An investigation into the effect of light intensity on the rate of photosynthesis of Canadian pondweed (*Elodea canadensis*)

Planning

Scientific knowledge and understanding

All green plants need to be able to make their own food. They do this by a process called photosynthesis, which means, "making things with light." Photosynthesis is a series of organic chemical reactions by which green plants produce glucose and oxygen from carbon dioxide and water. It occurs only in the presence of light, and takes place in the chloroplasts of green plant cells. Land plants get carbon dioxide from the air. Water plants get carbon dioxide from water (carbon dioxide in the air dissolved into water). Photosynthesis creates oxygen and sugar. Oxygen is released into the air and used by all animals, including humans, in order to respire. Sugar is used by the plant to respire or store them inside their body.

The overall chemical equation for photosynthesis can be expressed as:

$$6CO_2 + 6H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light}} C_6H_{12}O_6 + 6O_2$$

Plants convert the light energy into stored chemical energy. Photosynthesis is possible because green plants contain an energy-capturing substance called chlorophyll. The plant gets its green colour because chlorophyll is green.

Light energy drives photosynthesis. The chlorophyll captures the light energy and uses it to build carbohydrates from simple raw materials (water, carbon dioxide and minerals). The raw materials that are needed for photosynthesis provide the element to make up carbohydrates – carbon, hydrogen and oxygen. The carbon dioxide in the air is the source of carbon. Hydrogen and oxygen is taken from water by a process called photolysis. These raw materials enter the plant through its roots and leaves. Both water and carbon dioxide enter the pondweed through their leaves.

The rate of photosynthesis is affected by changes in light intensity, temperature and carbon dioxide concentration etc. It may be limited by conditions such as light intensity temperature and carbon dioxide concentration. Light intensity has a more immediate effect on the rate of photosynthesis than any other factor. In the dark, photosynthesis stops completely. Light, temperature and carbon dioxide not only affect the rate of photosynthesis but also limit how fast it goes. They are called limiting factors. For example, as the light intensity increases, so does the rate of photosynthesis. But then it reaches a maximum rate which when the light intensity increases; there is no more affect of the rate of photosynthesis. Now carbon dioxide concentration or temperature may become the limiting factor.

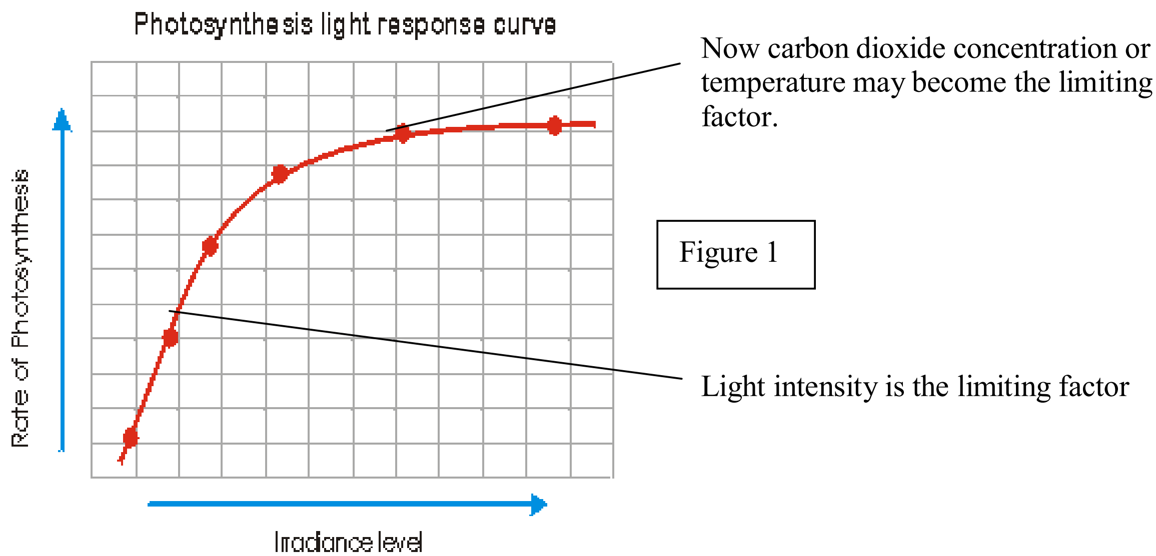


Figure 1

(This picture is from: www.marietta.edu/~spilatrs/biol103/photolab/photosyn.html)

In this investigation, I will investigate the photosynthesis of Canadian pondweed – a water plant. This is because pondweed will have to stay under the water to be alive. Oxygen bubbles will be produced from the cut end of the plant and we can tell from the number of the bubbles that what is the rate of the photosynthesis. If I use a land plant, I will not be able to tell how much oxygen has been produced. So I will not be able to find out the rate of photosynthesis. Also if I use a land plant, water will likely to be a limiting factor as if the soil is not wet enough.

The aim of my investigation has been to determine how the intensity of light affects the rate of photosynthesis in Canadian pondweed. To do this, I placed a piece of pondweed in varying light intensities, and observed the number of oxygen bubbles giving off in a given time. I used pondweed because of its quality of giving off bubbles of gas from a cut end, when placed in water.

Prediction

1. I predicted that as the light intensity increased, so would the rate of photosynthesis. This is because when the light source is nearer, more light will take part in the reaction therefore more photosynthesis will occur which means more oxygen will be produced.
2. Furthermore, I predicted that if the light intensity increases, the rate of photosynthesis would increase at a constant rate until a certain level is reached where an increase in light intensity will have no further effect on the rate of photosynthesis. There will be another limiting factor, in this case probably temperature or carbon dioxide.

As one can see that figure 1 supports my prediction.

Key factors

Independent variable

Light intensity is the independent variable. It is to be varied by increasing and decreasing the distance from the light source to the plant. I am going to put a ruler between the desk lamp and the beaker. Every time I move the desk lamp, I would get a distance. From the distance, I could calculate the light intensity by this equation:

Light intensity α /distance^2

I am going to take 5 distances and measure the oxygen bubble produced in each distance. I am going to take 5 values because it is the minimum value required to draw a smooth curve. It is better to have more values but the time is not allowed.

This is a table to calculate the light intensity from distance

Distance/cm	Distance^2/cm^2	1/d^2/arbitrary unit	1/d^2 x 100
1	1	1	100
2	4	0.25	25
3	9	0.11111	11.11
4	16	0.061	6.1
5	25	0.028	2.8

(Table 1)

A table to calculate the distance from light intensity

Light intensity ($1/d^2$) x 625	Light intensity ($1/d^2$)/arbitrary unit	Distance^2	Distance/cm
1	0.0016	625	25
2	0.0032	0.5	17.6
3	0.0048	0.3333	14.4
4	0.0064	0.24	12.5
5	0.0080	0.2	11.2

(Table 2)

The numbers I get from this equation will be too small to make any sense and hard to draw a graph with them. So I decide to use them multiplied by a big number. If I use the light intensity from table 1, it will be quite hard to draw a graph and I will not get a very nice graph. This is because although the distance is evenly distributed (1cm, 2cm, 3cm, 4cm and 5cm), I cannot get the evenly distributed numbers if I just calculate the light intensities from them. If I use the distances in table 2, 25cm, 17.6cm, 14.4cm, 12.5cm and 11.2cm, they looks strange, but I will get a group of evenly distributed numbers – 0.0016, 0.0032, 0.0048, 0.0064 and 0.0080 if I calculate the light intensity from them. I can then multiply them by a big number to get the evenly distributed light intensities. I have chosen 625 to be the number because I will get 1, 2, 3, 4 and 5 if I do so, which is very easy to use to draw a graph.

Dependent variable

The rate of photosynthesis is the dependent variable. The way to find this is finding the number of oxygen bubbles produced in a minute. During photosynthesis, the pondweed produces oxygen. The oxygen gas would come out from the cut end. Though counting the number of the bubbles is not a very accurate way to get the rate of photosynthesis because the size and oxygen concentration varies of the bubbles, it still could show the rate of photosynthesis.

Control variables

These need to be kept constant because they will affect the results and shape of the graph if they are not constant.

Temperature – Enzymes are used in the photosynthesis reactions of a plant. A higher temperature will provide the plant more kinetic energy. Therefore, temperature will increase the rate of photosynthesis, until a point at which the enzymes denature. Although performing the experiment at a temperature slightly higher than room temperature, perhaps 25°C, would have a positive effect on the accuracy of the readings I took, as it would reduce the percentage error, by increasing the number of bubbles, I decided that the inaccuracy of maintaining a constant higher temperature would outweigh any advantages. I am therefore going to perform the experiment at room temperature, checking the temperature frequently, in case the heat given off from the light should slightly raise the temperature, in which case I shall simply refill the beaker with more water after each experiment.

Light wavelength (colour) – light energy is absorbed by the pigment, chlorophyll, in the leaf. Chlorophyll easily absorbs some colour of light, such as blue and red. However it does not easily absorb green or yellow light, rather it reflects them, decreasing the amount of light absorbed, and therefore the rate of photosynthesis. This can easily be controlled, simply by using the same lamp throughout the experiment.

Carbon dioxide concentration – This can affect the rate of photosynthesis, since if there is too little carbon dioxide, it can become the limiting factor, thus impeding the rate of photosynthesis. In this case, I would use 0.5% sodium hydrogen carbonate solution instead of water, thus ensuring a large enough supply of carbon dioxide.

Water availability – water is also required in the photosynthesis reaction. Clearly, in a water plant, like the pondweed, as long as the plant is fully submerged in water at all times, this will not be a problem.

Outline of method

A piece of pondweed will be cut and placed into a specimen tube containing sodium hydrogen carbonate solution. A desk lamp will provide the light for the pondweed and the number of bubbles released from the plant will be counted. The lamp will be adjusted to different distances from the plant to try and obtain different results.

The possible risks are:

- When one is counting the oxygen bubbles, one's eyes may be hurt by the bright light. The protection is to choose a good angle so that the light is not directly irradiate into one's eyes.
- When one is using the sodium hydrogen carbonate solution, the liquid may be splashed out and damage one's eyes though it is only 0.5%. Should be careful when using it.

Preliminary work

Initially, to ascertain a suitable range of distances at which to record results for my experiment, I did a preliminary investigation in which I recorded the number of bubbles of oxygen given off in a given time at various light intensities. To alter the light intensity, I placed a lamp at various distances from the plant.

I got the following results:

Distance/cm	Number of oxygen bubbles per minute
10	54
20	35
30	23
40	17
50	5

(Table 3)

Things I learned from this pilot study:

- From the results, I can see that when the distance is more than 40cm, there will be too few bubbles produced in a minute. There will be more error if too few bubbles are produced. But if the distance is less than 10cm, there will be too many bubbles produced in a minute, about one bubble per second. Though this will give me a more accurate result of the rate of the producing of bubbles, it is quite hard for someone to concentrate on counting fast moving bubbles for a long period of time. So in the main experiment, I will try to make the distance between 10cm and 30cm. This will give me accurate results and also the bubbles will not be produced very fast.

- I find it is quite difficult to draw a graph from these data, this is because when I calculate the distance into light intensity, they are not evenly distributed. If I use the data like this, the graph will not as the nice as that using evenly distributed numbers. So I decide to make the final light intensity 1, 2, 3, 4 and 5. Then use them to calculate the distances that I should use (see table 2).

- I find out that the temperature of the water will go up after a period of time. I think it is probably because the heat comes from the desk lamp. In the main experiment, I will measure the temperature regularly to make sure the temperature keeps at about 20°C.

Detailed method

I can clear see what am I going to do from this simple diagram.

1. Collect all apparatus

See “Equipment and materials”

2. Set up the equipments as the diagram shows.
3. Cut a stem of pondweed of about 6cm in length.
4. Fill a specimen tube with 0.5% sodium hydrogen carbonate solution, and place into a large beaker contains 20º C water.
5. Connect the end of the pondweed with a lead weight and put it into the test tube.
6. Insert a thermometer into the specimen tube, and take a look at the temperature every frequently to make sure that it keeps constant at 20º C.
7. Set up a lamp at a set distance from the plant, ensuring that this distance is from the filament of the lamp to the actual pondweed, rather than the edge of the beaker.
8. Start the stopwatch, and wait for 5 minutes to allow the pondweed to adapt the new condition. If the bubbles are being produced at a steady rate restart the stopwatch and begin to count the bubbles. After 1 minute, stop the stopwatch and record the result into the table. After another minute, record the result into the table, do the same thing for the third time to get an average result for each distance.
9. Now repeat step 7 and 8 with the other distances.

Equipment and materials

The Equipment and materials I plan on using are:

a. Canadian Pondweed (*Elodea canadensis*) (being cut in one end about 6cm in length) – used as the object of the investigation
b. Desk lamp (40W, 60V) x 1 – used for provide light for the pondweed
c. Stop watch x 1 – used for timing
d. Metre ruler x 1 – used for setting up the distance between the desk lamp and the pondweed
e. Sodium hydrogen carbonate solution (0.5%) – used for provide carbon dioxide for the pondweed
f. Specimen tube x 1 – used for filling in with sodium hydrogen carbonate solution and pondweed
g. Thermometer x 1 – used for making sure the temperature of the sodium hydrogen carbonate solution stays constant
h. Measuring cylinder (100cm^3) x 1 – used for measuring the volume of the sodium hydrogen carbonate solution
i. Beaker (250cm^3) x 1 – used for filling in with water to keep the temperature of the specimen tube constant
j. Hot water – used for making sure that the temperature in the test tubes remains constant
k. Scissors x 1 – used for cutting the pondweed
l. Lead weight – used for keeping the pondweed under the water

Obtaining evidence

Result table

Distance/cm	Light intensity/ arbitrary units	Number of oxygen bubbles per minute			
		Replicate 1	Replicate 2	Replicate 3	**Mean**
25.0	1	23	25	24	24
17.6	2	32	33	28	31
14.4	3	39	43	41	41
12.5	4	46	52	48	49
11.2	5	56	61	58	58

(Table 4)

Analysis and considering evidence

Calculations

I will use the distances to calculate the light intensity by using this equation:

Light intensity α $1/\text{distance}^2$

The numbers I get from this equation will be too small to make any sense and hard to draw a graph with them. So I decide to use them multiplied by a big number. I used the distances in table 2, 25cm, 17.6cm, 14.4cm, 12.5cm and 11.2cm, they looks strange, but I will get a group of evenly distributed numbers – 0.0016, 0.0032, 0.0048, 0.0064 and 0.0080. I can then multiply them by a big number to get the evenly distributed light intensities. I have chosen 625 to be the number which is multiplied by the light intensities. This is because it will give me 1, 2, 3, 4 and 5, which is very easy to use to draw a graph.

$1/25^2 = 0.0016$
$0.0016 \times 625 = 1$

$1/17.6^2 = 0.0032$
$0.0032 \times 625 = 2$

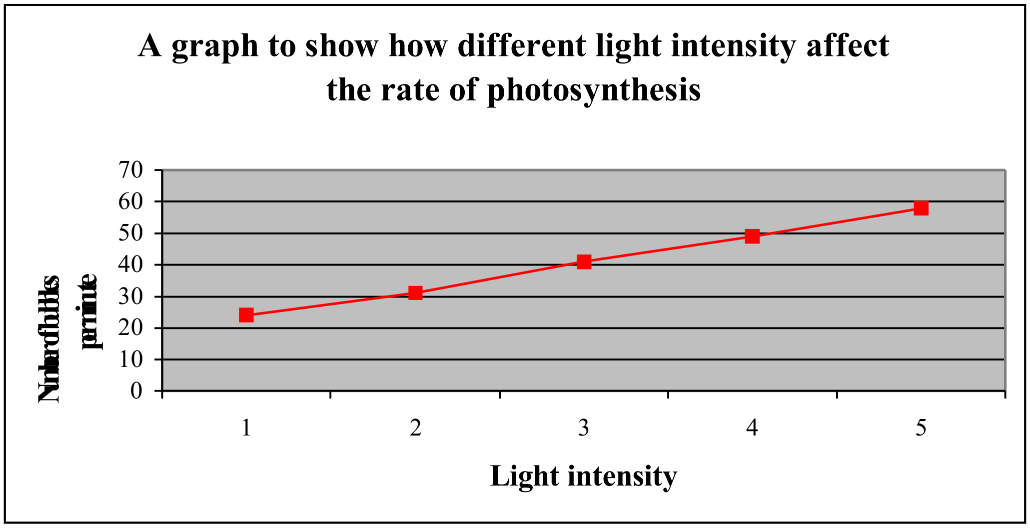
$1/14.4^2 = 0.0048$
$0.0048 \times 625 = 3$

$1/12.5^2 = 0.0064$
$0.0064 \times 625 = 4$

$1/11.2^2 = 0.0080$
$0.0080 \times 625 = 5$

Graph

This is a graph which drew by the computer.



Trends and patterns

From the graph, I can see that as the intensity of light increased, so does the rate of photosynthesis. As the light intensity keeps increasing, the rate of photosynthesis increased proportionally but it didn't reach that certain level where an increasing of light intensity will not affect the rate of photosynthesis any more. As the light intensity increase from 1 to 3, the number of bubbles produced increases from 24 to 41 (increases 17). As the light intensity increases from 4 to 5, the number of reaction decreases from 49 to 58 (increases 9). Compared with the increasing between light intensity 1 and light intensity 3, I can see that the increasing is just about the same between light intensity 4 and light intensity 5. ($9 \approx 17/2$) In the graph, I can see the number of bubbles produced should be at about 33 for light intensity 2. But actually, its number of bubbles produced is only 31. I think this may because error of countin g. Or it may because the error of the distance measuring.

Explanation of trends

As the intensity of light increased, so would the rate of photosynthesis. The elements that are needed for photosynthesis are carbon, hydrogen and oxygen. The carbon dioxide in the water is the source of carbon. Hydrogen and oxygen are taken from water by a process called photolysis. If the light intensity is higher, there will be more energy for this process. Therefore the rate of photosynthesis will be increased. As the light intensity keeps increasing, the rate of photosynthesis increased at a proportional rate but it didn't reach that certain level where an increasing of light intensity will not affect the rate of photosynthesis any more. This is because the light source is not bright enough. Even when the light intensity is 5, it is still a limiting factor. So the graph didn't level off. If you want to get a graph which levels off, you should use a more powerful bulb.

Original prediction

The conclusions support a part of my predication.

Review my predication, it said: “as the intensity of light increased, so would the rate of photosynthesis, the rate of photosynthesis will increase at a constant rate”. On my graph, I can see that as the intensity of light increased, so does the rate of photosynthesis.

Review my predication, it also said: “if the light intensity increases, the rate of photosynthesis would increase at a constant rate until a certain level is reached where an increase in light intensity will have no further effect on the rate of photosynthesis. There will be another limiting factor, in this case probably temperature or carbon dioxide.” On my graph, I can’t see that curve levels off. This means that my independent variable didn’t cover the whole range of value, which my prediction refers to. I need a higher light intensity to get the graph which levels off.

Evaluating

Quality of the evidence

I have used error bars on my graph. I can see exactly how close the replicates were. In all light intensity, the replicates are quiet close. All the replicates are within 10% of the mean value. On light intensity 1, I got the closest replicates: 23 bubbles, 24 bubbles and 25 bubbles. These replicates are within 5% of their mean value – 24 bubbles. On light intensity 2, I got the worse replicates of five: 32 bubbles, 33 bubbles and 28 bubbles. They are just about within 10% of their mean value.

It is impossible to say how much error there is in my reading. Firstly, the distance between the light sources and the Canadian Pondweed were not measured to a very high degree of accuracy, especially when you note the fact that the distance should have been measured exactly from the filament of the light bulb to the centre of the plant. There may be only 10 bubbles produced, but I may count 9 or 11 bubbles. I have some problem in taking reading. When I concentrate on the glass baker under a bright light for too long period of time, I will lose my concentration. It is easy to make some error.

There isn’t any obvious anomalous mean value on my graph. But in light intensity 2, the mean value it not on the line of the best fit. It is only a few bubbles away from the line of best fit so it can’t be count as an anomalous value.

Suitability

Independent variable: light intensity. I do not think that the chosen numbers of values are sufficient. I only chose five values because of the time limit. I can only draw a basic curve using five values. Also these five values are not good because they don't allow the full-expected shape of the curve to be shown. To draw the full-expected shape of the curve, I need some light intensity which is bigger than 5. I expect the curve to go up at first and then level off at about light intensity 4. So I choose light intensity 1 to light intensity 5. But actually, it didn't even level off at light intensity 5. In the experiment, I find that in light intensity 5, the curve is starting to level off a little bit. But the curve is not level off completely. So it cannot allow the full-expected shape of the curve to be shown.

Dependent variable: the rate of photosynthesis. For dependent variable, I need the number of oxygen bubbles produced per minute in different light intensity. I do not think that it measured in the best way at the most appropriate times. The number of oxygen bubbles I counted has different sizes and different oxygen concentration. It can only show roughly the rate of photosynthesis.

Control variable: temperature. I kept the temperature at 20 °C to 22 °C all the time. So they were kept constant and at the best value.

Light wavelength (colour). I have been using the same lamp through the experiment. So I think they kept constant.

Carbon dioxide concentration. I have been using sodium hydrogen carbonate solution (0.5%). So it kept constant and supplies enough carbon dioxide for the plant.

Water availability. The plant kept in the water so this isn't a problem.

Chlorophyll. I used the same plant through the whole experiment. So the chlorophyll should be the same.

Replicates: It is better to have replicates. If I just do one experiment, I may make some mistakes in that particular experiment and I cannot find out. If I do three, it will be more reliable; their average value will be more believable. I think 3 replicates is enough. Of course, it is better to have more replicates, but the time is not enough.

Reliability of the evidence

I have used error bars on my graph. I can see exactly how close the replicates were. In all light intensity, the replicates are quiet close. All the replicates are within 10% of the mean value. On light intensity 1, I got the closest replicates: 23 bubbles, 24 bubbles and 25 bubbles. These replicates are within 5% of their mean value – 24 bubbles. On light intensity 2, I got the worse replicates of five: 32 bubbles, 33 bubbles and 28 bubbles. They are just about within 10% of their mean value.

Not all the points are on the line of the best fit. On my graph light intensity 2 is not on the line of best fit. If I have bigger light intensity, I will have the similar shape as figure 1 which is from the Internet.

Is the evidence sufficient to support the conclusion?

I think it would have helped to have a wider range of values of light intensity. For example, I can have light intensity 6, 7 and 8. If I have a wider range of values of light intensity, I will be able to show the full-expected curve.

I think it would also be helpful to have additional intermediate values or different values. For example, I can have light intensity 1.5, light intensity 2.5 etc. I think these additional intermediate are most needed between light intensity 1 and light intensity 3. This is because I got a value which is not on the line of best fit for light intensity 3. I need more information to make the curve between light intensity 1 and light intensity 3 smoother. If I have some different values, it will show very clearly what the whole shape of it.

Further work

- In the experiment, I only have counted the number of bubbles. It can only show roughly how much oxygen is produced. Because the size of the bubbles may be different slightly, and also the concentration of oxygen in these bubbles may be different as well. A better way to do this is to use an Audus apparatus. It can collect the oxygen gas into a little tube to how much oxygen gas is produced. It is also possible to use a density-metre. To measure the concentration.
- If the time allows, find out more data about the rate of reaction in each value. Instead of doing three groups, I can do more groups. For example 4 groups, 5 groups or 6 groups. If I have more values, the mean value is more accurate.
- Make sure the temperature is 20 ˚C all the time. I do not think it is possible because the desk lamp would produce a lot of heat, which would heat the water up. But if I can do it, I will get better results.
- Though using distance to calculate the light intensity is one way to get the light intensity, it is not as good as measuring it directly using a . There must be some error when one is setting up the distance. Also it is much easier to use a .
- A different species of plant would be very helpful. This plant should also be a water plant. This will be helpful because the plant I am using may be not very healthy.