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Relationships between Light Conditions and Biomass of Floor Vegetation in a Tropical Forest

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Abstract

With the purpose of identifying relationships between light conditions and biomass of floor vegetation in the understory of a forest, an experimental study was implemented in the Philippines. The study site was selected in a tropical evergreen forest, which was predominated by *Pometia pinnata* and *Celtis luzonica*. The forest floor, which was weeded in advance, was covered with vegetation, consisting mainly of pinkball (*Calliandra portoricensis*), in 13 months after bush cutting. Five plots having pinkball shrubs of different heights were set up in the floor vegetation for the measurement of light and biomass status. Light conditions in the forest were measured with two methods: integrating photometers and hemispherical photographs. The former was exposed for five days in March, 1989. Based on the values of integrated light in each plot, the relative solar radiations were calculated. Using hemispherical photographs, which present areas of canopy gaps, relative diffuse and direct light intensities were calculated. Regarding the relationships among the three different indices of light conditions in five plots, a greater correlation was observed between two indices calculated from the photographs than the other pairs. The relationships of three indices each with the biomass of floor vegetation under different light conditions were not linear. From these results, it is concluded that in the dark understory of a forest, pinkball shrubs grow exponentially in the course of time in different relative growth rates proportionate to the relative light intensity and that the relative growth rate decreases in a more open site. It was also suggested that a greater influence on the growth of pinkball be provided by the penetrating direct light than the diffuse light in the dark understory.

Discipline: Forestry and forest products
Additional key words: *Calliandra*, canopy gap, hemispherical photograph, integrating photometer, tropical evergreen forest

Introduction

In the Taunya type agroforestry system, various types of crops are cultivated in between the trees grown in a forest. Growth of those crops, which are a vital component for the success of agroforestry,

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is greatly affected by light as well as water and nutrient conditions in the forest. Provision of adequate light conditions for floor vegetation is particularly important to ensure the growth and yield of crops. From this point of view, information on the crop yields under various light conditions are required for the establishment of a well-designed agroforestry system.

In measuring light status of the understory in agroforestry systems, various methods have been developed in the past. However, it is still not satisfactory to precisely estimate light conditions in connection with the growth of plants in the understory. In order to estimate light conditions in a tropical forest, two methods were proposed: one was to use integration photometers which measure an amount of light energy for a certain period of time[3,6,7]; and the other was to use hemispherical photographs, which present an area of canopy gaps for the estimation of penetrating radiation. The relationships of the values obtained by these two methods were analyzed, taking into account the growth of biomass of floor vegetation in a tropical evergreen forest.

Study site and methods

1) Study site

The study site was selected on a slopeland in a tropical evergreen forest of the Makiling Botanical Garden, UPLB. Predominated by *Pometia pinnata* (Malugai) and *Celtis luzonica* (Magabuyu), the canopy was composed of more than 10 tree species with heights of 25–35 m. The forest floor was covered with vegetation dominated by exotic shrubs, i.e. pinkball (*Calliandra portoricensis*) native to tropical America. The floor vegetation was weeded in February, 1988 and left intact for 13 months after bush cutting. The pinkball shrubs were regenerated by sprouting. Since there were great variations in shrub height among the places in the forest, five plots (1 × 1 m each) with different shrub heights, varying from 93 to 452 cm, were set up for the measurement of light and biomass.

2) Measurement of light conditions

Light conditions in the forest were measured with two methods: i.e. integrating photometers (Sunstations) and hemispherical photographs. The former provides measurements on amounts of integrated light supplied for a long period of time, while the latter records the area of canopy gaps. The hemispherical photographs have an advantage over the other, since only a few minutes are enough to take a photograph with fisheye lens at a given site, though they do not directly measure the amount of light.

The integrating photometers were used to measure light conditions above the floor vegetation. Two photometers were installed in each plot, including an open site as a control, except Plot 4 where only one photometer was set. A total of 11 photometers were continually exposed for five days in March, 1989. Based on the values of integrated light obtained in each plot, relative solar radiations (p) were calculated.

Anderson[1,2] used hemispherical photographs for the first time in estimating woodland light status by separating it into diffuse and direct fractions. Each of these two parameters, i.e. relative values of diffuse and direct light fractions, is expressed as q and r, respectively.

The relative diffuse light intensity (q) can be expressed theoretically as follows:

$$q = \frac{\int_0^{\pi/2} \cos\delta \cdot \sin\delta k(\delta) \cdot d\delta}{\int_0^{\pi/2} \cos\delta \cdot \sin\delta \cdot d\delta}$$

where δ and $k(\delta)$ refer to zenith angle and proportion of the unshaded arc on the circumference at a given angle, respectively[5]. Based on this equation, q was calculated using hemispherical photographs. In this analysis system, $k(\delta)$ values were computed at every 5 degrees after reading of the photograph by an image scanner, assuming that a radius in the hemispherical image is proportional to the zenith angle.

In calculating the relative direct light intensity (r), a solar track was computed first from the latitude of the study site, the hour angle of the sun, and the sun's declination for a given day. The track was superimposed on the hemispherical image in the computer. As the next step, sun-beams were generated azimuthally every 1 min from sunrise to sunset. From these observations, r can be calculated using the following equation:

$$r = \frac{\Sigma \sin\theta_{Ri}}{\Sigma \sin\theta_{Tj}},$$

Table 1. Comparisons of height, above-ground biomass and leaf ratio of vegetation among the five plots under different light conditions

Plot no.	Height (cm)	Pinkball Leaf (kg/m²)	Pinkball Stem & branches (kg/m²)	Pinkball Leaf ratio (%)	Pinkball Total (kg/m²)	Other species (kg/m²)	Total (kg/m²)
1	93	0.018	0.020	91	0.038	0.046	0.084
2	110	0.036	0.051	72	0.087	0.044	0.131
3	150	0.100	0.171	59	0.271	0.015	0.286
4	260	0.166	0.531	31	0.697	0.015	0.712
5	452	0.762	4.033	19	4.795	0.001	4.796

where θ_{Ri} and θ_{Tj} refer to altitudal angle of the ith beam reaching the site and that of the jth beam emitted from sunrise to sunset, respectively.

3) Measurement of biomass

After the measurements of light conditions, the floor vegetation above the ground in each plot was reaped to estimate total biomass. The reaped vegetation was separated into leaves and other parts (stems and branches) of pinkball and other species. The three parts of each biomass were dried at 80°C for two days and weighed.

Results and discussion

The results of measurement on the biomass are shown in Table 1. Pinkball was predominant in the biomass in each plot. The heights of pinkball were higher in order of Plots 1 to 5. The leaf ratio, which was expressed by a weight ratio of leaf to non-assimilatory parts, decreased with an increase of the biomass. The canopy of pinkball was closed only in Plot 5. The other species were *Homalomena philippinensis, Maesa denticulata, Paspalum conjugatum, Centhotica latifolia, Athyrium esculentum* and *Melicope triphylla*. The biomass of these species was negligible in Plots 3, 4 and 5, while their presence was significant in Plots 1 and 2, where the total amount of biomass was rather limited. These plants were major components of the dark forest floor; they seemed to be more shade-tolerant than pinkball. Since the floor vegetation was cleared 13 months in advance, the different amounts of biomass obtained in the experimental plots indicated relative growth rates of the floor plants in the respective plots during that period.

The relationships among three different indices (p, q, r) of light conditions of five plots are shown in Fig. 1. The coefficient of correlation between two indices calculated from the photographs (q and r) was higher than the other pairs. This high correlation was attributed mainly to the random distribution of gaps in the hemispherical photographs. Ando[4] and Waseda[8] reported a linear relationship between the amount of light and the canopy gap ratio in uniformly aged forests under various degrees of thinning. The apparent linear relation may be due to homogenous distribution of gaps in such man-made forests.

The relationships of p, q and r with the biomass of floor vegetation under different light conditions are shown in Fig. 2. There appeared to be linear relations between each of these indices and the logarithmic values of biomass in Plots 1 to 4. However, the amounts of biomass in Plot 5 were much smaller than those calculated by regression lines determined by the other plots. These relations suggest that in the dark understory, i.e. less than 25% in p, the pinkball shrubs grow exponentially in the course of time in different relative growth rates proportionate to the relative light intensity and that the relative growth rate decrease in a more open understory. Variations in weight of the above-ground part of floor vegetation may be caused by different stocks of underground biomass from which the plants initiate their growth after bush cutting, as well as by different light intensities in the understory. The decrease in the relative growth rates taking place in Plot 5 might be caused by either the saturation of photosynthetic rate occurring under high light intensity on sunny days or the limits of leaf growth due to the canopy closure.

Dry weight of the floor vegetation increased rapidly in accordance with the increased relative light

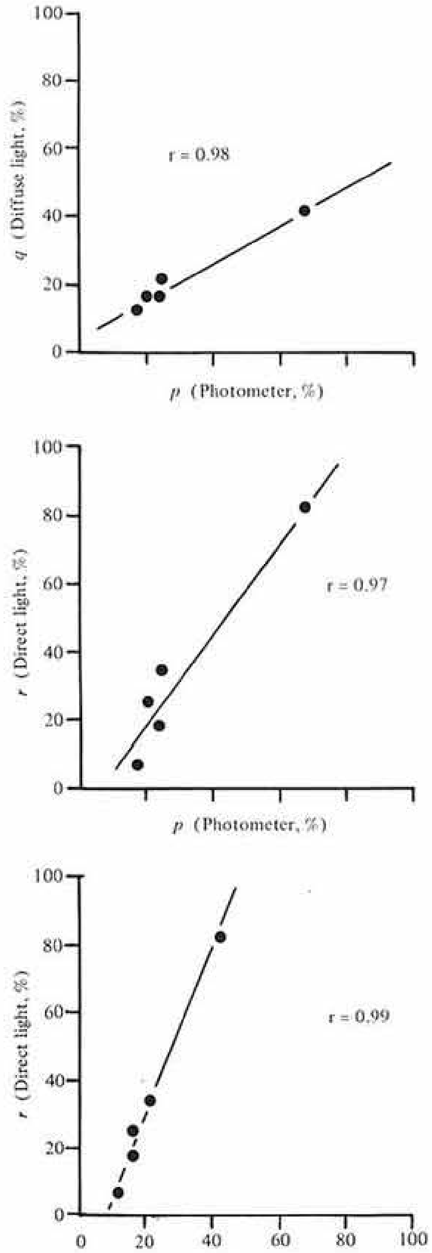

Fig. 1. Relationships among the three different indices of relative light intensity (p, q, r)
p: Relative light intensity estimated with integrating photometers,
q: That calculated from hemispherical photographs under the uniform overcasting sky condition,
r: That calculated from the photographs under the clear sky condition.

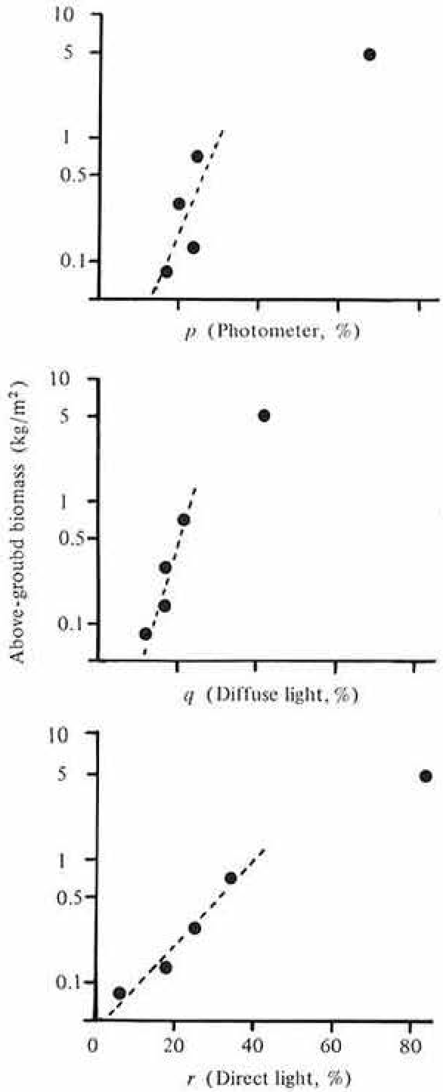

Fig. 2. Relationships among the three different indices of relative light intensity (p, q, r) with the biomass of floor vegetation under different light conditions

intensity from approximately 15 to 25% in p. The similar trends were reported in some previous studies[3,6,7]. This implies that the growth of floor vegetation is highly sensitive to a small difference in the relative light intensity of the dark understory. The measurements of the intensity of diffuse and direct radiation and plant responses to them are important in identifying the causes of differences in plant growth in the understory.

The correlation between the light intensity and the amount of floor vegetation is influenced by weather conditions under which the light is measured. The correlation coefficient between the light intensity in the understory and the coverage of floor vegetation was higher on a cloudy day (0.79) than on a clear day (0.60) in a coniferous forest[3]. Saito and Niki[7] reported the similar results indicating that the values of vegetation coverage in a coniferous forest were positively correlated with those of accumulated light for a day, and that the correlation coefficient under a cloudy weather, i.e. $r = 0.80$, was higher than that under the other weather condition.

In the dark understory of Plots 1 through 4, the coefficients of correlation between logarithmic amounts of biomass and r were higher than the other pairs (Fig. 2). This result suggests that a greater influence on the growth of pinkball be provided by the penetrating direct light than the diffuse light in the dark understory.

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