

Effect of light intensity on photosynthesis



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Photosynthesis is the process by which a plant cell converts carbon dioxide (CO₂) to food sugars via light energy. The aim of the experiment was to determine whether different light intensities have different effects on the rate of photosynthesis of two plants, one grown in normal light conditions and one grown in shade conditions. Each plant was placed in a sealed plastic box and was allowed to acclimatise. A Vernier CO₂ electrode was used to measure the concentration of CO₂ at one minute time intervals for each plant over a period of five minutes. This was repeated for different light intensities which were measured using a light sensor. Overall the rate of change in CO₂ concentrations decreased for both plants. At certain light intensities the rate of change in CO₂ levels was a negative value (approximately 45 arbitrary units for shade grown plants and 80 arbitrary units for light grown plants). This implies that from this point at greater light intensities the net rate of photosynthesis became greater than the net rate of respiration. The rate of change in CO₂ levels for the light grown plant is greater than that of the shade grown plant for light intensities greater than 50 arbitrary units. This implies that the light grown plant was able to achieve a higher rate of photosynthesis than the shade grown plant.

Introduction

Photosynthesis is the process by which a green plant converts light energy to chemical energy thereby creating food sugars (Johnson G, 2006). Plants are the main energy source of every food chain, making photosynthesis one of the most important biological processes (Raven P. et al, 1986). It is also believed that many forests, due to photosynthesis, can act as carbon sinks

by net absorption of carbon dioxide and may be able to help prevent climate change (Johnson G, 2006).

During C3 photosynthesis, carbon dioxide (CO₂) is taken in from the atmosphere, via stomata, to provide carbon for the carbohydrate food source produced (Raven P. et al, 1986). Water is also required for photosynthesis. A molecule of water needs to be split to release an electron for an electron transport chain which reduces NADP and ADP to NADPH and ATP (Raven P. et al, 1986). This is known as the light dependent stage of photosynthesis since light energy is required to hydrolyse the molecule of water. The next stage of photosynthesis is known as the light independent stage (Johnson G, 2006). This where CO₂ is taken in and fixed via the Calvin cycle to create organic compounds (Raven P. et al, 1986). The coenzymes that are reduced by the electron transport chain in the light dependent reaction are needed for these reactions. Oxygen is produced as a by-product of the hydrolysis of water.

Various species of plant adapted to warmer climates have slightly alternative methods of photosynthesising; The C4 and CAM pathways (Johnson G, 2006). These pathways are essentially the same as the C3 pathway in that CO₂ is converted to food sugars via light. However, the CAM pathway is separated in time and the C4 pathway is separated spatially (Raven P. et al, 1986). A plant species that photosynthesises using the C3 pathway was chosen for this experiment since this is deemed the standard, non-adapted form of photosynthesis (Johnson G, 2006, Raven P. et al, 1986).

Many plants can adapt to both shade conditions (low light conditions) and full light conditions (Salisbury and Ross, 1992). These adaptations are

designed to optimise photosynthesis under these different light conditions. Plants adapted to shade may not be able to photosynthesis at the same rate as light grown plants at high light intensities and vice versa. The lack of light in shade environments can lead to stunted and slower growth (Johnson G, 2006).

This study aims to determine whether the amount of light, and therefore light energy available, affects the rate of photosynthesis by comparing shade and light grown plants. This can be achieved by measuring the change in CO₂ concentration of each plant in a sealed environment over a given time period at different light intensities. CO₂ is absorbed during photosynthesis, therefore a decrease in CO₂ concentrations would demonstrate that photosynthesis was occurring. The study will also determine whether plants grown in light or shade conditions have the ability to photosynthesize equally at different light intensities.

Materials and Methods

Two plants of the same species were used. One was grown under shade (low light) conditions. The other was grown under direct light (high light) conditions. The leaves of each plant were placed in a sealed plastic box and were allowed to acclimatise. A Vernier CO₂ electrode was used to measure the concentration of CO₂ at one minute time intervals for five minutes for each plant. This was repeated for different light intensities (0, 10, 50, 150, 200, 300 and 400 arbitrary units) which were measured using a light sensor. To ensure the temperature remained constant a temperature sensor was used to monitor the temperature. The concentration of CO₂ was logged onto

a computer. To calculate the rate of change in CO₂ concentration, the difference in CO₂ concentration was plotted against time graphically and a tangent taken.

Results

The rate of change in CO₂ concentration was calculated for the different light intensities for each plant. This was then displayed graphically to allow comparison of the results (Figure 1).

Figure 1. The rate of change in CO₂ concentrations for each light intensity. The two plants are shown (shade grown and light grown) for comparison. The compensation points for both plants are labelled. The compensation for the shade grown plant is further to the left than the light grown plant.

The compensation point for the light grown plant.

The compensation point for the shade grown plant.

Overall the rate of change in CO₂ concentrations decreased for both plants. At a light intensity of 50 arbitrary units for the shade grown plant, and 150 arbitrary units for the light grown plant, the rate of change in CO₂ levels was a negative value (-1.5, -10.4). This implies that the net rate of photosynthesis was greater than the net rate of respiration. The rate of change in CO₂ levels for the light grown plant is greater than that of the shade grown plant for light intensities greater than 50 arbitrary units. The rate of change in CO₂ levels increased at 400 arbitrary units for both plants.

A reduction in the concentration of CO₂ over time implies that photosynthesis is occurring. This would give a negative rate of change in CO₂ levels. As such, the shade grown plant has a higher rate of photosynthesis at lower light intensities than the light grown plant (Figure 1). At higher light intensities this changes. The light grown plant has a higher rate of photosynthesis at higher light intensities than the shade grown plant (Figure 1). At approximately 300 arbitrary units the light grown plant reaches its light saturation point (Figure 1). This is the point where another factor becomes limiting, for example the amount of CO₂ available (Raven P. et al, 1986). The shade grown plant reaches its saturation point at approximately 200 arbitrary units (Figure 1). The rate of change in CO₂ concentration is less for the shade grown plant than the light grown plant.

Discussion

The shade grown plant appears to be better adapted to photosynthesising at low light intensities than the light grown plant. One of these adaptations may be having thinner, larger leaves (Salisbury and Ross, 1992). A larger surface area would allow the chloroplasts to be arranged, by phototaxis, into patterns that would maximise light absorption (Salisbury and Ross, 1992). Leaves from the plant grown at high light intensities might be thicker since they are more likely to have a waxy protective coating to prevent solarization of the chlorophyll pigments (Salisbury and Ross, 1992).

Plants grown in the shade are more likely to invest resources in light harvesting equipment such as grana and thylakoids than enzymes that are required for the Calvin Cycle (Salisbury and Ross, 1992). This is because in

the shade light will be the main limiting factor to the rate of photosynthesis as opposed to CO₂ levels. As such when a shade grown plant is exposed to high light intensities the rate of photosynthesis cannot increase dramatically since the rate of the light independent reactions cannot increase. This is another reason why the rate of photosynthesis in the shade grown plant doesn't increase as much as the light grown plant (Figure 1).

The rate of photosynthesis decreases at 400 arbitrary units for both plants (Figure1). This is a very high light intensity and as such denatures chlorophyll and the photosynthetic apparatus by solarization. The light grown plant would be more likely to have certain carotenoid pigments which could convert the excess light energy into heat energy and thus prevent the solarization of chlorophylls (Salisbury and Ross, 1992). This would explain why the light grown plant has a higher rate of photosynthesis at higher light intensities than the shade grown plant (Figure 1).

The compensation point is the point at which the rate of photosynthesis and the rate of respiration are equal (Salisbury and Ross, 1992). As such there is no change in the concentration of CO₂. Only when the light intensity is higher than the compensation point can photosynthesis occur (Salisbury and Ross, 1992). The compensation point for the shade grown plant is much lower than the compensation point for the light grown plant. This would be expected, since under shade conditions it is more beneficial to have a low compensation point, because it allows photosynthesis to occur in low light levels (Salisbury and Ross, 1992).

Future studies may benefit from testing a wider variety of C3 plants to see if the conclusions found here are specific to this species of plant or to C3 plants in general. Also it may be beneficial to use the whole plant rather than just the leaves. Repeat cycles of the experiment would confirm that the results are consistent and not linked to a failure in the control environment or equipment on a one off basis. The results discussed here were based on just the leaves rather than the plant as a whole. As such firm conclusions cannot be drawn.