E90 Final Proposal

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Introduction

Autotrophic organisms create sugars using photosynthesis, a reaction summarized by $6\ CO_2 + 12\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O$, where $C_6H_{12}O_6$ is the sugar glucose. Photosynthesis is measured by enclosing a plant or plant section and measuring the change in amounts of carbon dioxide and water vapor in air before and after contact with the plant. Using the chemical equation, the amount of sugar produced can be calculated.

Biologists often want to measure photosynthesis as a vital parameter of plants. However, existing commercial technology is designed to measure photosynthesis on a single leaf, which is extrapolated to the entire plant by multiplying by the number of leaves. As a result, these measurements are extremely approximate and do not take into account within-plant variations in terms of leaf photosynthesis that may be caused by leaf orientation, leaf age, or other factors.

The objective is to find the effect of the plant's life history on its photosynthesis, not to measure the effects of the immediate inputs. In order to get as realistic a picture as possible of the plants in the field when compared with greenhouse plants, many variables, such as water and carbon dioxide content of air, will be controlled for.

Project Plan

Plant Chamber

The chamber will be sized to accommodate a small plant, and will be in the shape of a cube with each side length around 30 cm (Figure 1). The material used to create the plant chamber has several constraints. It must be sufficiently clear to minimize interference with solar radiation received by the plant. The material must also block gas diffusion. Many common materials such as Plexiglas "breathe", allowing transfer of gases. Since the change in concentration of CO_2 and H_2O is being measured, this diffusion will produce inaccurate data. To prevent the material from "breathing," Plexiglas with a clear anti-diffusion film will be used to make the chamber. The sides of the chamber will be connected with acrylic cement. To separate root and soil respiration gas transfer from photosynthesis, the chamber will have a floor. This floor will be in two parts, with a hole for the plant stem and a flexible collar to fill the gap between the plant stem and the floor (Figure 2). The floor will be constructed of the same material as the rest of the chamber, and the collar material will be a flexible rubber material.

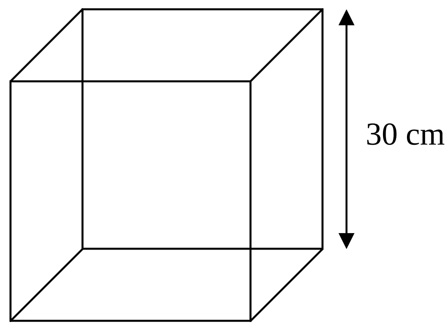

Figure 1

Dimensions of Plexiglas chamber (30cm x 30cm x 30cm)

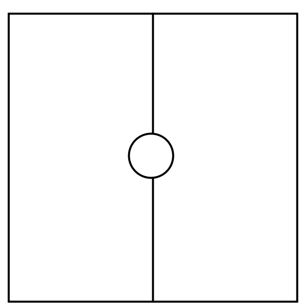

Figure 2

Bottom of Plexiglas chamber. The hole in the middle is for the plant stalk, and will be filled with a flexible rubber material to minimize leakage.

Temperature Control

The most important parameter to control is the chamber temperature. The action of solar radiation on the chamber will cause the chamber's internal temperature to increase. Temperature fluctuation may cause the plant to photosynthesize in an unusual way, making measurements difficult to compare to greenhouse controls, which have comparatively constant temperatures. Extreme temperatures can also stress plants, causing damage and invalidating measurements. Temperature also affects the water vapor deficit and dew point. Water condensation must be avoided, since carbon dioxide will dissolve in water, obscuring measurements, and since condensation on chamber walls will change the amount and type of light coming into the chamber. To avoid these difficulties, the temperature in the chamber will be maintained within a user specified range. Recommended ranges will be calculated. This control will be accomplished using a Peltier effect thermoelectric cooling unit.

Gas Mixing

For gas output measurements to be accurate, the air within the chamber must be perfectly mixed to ensure constant gas concentrations. Mixing will be achieved using small electric fans. A sufficiently high wind speed will also discourage condensation. However, the air velocities created by the fans cannot be excessively high. To a certain extent, high wind speeds will affect gas transfer on the leaf surface and thus photosynthesis. More importantly, plants can become wind stressed, altering photosynthesis, and producing invalid results. Thus, the smallest air velocity at the fans that will still create sufficiently perfect mixing must be found. Fans producing the calculated velocity will be installed.

Solar Radiation

Photosynthesis is a well characterized function of light. To account for this dependence, the radiation incident on the plant will be measured using small photovoltaic transducers. These will be mounted inside the chamber to account for the reflectivity and absorptivity of the chamber material.

Input Water Vapor

In an open system, the mass balance of water vapor can be expressed as $E = \frac{u_i(w_o - w_i)}{s(1 - w_o)}$, where s is the total leaf area, E is the transpiration rate, u_i is the incoming flow rate flow rate, and w_i and w_o are water mole fractions. Control of water vapor is important for two main reasons. First, if the humidity of the incoming air is too extreme, the plant's behavior will change and measurement will become more difficult. In particular, plants that grow in Pennsylvania will close their stomata if the humidity is too high. Closed stomata block gas transfer into the plant, and thus disrupt photosynthesis. In addition, high water vapor concentrations can disrupt carbon dioxide measurements. At extremely high humidities, water vapor will condense. Since carbon dioxide dissolves in water, some of the carbon dioxide to be measured will be trapped in water. Since high humidity is the primary concern, the control mechanism will focus on ensuring the incoming humidity is always below a user supplied threshold. Recommended thresholds will be calculated. Water vapor can be removed from the air using a dessicant column. If the incoming air humidity is too high, the air intake will be split between a soda lime column and an empty column in correct proportions.

Input Carbon Dioxide

Biologists often want to control the carbon dioxide concentrations experienced by the plant. Since carbon dioxide is a regent in the photosynthesis reaction, its concentration will affect the plant's behavior. Different degrees of control are possible. On one extreme, all the carbon dioxide in the incoming air could be removed using a soda lime column. The desired concentration could then be achieved using a carbon dioxide tank. The input carbon dioxide could also be kept below a given threshold using a splitting valve and two columns—one with soda lime and one empty—as described for controlling water vapor.

Even if the user does not want direct control over the input carbon dioxide, a relatively constant level of carbon dioxide is valuable. A rapidly fluctuating carbon dioxide concentration will yield photosynthesis measurements for transient states of many different concentrations. Since biologists often want to compare photosynthesis at different carbon dioxide concentrations, a more stable input concentration is important. One method of achieving a more uniform concentration is by using a large enclosure of air from which input air is taken. The enclosure acts as a buffer volume to smooth out variation.

LI-6400 Device

The primary objective of the electrical/control portion of the project will be in interacting with the LI-6400 leaf chamber fluorometer, determining when water and carbon dioxide filtering must be adjusted for optimal results, and analyzing the data obtained from the device.

The LI-6400 has an integrated eight-line by forty-character screen and both an RS-232 connection and Ethernet card for interfacing with a PC. It runs a primitive operating system that allows programs to be run. The main data-display program is called OPEN, but it is unclear as to whether user-defined programs can be run on the device. The instrument information page states that "other applications are stored in the file system and can be run," but does not give more detail about user-defined software. If it is possible to write programs for the LI-6400, one will be constructed to suit the chamber and threshold values for water and carbon dioxide levels. Otherwise a separate device may be constructed (to interact with the LI-6400 via its integrated Ethernet card) in order to display the required information in a concise and clear manner.

Direct control of water and carbon dioxide levels by the device will be considered and their merits evaluated, but given the portability required for the chamber and its accessories and the small assembly time that would make the instrument reasonably sized, it is likely that direct control will not be adopted.

There are two data-analysis options: the first is dynamic analysis, which would provide information as the test was running; the second is after-the-fact analysis, which would take place once the test was completed. Laptop scripts will be developed to process the data from the LI-6400 (using the built-in Ethernet card to stream the data) in order to allow up-to-the-minute (or up-to-the-half-hour, or whatever is reasonable given the timescale of the tests and analysis) information on the tests. This will allow for on-the-fly adjustment of testing procedures if desired results are not being achieved.

Budget

Item	Cost
Plexiglas Sheet	$250
Acrylic Cement	$15
Cooling Unit	$60
Filtration Equipment	$25
Tubing/Valves	$40

Thermistors	$80
Fans	$60
Solar Transducer	$50
TOTAL	$580