

E-4.1 Studies on natural regeneration of tropical forest

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Abstract

(1) The process of fruit production

Morphological characteristics of fruits of *Durio zibethinus* Murray were investigated at an experimental field of Universiti Pertanian Malaysia (UPM) in Kuala Lumpur. Proportionality was observed in the allometries of lateral fruit diameter to longitudinal fruit diameter and of fruit volume to the $3/2$ nd power of the product of lateral and longitudinal fruit diameters. The allometry of fruit weight to the product of lateral and longitudinal fruit diameters was derived from the allometry of fruit volume to the product of lateral and longitudinal fruit diameters. The relation of fruit weight to the sectional area of peduncle satisfied a generalized power function whose exponent was ca. 2. Namely, the fruit weight dropped abruptly when the sectional area approached the minimum. The gradient of the generalized power function on log-log coordinates was hyperbolically related to the sectional area of peduncle.

(2) The growth of seedlings under different light conditions.

To know the regeneration processes of tropical rain forest, growth of seedlings under the natural and artificial light conditions was surveyed. Seedlings of *Shorea leprosula* were cultivated under the various sizes of gaps and heights and basal diameters were measured. Both height- and diameter-growths were influenced by the gap-sizes and were high under the big gap. The effect of shading on the growth and photosynthesis of 1.5 year old seedlings of *Shorea maximum* was also determined. Seedlings grown under low-shaded (45% of full sunlight) condition were 1.7 times larger in height, 2.1 times larger in phytomass and 1.2 times larger in leaf area ratio than seedlings grown under high-shaded condition (15%). Results suggested that photosynthetic products should be more effectively allocated to leaves in low-shaded seedlings than in high-shaded seedlings.

(3) CO₂ profile in soil at the secondary forest and grassland.

The CO₂ profile in soil was determined in a secondary forest and a grassland. The CO₂ concentration increased with increasing depth and exceeded 100 times at 50 cm deep as compared with the concentration at the soil surface. In a grassland, the CO₂ concentration was higher than that in a secondary forest at any depth and was approximately double of the concentration observed in a secondary forest. These differences in CO₂ concentration between the secondary forest and the grassland were considered to be caused by the carbon supplied from the buried wood. However, the profile of the CO₂ concentration and the amount of carbon in soil was quite different in both sites, another factor should be considered to make clear the cause of higher CO₂ concentration in the grassland.

Key Words disturbance of tropical forest, regeneration, seedling establishment, soil respiration

1. Introduction

Tropical forests are rapidly diminishing. There is an urgent need to develop strategies for recreating the forests. It is, therefore, critically important from the aspects of forest conservation and management, to analyze the natural mechanisms by which tropical forests recover following disturbance.

Tree growth in tropical forests is usually coordinated with seasonal fluctuation in precipitation, though monthly average precipitation does not restrict the growth of trees in tropical humid forests. Despite the high annual precipitation, limitations to photosynthesis during the period of less precipitation can constrain the whole-plant carbon budget, resulting in reduced growth and reproduction. Many tropical species are deeply-rooted and escape from the damage caused by drought by maintaining high hydraulic conductivity. While those trees with shallow roots are frequently suffered from water limitations and are occasionally shifted into the death. These phenomena are not popular in humid tropical forest, however, in the disturbed area the soil surface is attacked by the sun radiation and these occasion should be frequently occurred.

From these aspects, we focused on the regeneration process of tropical tree species and the natural environment in a disturbed area. For this purpose, (1) the process of fruit production to estimate the efficiency and photosynthesis products partitioning into fruits and/or seeds in tropical trees, (2) growth of seedlings under the different sized gaps or artificially modified light environment to analyze the strategy of seedlings grown under the limited light source, (3) comparison of CO₂ profile in disturbed and non-disturbed area to assume the changes of environmental factors by disturbance of tropical forests.

2. Materials and Methods

(1) The process of fruit production

Research site

The present research was conducted on two sample trees of *Durio zibethinus* Murray at an experimental field station of Universiti Pertanian Malaysia (UPM) in Selangor, Malaysia. The sample trees, which were the same clone, were planted distantly enough to be exposed to the full sunlight. The stem diameters at breast height were 27.4 and 34.1 cm in tree Nos. 1 and 2.

Gas measuring apparatus

An open gas exchange system was used for determining in situ CO₂ exchange of leaves of *Durio zibethinus* trees growing in the field. The shoots were enclosed with a cylindrical assimilation chamber with the size of 18 cm in height and 33 cm in diameter. The assimilation chamber had a thermomodule and a fan in the bottom part which was made out of two aluminum fin-plates. The inside wall of the chamber was covered with a transparent FEP Teflon film (du Pont). Air temperatures were measured both outside and inside the chamber with platinum resistance thermometers. The chamber-temperature was adjusted to match the outside temperature by the temperature controller (Koito, MC-A04A/S). The ambient air was taken at the height of 11 m above the canopy. After CO₂ content in the air was stabilized in two air buffers, the air was fed into an assimilation chamber at a rate of 5.0 l min⁻¹. Before the chamber and ambient airs were taken to an infra-red gas analyzer (ADC, EGA), the moisture of the air was removed by a perma pure drier (Fuji Elect., ZBJ02502-72P) and two glass tubes containing a drying agent (magnesium perchlorate). Using a three minute interval, sample gases were alternatively drawn into the gas analyzer. Switching was done using two magnetic

valves (CKD, SAB 352-6-0-AC100V) which were controlled with timers (Omron, H3BA). The signals from the CO₂-analyzer and temperature measurements were monitored with a chart recorder (Yokogawa Elect., LR4100). The integrated values of photon flux density were measured with two quantum sensors (LI-COR, LI-190SA) on the chamber and outside the canopy. The values were stored in a data logger (LI-COR, LI-1000) at one hour intervals in August and half an hour intervals in September. In the present report, CO₂ exchange rate was calculated at half an hour intervals on the basis of three-minute interval data. We distinguished the daytime from nighttime by defining night as the period when the integrated value of photon flux density outside the crown was zero.

(2) The growth of seedlings at different light conditions.

Seedlings of *Shorea leprosulla* were transplanted in different sized gaps. Height, number of leaves and branches and basal girth were measured.

To demonstrate the effect of shading on growth and photosynthesis, 1.5-year old seedlings of *Shorea maximum* was transplanted from the forest. Seedlings were grown under high (45%) and low (15% of full sunlight) shade conditions.

(3) CO₂ profile in soil at the secondary forest and grassland.

This study was performed on a secondary forest in the Air Hitam Forest Reserve, Universiti Pertanian Malaysia, Serdang, Malaysia. Soil respiration was measured with the sponge method³). A disk of plastic sponge as an absorption holder of 25 mL of 1 N KOH solution was enclosed in a cylindrical tin can (12.5 cm in diameter) inserted into soil for about 24 hours. At 10 points in the secondary forest and 5 points in the grassland, the evolution of carbon dioxide from the mineral soil surface without A₀-layer and from the undisturbed ground surface with A₀-layer was simultaneously measured. Control tests were also run. Mean soil temperature at a depth of 5 cm below the ground during the experiment period was determined from maximum and minimum readings of thermometers. The differentiating titration method was applied to 5 mL of the sample using 0.1 N HCl solution. The end of vinyl tubes, with an air stone, was buried in the ground at 5 cm-intervals from the ground surface down to 50 cm and at 10 cm-intervals from 50 cm to 100 cm. Another end with a rubber stopper was led to the ground surface. A three mL gas sample was taken from each depth through the vinyl tubes using a plastic syringe. The gas sample was immediately analyzed with an infrared gas analyzer (LI-6252, LI-COR, USA). The CO₂ concentration of the sample gas was determined using the prescribed relationship of the CO₂ concentration (y , $\mu\text{mol mol}^{-1}$) of standard CO₂ gas and the corresponding output of the analyzer (x) in a flow rate of 1.0 L min⁻¹ of CO₂-free air and a volume of 3 mL of sample gas; $y = 87.8 x$.

3 . Result and Discussion

(1) The process of fruit production

We measured the size changes of fruits of *Durio zibethinus* grown at the nursery of Universiti Pertanian Malaysia in Selangor. For whole growing period, we found a proportionality of the allometries of lateral to longitudinal fruit diameters and of fruit volume to the 3/2nd power of the product of lateral and longitudinal fruit diameters. The fruit weight was also proportional to the fruit volume. This result indicates that the ratio of fruit weight to fruit volume or in other word, specific gravity of fruit, is constant irrespective of fruit size. The relationship of fruit weight to the sectional area of peduncle satisfied a generalized power function with a power factor of ca. 2. The fruit weight dropped abruptly as the sectional area approached the minimum area, while the relationship followed the power function in the range where the sectional area was sufficiently larger than the minimum sectional area. The gradient

of the generalized power function on log-log coordinates was hyperbolically related to the sectional area of peduncle. The reasonability of the pipe model theory was discussed on the basis of the relation of fruit weight to the sectional area of peduncle, taking translocation of photosynthates to the fruits into consideration.

The CO₂ gas-exchange of fruits of a tropical tree, *Durio zibethinus* Murray, was examined. Day and night dark respiration rates were exponentially related to air temperature. The temperature dependent dark respiration rate showed a clockwise loop as time progressed from morning to night, and the rate was higher in the daytime than at night. The gross photosynthetic rate was estimated by summing the rates of daytime dark respiration and net photosynthesis. Photosynthetic CO₂ refixation, which is defined as the ratio of gross photosynthetic rate to dark respiration rate in the daytime, ranged between 15 and 45%. The photosynthetic CO₂ refixation increased rapidly as the temperature increased in the lower range of air temperature below 28.5 °C, while it decreased gradually as the temperature increased in the higher range (≥ 28.5 °C). Light dependence of photosynthetic CO₂ refixation was approximated by a hyperbolic formula, where light saturation was achieved at 100 $\mu\text{mol m}^{-2} \text{s}^{-1}$ and the asymptotic CO₂ refixation was determined to be 37.4%. The estimated daily gross photosynthesis and dark respiration were 1.15 and 4.90 g CO₂ fruit⁻¹, respectively. Thus the CO₂ refixation reduced the respiration loss per day by 23%. The effect of fruit size on night respiration rate satisfied a power function, where the exponent was larger than unity.

(2) The growth of seedlings at different light conditions.

Shorea leprosulla seedlings were cultivated under various sized gaps and seedlings of *Shorea maxima* were grown under the shade condition. The growth rate of *Shorea leprosulla* was higher in a large gap as compared with the growth rates of seedlings grown in a small gap or understory of the forest. The size and photosynthesis were compared between 1.5-yr.-old seedlings of *Shorea maxima* grown under 45% and 15% of full sunlight. Low-shaded seedlings were 1.7 times larger in height and 2.1 times larger in phytomass than high-shaded seedlings. The leaf area ratio was larger in low-shaded seedlings than in high-shaded seedlings by a factor of 1.2, which suggests that photosynthetic products are more effectively allocated to leaves in low-shaded seedlings than in high-shaded seedlings. Nitrogen content per leafmass decreased with decreasing leaf order from the top downwards. This suggests that nitrogen is retranslocated from older leaves to younger leaves, which mechanism is effective for younger leaves in increasing their photosynthetic activity. The quantum yield of light-photosynthetic reaction was higher in high-shaded seedlings than in low-shaded seedlings, which suggests that high-shaded seedlings are superior to low-shaded seedlings in light availability at lower light intensity. The light-saturated value of gross photosynthetic rate was larger in low-shaded seedlings than in high-shaded seedlings, which suggests that low-shaded seedlings can enhance their photosynthetic ability more effectively at higher light intensity. The light-saturated value of net photosynthetic rate on a leaf area basis was 1.8 times larger, while on a nitrogen basis was 1.2 times larger in low-shaded seedlings than in high-shaded seedlings. It may be concluded that high-shaded seedlings promote their photosynthetic ability by elevating nitrogen content of leaves, in compensation for insufficient light. The leaf nitrogen content of *Shorea maxima* cultivated under the shade condition was higher than those seedlings grown under the open area. The rate of net photosynthesis in seedlings grown under higher light condition was higher than the rate of those seedlings grown under the shade condition.

(3) CO₂ profile in soil at the secondary forest and grassland.

In the secondary forest the ratio of the solid phase of soil increased from 30% to 50%, whereas the ratio of the gaseous phase decreased from 45% to 10% with increasing soil depth

from the ground surface. The trend and ratios are almost the same as those reported by Kiguchi²⁾ in the Pasoh Forest. On the other hand, in the grassland the solid and gaseous phases were respectively 40% and 25%, more or less, regardless of soil depth. The ratios of the solid phase are larger than the ratio of 15 to 30% found by Kutsuna and Nioh (unpublished) for Black soil in Japan. Larger ratios of the solid phase in tropical forests indicate the inactivity of aerobic nitrifying bacteria²⁾.

The value of pH of soil increased regularly from 3.9 to 4.7 with increasing soil depth from the ground surface in the secondary forest. This trend is the same as in the Pasoh Forest²⁾. On the other hand, the pH-value changed irregularly with soil depth in the grassland.

The concentration of CO₂ increased to a maximum of 23,700 $\mu\text{mol mol}^{-1}$ at a soil depth of 70 cm in the secondary forest and 43,500 $\mu\text{mol mol}^{-1}$ at a soil depth 80 cm in the grassland, and then decreased with increasing soil depth from the ground surface. In this context, the concentration of CO₂ in air just above the ground surface was 420 $\mu\text{mol mol}^{-1}$. The maximum concentration of CO₂ in soil air in the secondary forest was twice as large as that in the grassland. This high concentration of CO₂ in the grassland may be attributed to CO₂ release from a large amount of charcoal buried in the ground. The maximum concentration of CO₂ in soil air in the secondary forest is nearly equal to a yearly maximum in soil air observed in September by Hagihara et al.¹⁾ in a secondary temperate forest in central Japan.

Mean total soil respiration was 600 ± 103 (SE) and $1,122 \pm 100$ (SE) $\text{mg CO}_2 \text{ m}^{-2} \text{ h}^{-1}$ in the secondary forest and the grassland, respectively. Ogawa⁴⁾ obtained in the Pasoh Forest a yearly mean value of $595 \text{ mg CO}_2 \text{ m}^{-2} \text{ h}^{-1}$, an average of 24X of which was CO₂ release from the A₀-layer. As compared with the secondary forest, the grassland showed high rates of soil respiration; 2.5 times in the mineral-layer, 1.4 times in the A₀-layer and 2.2 times in the total. In the grassland 85% of the total respiration were coming from the mineral layer, whereas in the secondary forest 76% were coming from the mineral-layer. It is apparent that the contribution of the mineral-layer is larger in the grassland than in the secondary forest in terms of both absolute and relative values.

Turnover time of CO₂ existing in soil 1 m deep can be estimated on the basis of the soil respiration rate and the CO₂-mass in soil air, which is calculated from the gaseous phase in soil and the CO₂ concentration in soil air. The turnover time in the secondary forest was about twice as large as that in the grassland; 15.6 h in the secondary forest and 8.3 h in the grassland.

4. References

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