Radiation Environment of Mangrove Pneumatophores in Brackish Water

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The pneumatophores of *Avicennia* and *Sonneratia* species photosynthesize and the photosynthetically generated O_2 is used for the respiration in the roots in subsoil. To understand the radiation environment of the pneumatophores, we measured solar radiation on the vertical surface (R_v) in the water with dye films. The R_v averaged over the daytime at a depth of 30 cm was similar to the light compensation points in the pneumatophores. From this result, it can be supposed that the photosynthesis nearly compensated the respiration at a depth of 30 cm and supplied O_2 to the roots in subsoil at shallower places, even when the pneumatophores were submerged in the daytime.

INTRODUCTION

Some species of the mangrove growing in muddy tidal flats have pneumatophores with a distinct green layer including chlorophyll just beneath the epidermis. These pneumatophores, shaped like a rocket, are standing on the mud and submerged according to the tide.

Yabuki *et al.* (1990 a, b, 1991) found that the green layers in pneumatophores of *Avicennia* and *Sonneratia* species photosynthesize and that the photosynthetically generated O_2 is used for the respiration in the roots in subsoil. This photosynthesis has the same features as those of shaded leaves, which have low light compensation points (Yabuki *et al.*, 1990 a) and high activity at low light intensities (Aiga *et al.*, 1995).

In order to understand the radiation environment of the pneumatophores as the dominant factor of photosynthesis, we measured the solar radiation on both the vertical and horizontal surfaces in the brackish water by using the dye film developed by Yoshimura *et al.* (1990) for the estimation of integrated total solar radiation. From the cylindrical form of the pneumatophores, the photosynthesis should be estimated with the solar radiation on the vertical surface (R_v), not with that on the horizontal one (R_h).

MATERIALS AND METHODS

The experiment was conducted at a creek (8°20' N, 98°27' E) in a mangrove forest in Phangnga Bay, southern Thailand, for 48 h from 14:00 on Apr. 9 to 14:00 on Apr. 11, 1995. The creek was about 10 m in width and ran to the east at high tide and to the west at low tide. At the center of the creek, a square shaped styrofoam float, weighted to keep its draft constant, was attached to a fixed pole (Fig. 1). On the surfaces of the float and its arm projecting to the south, integrated total R_v (N, E, S and W) and R_h were measured with dye films (12×35 mm)

Fig. 1 Location of the dye films attached to the float.

above the water and at depths of 1, 5, 10, 15, and 30 cm in the water.

The dye film is a simple instrument for measurement of integrated total solar radiation by using the light fading of its color. This film is a photographic triacetylcellulose film base impregnated with an azo dye (Oil Red O). Integrated solar radiation was calculated from the following equation (Yoshimura *et al.*, 1990),

$$kR = -\ln \frac{D}{D_0} \quad (1)$$

where k is the rate constant, R the total amount of incident radiation, and D_0 and D the absorbance of the film before and after exposure to sunlight, respectively. Here, the value of k was determined from Eq. (1) with the D and D_0 on the horizontal surface above the water and integrated global radiation as R . D and D_0 were measured at the peak absorption wavelength (520 nm) by using a spectrophotometer (Jasco, Ubest-50) with an integration sphere (Jasco, TIS-341). Global radiation was measured with a pyranometer (Eko, MS-100) at the top of the 15 m high tower, about 5 m above the mangrove canopy, located about 50 m north from the experimental point.

RESULTS AND DISCUSSION

The result is shown in Table 1. The hourly average of global radiation is shown in Fig. 2. There was clear weather during most of the experimental period except for the late afternoon on Apr. 9. The films attached to the float were kept out of the shade of the surrounding trees throughout the experimental period. The solar altitude at culmination was 89°. The brackish water in the creek was always muddy because of fine suspended soil particles, so that the films at a depth of 30 cm were not visible.

The integrated R_h in the water decreased to half of that above the water (global radiation), at a depth of 5 cm, and to only 1/20 at 30 cm. From the data at 30 cm, Lambert-Beer's law gave an extinction coefficient of 10 m^{-1} .

Table 1 Integrated solar radiation (MJ m^{-2}) for 48 h (Apr. 9 to Apr. 11, 1995).

Direction		Above water	Depth of water (cm)				
			1	5	10	15	30
Horizontal		$47.7 \pm 0.7^*$ (100)**	40.5 ± 0.9 (85)	23.9 ± 0.8 (50)	15.3 ± 0.4 (32)	7.6 ± 0.6 (16)	2.4 ± 0.2 (5)
Vertical	N	2.9 ± 0.2 (6)	2.8 ± 0.3 (6)	2.8 ± 0.3 (6)	2.4 ± 0.2 (5)	2.3 ± 0.2 (5)	1.9 ± 0.2 (4)
	E	14.8 ± 0.4 (31)	7.2 ± 0.4 (15)	3.4 ± 0.3 (7)	2.9 ± 0.2 (6)	2.4 ± 0.2 (5)	1.5 ± 0.1 (3)
	S	6.7 ± 0.3 (14)	4.3 ± 0.3 (9)	3.3 ± 0.3 (7)	2.4 ± 0.2 (5)	1.9 ± 0.2 (4)	1.4 ± 0.1 (3)
	W	12.9 ± 0.4 (27)	6.2 ± 0.4 (13)	3.8 ± 0.4 (8)	2.9 ± 0.3 (6)	2.3 ± 0.2 (5)	1.9 ± 0.2 (4)

* Mean $\pm$ SD ($N=4$ for the horizontal surface and $N=3$ for vertical surface).

** Percentage of the mean at the horizontal surface above water.

Fig. 2 The change in hourly averaged global radiation measured with a pyranometer.

independent of the depth. At a depth of 1 cm, the R_v on the east and west surfaces was 13–15% of global radiation, and higher than that on the south and north. However, at depths of over 5 cm, the R_v on all 4 directions were similar. Moreover the difference between the R_v and R_h was very small at 30 cm. These showed that almost all sunbeams became diffused at depths of over 5 cm in this muddy water. Although the diurnal changes in the R_v on the 4 directions were probably different even in the water, it was inferred that the amount of solar radiation incident upon the whole surface area around the pneumatophore, at a depth of 30 cm, changed little over the daytime except for the early morning and evening. At 5, 10, 15, and 30 cm, averages of the R_v for the 4 directions were 3.33, 2.65, 2.23, and 1.68 MJ m⁻², respectively. From these averages and the total day length (24 h) during the experimental period (48 h), the R_v averaged over the daytime of 39, 31, 26, and 19 W m⁻² was determined at depths of 5, 10, 15, and 30 cm, respectively.

Yabuki *et al.* (1990a) reported that the light compensation points of photosynthesis in pneumatophores of *Avicennia marina* and *Sonneratia alba* range from 0.02 to 0.03 cal cm⁻² min⁻¹ (= 14 to 21 W m⁻²). These values are similar to the R_v averaged over the daytime at a depth of 30 cm. In their study, the compensation points were determined from the relation between light intensity per unit horizontal area and photosynthetic rates measured with a chamber in which pneumatophores were laid horizontally, under the condition of downward lighting. In the measurement, the lower surfaces of the laid pneumatophores were probably shaded. Therefore, if the light intensity averaged over the surface area was used as in this study, the light compensation points would become lower. In conclusion, it can be supposed that the photosynthesis in the pneumatophores nearly compensated the respiration at a depth of 30 cm, and could supply O₂ to the roots in subsoil at shallower places, even when the pneumatophores were submerged in the daytime. It is needless to say that this conclusion was derived from results under limited environmental conditions and further experiments are needed under other conditions.

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The integrated R_v above the water was about 30% of global radiation on the east and west surfaces, 14% on the south and only 6% on the north. Since the R_v became higher when solar altitude was low, such as in the early morning and evening, the R_v on the east and west surfaces was higher than that on the south. On the north surface, the R_v consisted of only diffused and reflected radiation. In the water, the R_v on both the east and west surfaces decreased as the depth increased although that on the north was nearly

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〈和文抄録〉

マングローブ直立気根の水中光環境

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潮間帯に生息するマングローブの *Avicennia* 属や *Sonneratia* 属の直立気根には、表皮の直下に葉緑素を含む層状の組織が存在する。この組織では光合成が行われ、生成される酸素が地中根の呼吸に利用されることが知られている。本研究では、直立気根の水没時における光合成を評価するために、色素の光退色を利用した簡易積算日射フィルムを用いて、水中での水平面および鉛直面における積算日射量をタイのマングローブ林において測定した。その結果、かなり濁った水中においても、30 cm 程度までの水深では、鉛直面での日平均日射量は光合成の光補償点以上であった。このことは、水没時においても直立気根が光合成によって地中根へ酸素を供給することを示唆している。