analogous biological characteristics. The removal of dissolved inorganic compounds from domestic and agricultural waste using aquatic plants, such as *P. communis,* are of increasing demand. The concept behind waste-water treatment plants using *P. communis* is to remove mainly nitrogen and phosphorous by harvesting the *P. communis* shoots when they contain their maximum amounts of nutrients. The model, with a further extension to the nutrient budget, has the scope to predict this period, thus enabling it to be used as a management tool to plan the harvesting season.

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