A fundamental study on mangrove plantation at mud flats

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Abstract
The coastline where the mangroves disappeared easily suffers erosion by rough waves of sea water. Afforestation of mangroves and restoration of coastal zones, therefore, has recently become an urgent issue. In order to carry out afforestation of mangroves efficiently, it is important to understand the growth characteristics of young seedlings as affected by environmental elements at plantation sites. Young seedlings of some mangrove species have well developed hypocotyls. The hypocotyls of the seedlings are expected to have important role for their growth in an early growth stage. In this paper, photosynthetic activity of the hypocotyls of the seedlings, O_2 concentrations in hypocotyls and roots, and the function of oxygen supply from hypocotyls to roots are outlined. The photosynthetic rates of hypocotyls increased with increasing light intensity. The O_2 concentrations were lower in the roots than in the hypocotyls. The O_2 concentrations in the hypocotyls and the roots decreased when they were submerged and showed greater values at higher light intensities. The hypocotyls diffused gases through their inner tissue system. Extended submersion of hypocotyls under water and shading of hypocotyls suppressed growth of young seedlings. In conclusion, the hypocotyls generate O_2 with photosynthetic action and could transport O_2 to the roots during daytime even when the hypocotyls were submerged under water at a high tide. This function would allow seedlings of mangroves such as *Rhizophoraceae* having well developed hypocotyls to grow under muddy anaerobic soil conditions in estuaries.

Keywords: *coastal zones, mangroves, mudflats, plantation, seedlings, hypocotyls, oxygen*

1. Introduction
Tropical coastal zones have recently been damaged by increasing of population pressures, food production and industrial and urban development in many parts of the world. Especially in Vietnam, the mangroves were destroyed during the two Indochina wars. Recently, excess cutting of mangroves for fuel and construction materials and conversion of mangrove forests to agricultural lands and aquaculture ponds for commercial production have caused environmental problems. The coastline where the mangroves disappeared easily suffers erosion by rough waves of sea water. Afforestation of mangroves and restoration of coastal zones, therefore, has recently become an urgent issue. Effective afforestation would be achieved by increasing survival and growth rates of young seedlings through understanding how their growth characteristics are affected by environmental conditions in the plantation sites.

Several mangrove species such as *Rhizophore, Bruguiera* and *Ceriops* genus are usually important candidates for plantation because they produce useful materials such as wood and charcoal. These families produce viviparous seeds as propagules for regeneration and hypocotyls of young seedlings are established from viviparous seeds as shown in Fig. 1. The hypocotyl is expected to play an important role in promoting growth through supplying oxygen to the roots as well as supplying nutrient to the newly developing shoots and roots in an early growth stage.

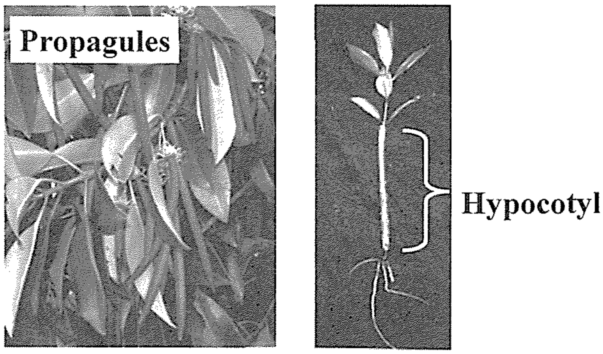

Fig. 1. Propagules and a hypocotyl of a young seedling of *Bruguiera cylindlica.*

The roots of mangrove plants are considered to have high capability to absorb water from the soil under saline and anaerobic conditions. In order to maintain the water absorption power, the roots could respire at a high rate. The oxygen diffusing to the roots through the hypocotyls would contribute the root respiration in young seedlings under anaerobic soil conditions. Flooding caused a decrease in leaf water potentials and stomatal conductance in *Bruguiera gymnorrhiza* (Naidoo, 1983). Reduced stomatal conductance retards the growth of plants in general by suppressing gas exchange in leaves. Poorer survival and growth of mangroves planted at lower elevations (Kitaya et al., 2002a; Komiyama et al., 1996) may be partly due to the decrease in stomatal conductance of leaves caused by flooding for a prolonged period.

In order to carry out afforestation of mangroves efficiently, it is important to understand the growth characteristics of young seedlings as affected by environmental elements at plantation sites. Young seedlings of some mangrove species have well developed hypocotyls. The hypocotyls of the seedlings would play an important role in their growth at early stages.

Pneumatophores of mangrove plants are the organs to supply O_2 to the roots. The pneumatophores of *S. alba*, *A. marina* and *R. stylosa* generated O_2 by photosynthesis and could transport O_2 to the roots during daytime even when the pneumatophores were submerged under water at a high tide (Yabuki et al, 1990a, b; Kitaya et al., 2002e). The surfaces of the hypocotyls of young seedlings are green, like the pneumatophores. In the present study, it was hypothesised that the hypocotyls have the same function as the pneumatophores and generate oxygen at their surfaces. In this study, the function of oxygen supply from hypocotyls to roots was investigated with young seedlings. Photosynthetic activity of the hypocotyls of the seedlings, O_2 diffusion to the roots, O_2 concentrations in the hypocotyls and the roots, and suppression of seedling's growth after submerging and shielding hypocotyls from light were also examined.

2. CO_2 exchange rates of hypocotyls

CO_2 exchange rates of the hypocotyls of the seedlings were measured by modifying a commercial photosynthetic measurement system (Fig. 2). Irradiance levels from sunlight were controlled by covering the whole plant with shading nets during the measurement.

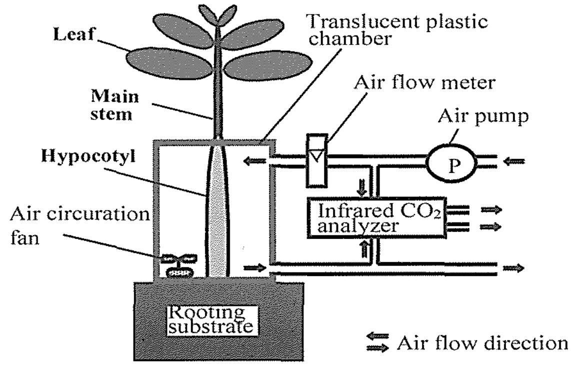

Fig. 2. Apparatus for measuring CO_2 exchange rates in hypocotyls.

The hypocotyls released CO_2 regardless of the presence of light (Fig. 3). The CO_2 release rates (i.e., the absolute values of the CO_2 exchange rates in Fig. 3) decreased with increasing photosynthetic photon flux density (PPFD) levels (Kitaya et al., 2002b, d). The gross photosynthetic rates, expressed as the sum of the net photosynthetic rates and the dark respiration rates increased with increasing PPFD levels and became saturated at PPFD levels of 300-400 μmol m^{-2} s^{-1}. The saturated value of the gross photosynthetic rate in the hypocotyls was 2.7 μmolCO_2 m^{-2} s^{-1} for *R. stylosa* (Kitaya et al., 2002b) and 0.32 μmolCO_2 m^{-2} s^{-1} for *B. cylindlica* (Kitaya et al., 2002b). The proportion of the gross photosynthetic rate in the hypocotyls for the CO_2 release rates from hypocotyls under the dark was 80% for *R. stylosa* and 70% for *B. cylindlica.* The gross photosynthetic rate in hypocotyls was greater for *R. stylosa* than for *B. cylindlica*. This means that the photosynthetic ability of the hypocotyls to produce O_2 is higher for *R. stylosa* than for *B. cylindlica*.

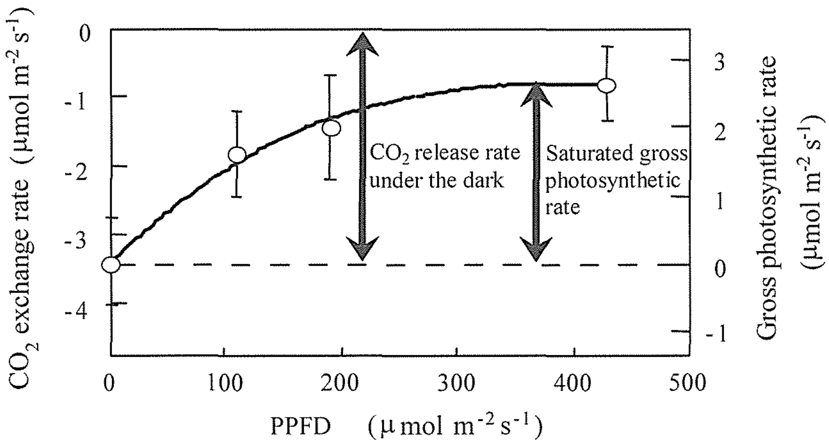

Fig. 3. The CO_2 exchange rates and the gross photosynthetic rates in hypocotyls as affected by PPFD levels. Length of arrows indicates the saturated gross photosynthetic rates in hypocotyls and CO_2 release rates from hypocotyls under the dark, respectively. Vertical bars indicate standard deviations (n=5)

3. O_2 concentrations in hypocotyls and roots

The O_2 concentrations in the hypocotyls of *B. cylindlica* were measured with/without submerging hypocotyls in water, with/without shielding hypocotyls from light with an aluminium film, and combining these treatments under lighting and dark conditions as shown in Fig. 4 (Kitaya et al., 2002d). The O_2 concentrations in the hypocotyls and the roots of *R. stylosa* were measured with/without shielding the hypocotyl from air, with/without shielding hypocotyls from light with an aluminium film, and combining these treatments. In the treatment with shielding the hypocotyls from air, the hypocotyl surfaces were shielded with translucent silicon rubber putty for mimicking submergence of hypocotyls in water. The O_2 concentration was measured with a Galvanic-cell-type sensor given a waterproof treatment. The O_2 sensor was connected with the inner structures of the hypocotyls and roots with an aluminium tube through holes made on the surface of the hypocotyls and the roots.

The O_2 concentrations in the hypocotyls of *B. cylindlica* were fluctuated with the treatments on the hypocotyls (Fig. 5) and summarised as the mean value under each condition (Fig. 6) (Kitaya et al., 2002b). The O_2 concentrations in the hypocotyls were 16% and 12% under the sunlight and dark conditions, respectively. The O_2 concentrations in the hypocotyls decreased when they submerged and showed greater values under a lighting condition. Kitaya et al. confirmed that the gases diffused inside the hypocotyls through their inner tissue system (Kitaya et al., 2002d). The gas diffusion in the hypocotyls to the roots would follow almost the same manner as that in pneumatophores of mangroves.

The O_2 concentration in the roots was about 2/5 of that in the hypocotyls of *R. stylosa* without shielding hypocotyls from air (Fig. 7) (Yoshii et al., 2004). The O_2 concentration in the hypocotyls decreased from 16.8% to 0.5% by shielding the hypocotyls from air. The O_2 concentration in the root also decreased from 7.2% to 0.3%. The O_2 concentrations in the hypocotyls and roots decreased to 0.2% after shielding the hypocotyls from light.

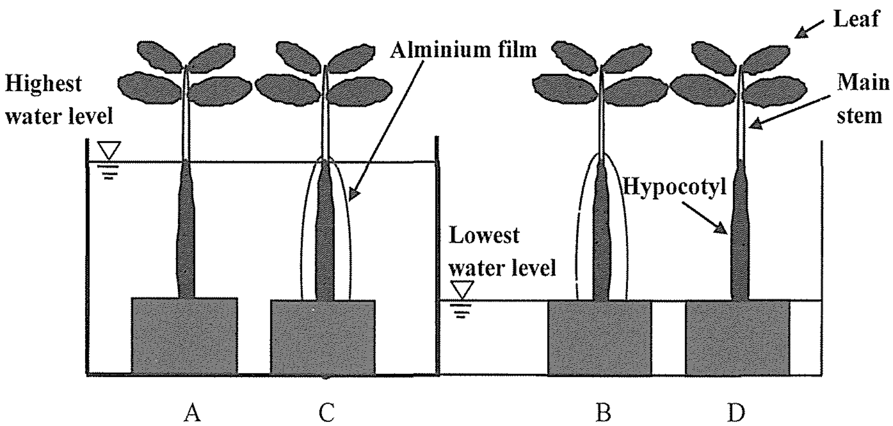

Fig. 4. Experimental treatments with submerging hypocotyls under water (A), shielding hypocotyls from light (B), combining these two treatments (C), and control (D).

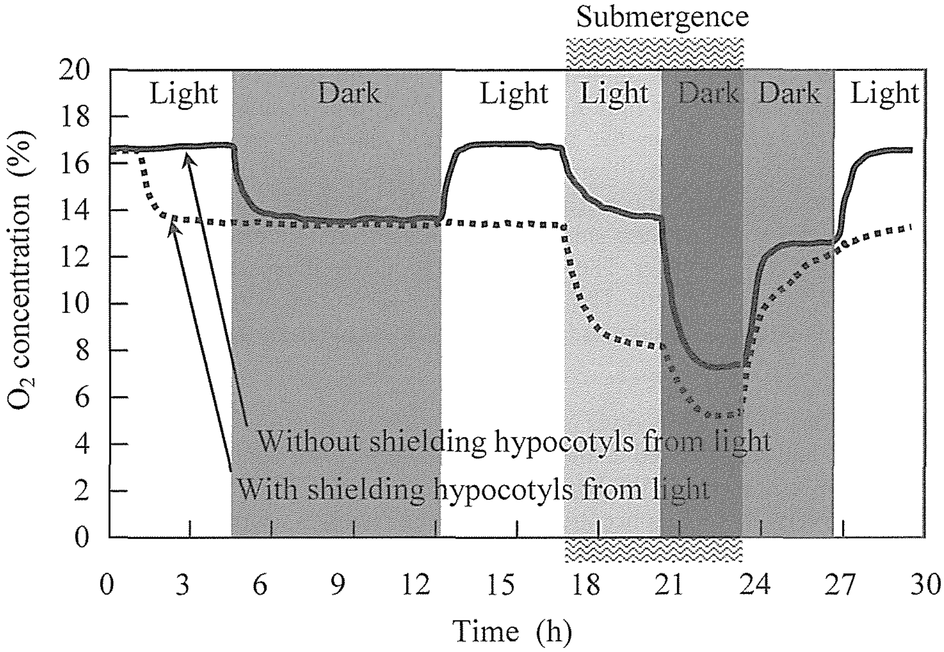

Fig. 5. Time courses of O_2 concentrations in hypocotyls of B. cylindlica with/without submerging hypocotyls under water, with/without shielding hypocotyls from light, and combining these treatments under lighting or dark conditions. Mean values of three repetitions are shown.

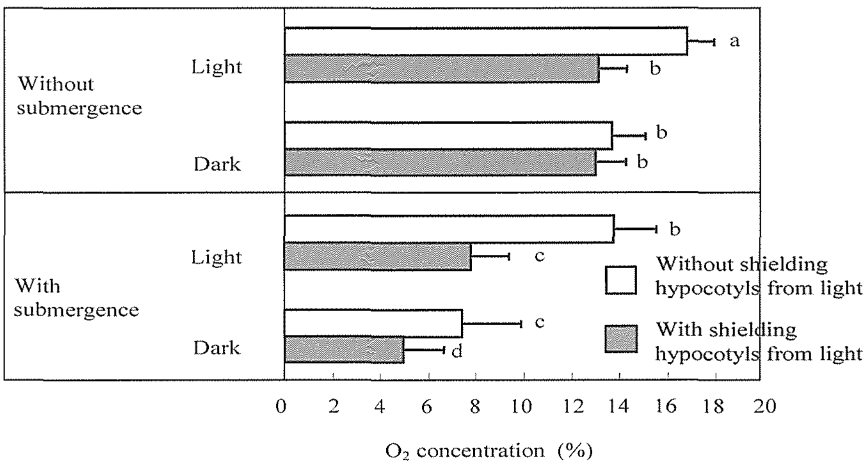

Fig. 6 The O_2 concentrations in hypocotyls of B. cylindlica with/without submerging hypocotyls under water, with/without shielding hypocotyls from light under lighting or dark conditions. Mean values of three repetitions are shown. Bars with the same letters are not significantry different ($p<0.05$).

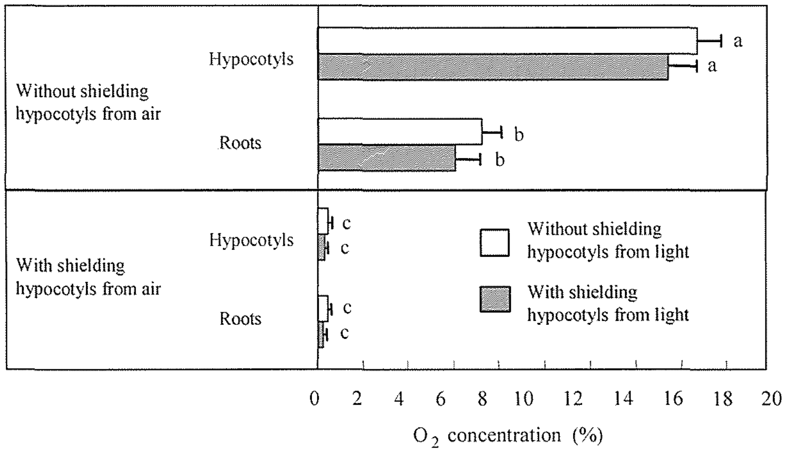

Fig. 7. The O_2 concentrations in hypocotyls and roots of R. stylosa with/without shielding hypocotyls from air and with/without shielding hypocotyls from light. Mean values of three repetitions are shown. Bars with the same letters are not significantry different ($p<0.05$).

4. Survival of seedlings as affected by the treatments on hypocotyls

The leaf conductance of one-year-old plants of R. stylosa decreased after submerging hypocotyls under water, shielding hypocotyls from light, and combining these treatments (Kitaya et al., 2002d). In this experiment, Survival of six-months-old plants of *R. apiculata* after submerging hypocotyls under water, shielding hypocotyls from light, and combining these treatments was monitored. Survival rates of seedlings of *R. apiculata* with submerging or shielding hypocotyls from light began to decrease four months after the start of the treatments as shown in Fig. 8. Seedlings with submerging or shielding hypocotyls from light were dead, while 80% of the seedlings with no treatment survived five months after the start of the treatments.

Younger seedlings were affected significantly by the treatments with submerging and shielding hypocotyls from light. This means that the role of the hypocotyls to supply O_2 to the roots is important for young seedlings.

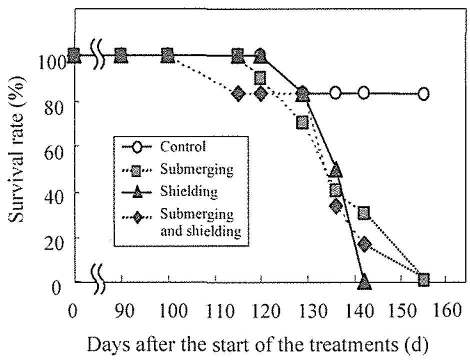

Fig. 8. Time courses of survival rates of six-month-old plants of R. apiculata after the start of the treatments of submerging hypocotyls, shielding hypocotyls from light and the combined treatment of submerging and shielding hypocotyls from light and control.

5. Concluding remaks

The function of the hypocotyls to supply O_2 to the roots is outlined in Fig. 9. The hypocotyls of the mangrove seedlings conduct photosynthesis. The hypocotyls can change internal carbon dioxide to oxygen by photosynthesis. The carbon dioxide inside the hypocotyl may be partly diffused from the root system. The hypocotyls of the seedlings are therefore considered to play an important role in supplying oxygen to the root system. Since submersion of hypocotyls decreased the leaf conductance, the hypocotyls are also considered to supply oxygen to the roots through gas transmission activity at their surfaces. The function of generating oxygen by photosynthesis in hypocotyls is considered to be effective especially when the habitat is flooded and the gas transmission at the surfaces of the hypocotyls is restricted. This function would allow mangrove seedlings having well developed hypocotyls such as *Rhizophorace* to grow under muddy anaerobic soil conditions in estuaries.

The gross photosynthetic rate was greater in the hypocotyls of *R. stylosa* than *B. cylindlica*. This means that the photosynthetic ability of the hypocotyls to produce O_2 is higher and contribution of O_2 produced in the hypocotyls to the root respiration would be greater for *R. stylosa* than for *B. cylindlica*.

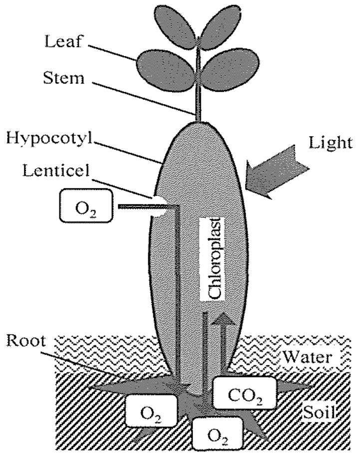

Fig. 9. A schematic diagram for showing the function of mangrove hypocotyls to supply O_2 from the hypocotyls to the roots.

Maintaining the function of oxygen generation and transmission at the surfaces of hypocotyls of young seedlings would be important to increase the survival and growth rates of seedlings. On the other hand submersion of hypocotyls under water and shading of hypocotyls for a prolonged period would retard growth of the young seedlings. Recently damage of young seedlings by barnacles constitute a new problem for mangrove plantation efforts (Angsupanich, 1998). Poor growth of seedlings as a result of covering their hypocotyls with barnacles may be partly due to the inhibition of the oxygen generation/transmission actions because of shading and shielding of the hypocotyl surface. Covering hypocotyls with sea weeds would also be a problem for growth of young seedlings in plantation sites. Our finding in this fundamental study will be expected to contribute to developing management techniques for establishing seedlings in mangrove restoration efforts.

The hypocotyls of young seedlings would supply O_2 to the muddy anaerobic soil as well as pneumatophores and thus modify the environment of their root zone. Quantitative research for clarifying the contribution of the hypocotyls and the pneumatophores that would oxidize the soil and thus affect decomposition of organic matter in the soil will be necessary in order to clarify the carbon cycle in the soil of mangrove forests.

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