Effect of Shading on Photosynthesis of Coffea arabica

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Abstract

Photosynthetic characteristics of coffee leaves developed under various shading levels (0, 30, 50 and 80%) were examined.

The net photosynthetic rate above 150 μmol m⁻² s⁻¹ PPFD was the highest in unshaded plants, and it declined with increasing degree of shading. Saturation and compensation irradiances of photosynthesis and dark respiration also declined with shading.

The net photosynthetic rate was highest at 20°C and relatively high within the range from 15 to 25°C irrespective of the treatments. The rate of photosynthesis declined above 25°C and the reduction was the greatest in unshaded plants. The difference in net photosynthetic rate among shaded and unshaded plants at higher temperatures was assumed to be associated with increased dark respiration.

Key words : Coffee, Coffea arabica, Photosynthesis, Shade

Introduction

Coffee plants are cultured under shaded conditions in many areas of the world. However, the effect of shading is complex, especially when determining the sun light usage because shading reduces the amount of light available for the crops. There are conflicting results on the net photosynthesis of coffee plants. NUTMAN and KUMAR and TIERSZEN showed that shaded plants had higher net photosynthesis than unshaded plants. On the other hand, YAMAGUCHI and FRIEND reported that the rate of net photosynthesis in unshaded leaves was higher than that of shaded ones.

BUTLER reported that the temperatures of sunlit coffee leaves were generally 10 to 15°C higher than the air temperatures, and these increases were reduced by shading.

In this study, young coffee trees were subjected to four levels of shading to evaluate influences of reduced light on photosynthesis and dark respiration of leaves and to clarify the influence of leaf temperature.

Materials and Methods

One-year-old seedlings of Coffea arabica L. var. Typica were grown in a 1/5000 a pot containing vermiculite under natural light conditions with a short day treatment (11 - 13 h) provided by a shelter. The plants were watered daily with Hoagland's solution except one day each week when pots were flushed with tap water. Shade treatments were performed by a steel frame (120 × 120 × 180 cm), covered with different kinds of shade cloths, during the period from June 1 to September 30. Monthly average temperatures were 21.9°C in June, 26.7°C in July, 26.3°C in August and 22.2°C in September (Kobe Marine Observatory). Four shade levels (0, 30, 50 and 80% shade) were evaluated in this study. The space between pots was covered with white styroform board to prevent abnormal fluctuation in soil temperature and nutrient conditions which might occur among treatments.

The 40 to 60 day-old intact leaves were used for the measurement of net photosynthesis as these leaves had relatively constant and high photosynthetic rates. Measurements of the rate of CO₂ uptake were conducted with a differential infrared gas analyser (Horiba LIA - 2). The air (340 - 350 ppm CO₂) used was humidified to avoid stomatal closure by water loss. The relationship between irradiance (photon flux densities, PPFD) and photosynthesis was examined within the range of 2 to 750 μmolm⁻² s⁻¹. Irradiance was altered by varying the distance between incandescent lamps and the assimilation chamber.
or by inserting neutral density papers between lamps and the assimilation chamber, and was measured with a photon flux density sensor (LI-COR LI-188). The leaf temperature was kept at 25 °C by circulating water around the assimilation chamber which was placed in a controlled-environment room. Air and leaf temperatures were monitored by small copper-constantan thermocouples. The temperature dependence of photosynthesis and respiration were examined within the range of 10 to 40 °C.

The determination of saturation irradiance and compensation irradiance, and measurements of maximum net photosynthesis and dark respiration were performed according to YAMAGUCHI and FRIEND.8)

Results

1. Effect of irradiance on net photosynthesis

Figure 1 shows on marked differences in net photosynthetic rates among shaded and unshaded plants below 150 μmol m⁻²s⁻¹ of photosynthetic photon flux density (PPFD). The photosynthetic rate above 150 μmol m⁻²s⁻¹ differed among shade intensities and was the greatest in unshaded leaves.

Table 1 shows the light relations of photosynthesis in leaves developed under various levels of shading. Both light saturation and light compensation points of net photosynthesis tended to be lower as the shading became heavier. However, there were no significant differences in 90% saturation irradiance and initial slope among shade treatments. Shade levels of 30 and 50% had little effect on photosynthesis when compared with the unshaded treatment.

![Fig. 1 Effect of irradiance on net photosynthetic rate (Leaf temperature : 25 °C)](image)

![Fig. 2 Effect of leaf temperature on net photosynthetic rate. (Photon flux density : 150 μmol m⁻²s⁻¹)](image)

Table 1 Effects of shading on photosynthetic characteristic of coffee leaves

<table>
<thead>
<tr>
<th></th>
<th>Unshaded</th>
<th>30% shade</th>
<th>50% shade</th>
<th>80% shade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photosynthetic rate at saturated (mg CO₂dm⁻²h⁻¹)</td>
<td>11.99</td>
<td>11.22</td>
<td>10.27</td>
<td>9.15</td>
</tr>
<tr>
<td>Irradiance (μmol m⁻²s⁻¹)</td>
<td>a*</td>
<td>ab</td>
<td>ab</td>
<td>b</td>
</tr>
<tr>
<td>Irradiance at 90% saturation (μmol m⁻²s⁻¹)</td>
<td>422.5</td>
<td>403.7</td>
<td>373.8</td>
<td>345.0</td>
</tr>
<tr>
<td>Initial slope (μg CO₂dm⁻²h⁻¹/μmol m⁻²s⁻¹)</td>
<td>a</td>
<td>a</td>
<td>a</td>
<td>a</td>
</tr>
<tr>
<td>Compensation irradiance (μmol m⁻²s⁻¹)</td>
<td>12.3</td>
<td>11.1</td>
<td>11.7</td>
<td>8.2</td>
</tr>
</tbody>
</table>

* Means followed by different letters are significantly different (p<0.05) by t test.
Table 2 Effects of shading and temperature on dark respiration (mg CO₂dm⁻²h⁻¹)

<table>
<thead>
<tr>
<th>Leaf temperature (°C)</th>
<th>Unshaded</th>
<th>30% shade</th>
<th>50% shade</th>
<th>80% shade</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.18</td>
<td>0.18</td>
<td>0.05</td>
<td>0.09</td>
</tr>
<tr>
<td>25</td>
<td>1.16</td>
<td>0.98</td>
<td>0.90</td>
<td>0.73</td>
</tr>
<tr>
<td>40</td>
<td>3.23</td>
<td>2.51</td>
<td>2.23</td>
<td>1.89</td>
</tr>
</tbody>
</table>

2. Effect of leaf temperature on photosynthesis and respiration

As shown in Fig. 2, the photosynthetic rate at 150 μmol m⁻²s⁻¹ was maximal at about 20 °C and then declined sharply above 25 °C in all treatment. Shaded plants maintained higher photosynthetic rates than the unshaded ones at high temperatures. Assuming the relative photosynthetic rates of unshaded plants at 20 °C as 100 %, the rates at 30, 35 and 40 °C were 61, 24 and 0 %, respectively. On the other hand, those of 80% - shade plants at 30, 35 and 40 °C were 75, 54 and 25 % of that at 20 °C. Thus coffee leaves developed under heavy shade had higher photosynthetic activities at high temperatures than those without shade.

Temperature response of respiration is shown in Table 2. Dark respiratory rate was greatest in unshaded plants and decreased with increasing levels of shading at all the temperatures.

Discussion

It is known that distinct differences exist in photosynthetic characteristics between shade and sun plants. Arabica coffee, growing wild as an understory tree in forests of Ethiopia, has been considered to be a shade plant. When grown under low light intensities, the photosynthetic rates of sun plants decline under high light intensities but those of shade plants do not. The present results show that the photosynthetic rate at saturating irradiance is higher in unshaded leaves than in shaded ones. It can be said that arabica coffee is a sun plant rather than shade plant with respect to compensation irradiance of net photosynthesis and dark respiration as well as photosynthetic capacity.

NUNE et al. reported that temperatures above 24 °C resulted in increased internal CO₂, associated with increased stomatal resistance and low photosynthetic rates. KUMAR and TIESZEN showed that the decrease in photosynthetic rate above 24 °C was due to a decrease in mesophyll conductance. KHAIRI and HALL also reported that the reduction in net photosynthetic rate due to higher temperatures was associated with a reduction in mesophyll conductance, whereas the effect of increased vapor pressure difference was associated with a decrease in leaf conductance. The reduction of net photosynthesis at leaf temperatures higher than 25 °C in these experiments was probably due to an increase in respiration and a decrease in mesophyll conductance. At high temperatures, unshaded coffee leaves have lower rates of net photosynthesis and higher rates of dark respiration than shaded leaves (Fig. 2, Table 2). Dark respiration increased markedly as temperature increased, resulting in a reduction of net photosynthesis.

High irradiance increases coffee leaf temperature. At the same air temperature, the temperature of unshaded leaves is much higher than that of shaded leaves. This difference might be reflected in net photosynthesis. Shading reduces the amount of available sun light, but reduces the increase of leaf temperature and hence the decrease of net CO₂ assimilation. In whole plants, however, leaf temperature and other deleterious consequences of direct irradiation are reduced by the mutual shading of leaves and the multiple angles of incidence of sun light. The high leaf density of a coffee plant may provide enough leaf surface area for net assimilation, even in unshaded conditions.

In this experiment, the conditions in the rooting zone were kept almost the same among shaded and unshaded plants. Realistically, sun light increases soil temperature and causes changes in soil moisture and nutrient conditions. An interesting finding has been obtained in the shade culture of cacao plants: At low nutrient levels the highest yield was achieved under shade, but the addition of N, P and K brought about the highest yield in full sun light. Differences in the soil conditions of shaded and unshaded plants seem to be responsible for the conflicting results.
in photosynthetic activities of coffee plants that have been reported.3,6,8) In our experiment, unshaded coffee plants may have had higher photosynthetic capacities compared with shaded plants because the nutrient and moisture status of the soil was controlled.

**Literature Cited**


**論文要旨**

コーヒーの光合成に及ぼす遮光処理の影響

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1年生のコーヒー（Coffea arabica var Typica）の実生に0, 30, 50, 80%の遮光処理を行ない、光合成の光・温度反応及び暗呼吸の温度反応を調べた。

みかけの光合成速度は無遮光条件下で栽培されたものが最も高く、遮光の程度が増すにしたがって低下した。光飽和点、光補償点及び暗呼吸速度も遮光処理にしたがい低下した。

光合成の最適温度は、20℃であったが、15～25℃でも高い活性を示した。温度の上昇による光合成の低下は無遮光区のものが大であった。即ち、高温下では遮光区のものが高い光合成活性を示した。このみかけの光合成の低下には暗呼吸の增大が関係しているものと思われた。

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