Experiment to investigate the effect of different concentrations of Carbon Dioxide on the rate of photosynthesis.

Introduction

Photosynthesis is the main source of energy in all plants and by this route supplies energy to the whole ecosystem. Photosynthesis is a plant's way of creating food, the plant takes in carbon dioxide and water and using light energy (usually from the sun) the plant converts the carbon dioxide and water into glucose and oxygen.

$$6CO_2 + 6H_2O \xrightarrow{\text{Light + chlorophyll}} C_6H_{12}O_6 + 6O_2$$

carbon dioxide + water → sugar + oxygen

The equation above shows the overall action of photosynthesis but represents the total of a number of different reactions going on.

Photosynthesis takes place mainly in the leaves of a plant. Leaves are a good location for photosynthesis to take place because they have a large surface area for light absorption. Leaves are also thin allowing easy gas diffusion in and out of the leaf and the vein system supports the leaf and provides a way of carrying substances to and from all the cells in the plant. The chloroplasts within the leaf cells contain chlorophyll. This substance gives the leaves their green colour and absorbs the sunlight providing energy for the photosynthesis.

Limiting factors

Light can limit the rate of photosynthesis even if carbon dioxide and water are both present; a maximum rate of photosynthesis is reached at a certain light intensity. The light must contain the right colours for photosynthesis to occur, blue or red is best, green, violet and ultra violet will not be absorbed by chlorophyll.

Carbon dioxide concentration is the major limiting factor for photosynthesis; concentration in the air is 0.03%.

Temperature rise causes a rise in the rate of photosynthesis because the heat causes the enzymes to react faster. But too much heat will kill the enzymes as it denatures their protein.
Chlorophyll concentration is normally a limiting factor in photosynthesis but the chlorophyll concentration sometimes decreases due to mineral deficiencies or disease.
Water is a limiting factor and without it photosynthesis cannot occur.

Planning

Aim: In the experiment a piece of Elodea (Canadian pond weed) will be taken and placed in to a measuring cylinder containing varying concentrations of sodium hydrogen carbonate. Then a light will be shone on the measuring cylinder from a set distance and the amount of bubbles being produced in the measuring cylinder for a set period of time will be recorded. Two readings of bubble production will be taken.

The equipment that will be used will be:

- a lamp to provide light for photosynthesis
- ruler for measuring the distance between the lamp and measuring cylinder before each experiment
- two measuring cylinders: one for performing each experiment in, one for keeping the Elodea in warm water (about 25°C) between experiments
- a thermometer for measuring the solution temperature during each bubble count
- a stopwatch for timing the bubble count
- a scalpel for cutting a piece of Elodea
- tile for cutting the Elodea on.

Other requirements for the experiment:

- A piece of Elodea
- Stock solution of 0.5 M sodium hydrogen carbonate
- Distilled water for dilution of the stock solution.

In the experiment the manipulated variable will be the concentration of sodium hydrogen carbonate in the measuring cylinder, this will be controlled by reducing the amount of sodium hydrogen carbonate and then making the solution in the measuring cylinder back up to 100 cm^3 with water.

Dilution of sodium hydrogen carbonate solution with water

Volume 0.5 M $NaHCO_3$ cm^3	Volume water cm^3	% solution (0.5 M $NaHCO_3$)
100	0	100
90	10	90
80	20	80
70	30	70
60	40	60
50	50	50

The responding variable will be the number of bubbles created over a set period of time (assuming that the bubbles are oxygen). This will therefore give the rate of photosynthesis.

To make sure that the experiment is a fair test:

- the amount of the solution in the measuring cylinder will always be 100cm^3 because it reduces the variables between the different experiments; the volume of solution might have an effect on the rate of photosynthesis and a smaller volume of solution would be heated up more by the lamp during the experiment
- the light will be at the same distance of 5 cm, location and position every time because the same light intensity had to be delivered for each experiment, to minimise the number of variables
- there will be no other light to ensure that the same light intensity is provided for each experiment
- the same type, length, and piece of plant will be used every time so that the potential for photosynthesis and therefore bubble production will be the same for each experiment
- the time allowed for counting the bubbles will always be one minute because this was a suitable time to allow the production of a

reasonable number of bubbles without being too long increasing the risk of loosing count of the bubbles

- the time for the solution to settle before the bubbles are counted will always be two minutes to allow photosynthesis to start and and reach a steady rate in the particular solution of sodium hydrogen carbonate for each experiment
- the temperature will be kept the same at all times and maintained because the temperature will affect the rate of photosynthesis; an increase in temperature will increase the rate of photosynthesis provided it is not great enough to damage the enzymes.

Prediction

My prediction is that as the concentration sodium hydrogen carbonate decreases the number of bubbles will be lower therefore the rate of photosynthesis will have decreased. I think this will happen because the amount of carbon dioxide is known to be a limiting factor for photosynthesis, and the sodium hydrogen carbonate is what is providing the carbon dioxide so decreasing that will decrease the amount of carbon dioxide.

At high levels of carbon dioxide it is possible that the rate of photosynthesis will not be able to increase further because it is already at a maximum.

Light is another limiting factor for photosynthesis but this will not affect my experiments because the same lamp will be used at the same distance from the plant each time.

Temperature of the surroundings can also be a limiting factor to the rate of photosynthesis but this should remain constant for each of my experiments and will be measured as a check on this. Any rise in temperature caused by the lamp should be the same each time as the lamp will be at the same distance and the volume of solution will be the same in each experiment.

Chlorophyll can be a limiting factor but the same piece of plant was used in each experiment therefore the amount of chlorophyll was the same.

Water can also be a limiting factor but the same volume of solution was used each time and water is probably never a limiting factor for a water plant.

Obtaining

A measuring cylinder was used to make the dilutions of sodium hydrogen carbonate accurately and to conduct the experiment in the same volume of solution each time.

A thermometer was used to record the temperature of the water to make sure that it was not heating up too much from the heat of the lamp.

A stopwatch was used to measure the 2 minutes for the plant and solution to settle before a reading was taken. It was also used to time the one minute bubble recording time accurately.

The lamp was set at 5 cm from the measuring cylinder because a distance of 5 cm was found to give a good rate of photosynthesis in a preliminary experiment. This distance was checked at the start of each experiment.

Results: Temperature and bubble count readings at each dilution of sodium hydrogen carbonate

$NaHCO_3$ %	Initial water temperature (°C)	Final water temperature (°C)	Number of bubbles/ min (1)	Number of bubbles/ min (2)	Average number of bubbles/ min
50	27	28	0	0	0
60	28	29	6	4	5
70	24	27	23	27	25
80	26	29	27	22	24
90	26	28	51	66	58
100	25	28	69	71	70

The average was found by adding the two sets of results and dividing the answer by 2.

Analysing

The products of photosynthesis are glucose and oxygen. The easiest product to measure is the oxygen. This can be done by counting the bubbles of oxygen given out by the plant as it photosynthesises when all the reactants and a light source are present.

The results show, that as the percentage of the sodium hydrogen carbonate solution decreased (100-50%) so did of the number bubbles (70-0 bubbles / minute). Therefore the rate of photosynthesis also went down.

Results also show that the rate of photosynthesis goes down quite sharply, as with the 100% solution the average number of bubbles was 70 but with the 70% solution the average number had dropped to 25. However the result at 80% is almost the same, the average number of bubbles for this percentage is 24, this would appear to be an anomalous result. The average for 60 percent being 5 bubbles and at 50 percent there were no bubbles at all. Suggesting that at 50% solution of 0.5 M sodium hydrogen carbonate solution there was not insufficient carbon dioxide present to allow photosynthesis to occur. These results show quite clearly that carbon dioxide does have a quite dramatic effect on that rate of photosynthesis .

These results agree with my prediction but a flattening off of the graph at higher concentrations of sodium hydrogen carbonate was not very obvious. However the points on the graph may be joined by a line of best fit which is not a straight line Graph 2. On this graph there is a slight levelling off of the graph at the highest concentration of sodium hydrogen carbonate. This suggests that the rate of photosynthesis was almost at a maximum, carbon dioxide was no longer limiting the rate but other factors may have been. Increased light or temperature might have allowed the rate of photosynthesis to increase further.

At first the light provided was not a limiting factor as a preliminary experiment had shown the lamp at a distance of 5 cm to provide adequate light for a good rate of photosynthesis. The temperature of

the solution only varied by 2-3°C during the one minute reading. The starting temperature of the solutions were all in the range 24-28°C thus very similar. Therefore temperature should not have been a limiting factor at the start of this experiment. The plant was healthy therefore chlorophyll would have been adequate for photosynthesis and there was plenty of water.

The result of zero bubbles with the 50% solution was accurate but the result at 60% does seem to fit the curved line of best fit well. It is possible that the zero bubbles point should not be plotted at 50% sodium hydrogen carbonate solution, 55% or 57% solutions might also have given zero bubbles but they were not tested.

The result with the 80% solution was low relative to the line of best fit. This may have been due to the initial stock sodium hydrogen carbonate having been made up with water that was not distilled water. The Elodea therefore had some calcium carbonate present as a white deposit on some of the leaves, which may have affected the plant's ability to photosynthesise, possibly by decreasing carbon dioxide absorption. The stock was remade with distilled water and further measurements were less likely to be affected because the plant was kept in warm water between experiments allowing deposits to be washed off the leaves.

Evaluating

The only result that could really be called anomalous is the result for 80% as the result was the same as at 70% that is 24 bubbles in one minute. According to the graph this result should have been about 40-50 bubbles in one minute. The zero result at 50% does not seem to fit the curved line of best fit very well. May be a 55 or 57% solution of sodium hydrogen carbonate would also have given zero bubbles if they had been tested and this would have been closer to the line of best fit. Other than that the results seem to be reliable.

There were several possible sources of error:

- The temperature of the water – there was a slight variation but it was observed. The starting temperature of the water could have been exactly the same for each experiment but this would have been quite hard to do.
- When the sodium hydrogen carbonate was being changed the Elodea did not have very much carbon dioxide but the Elodea was kept in warm water so that it would keep photosynthesising at least at a low rate. Keeping the Elodea in water allowed the previous concentration of sodium hydrogen carbonate solution to be washed off the leaves before the next experiment.
- The light intensity might have been changed if the lamp had been moved accidentally. This could have been avoided if the lamp stand had been clamped to the bench and the bench marked with where to place the measuring cylinder.
- The number of bubbles could have been miscounted. It was difficult to know whether to count small bubbles or not. Taking more than 2 readings at each concentration of sodium hydrogen carbonate would have increased the accuracy of the results. Graph 2 shows that some of the readings for a given sodium hydrogen carbonate solution were not very close to each other. This variation could have been reduced if the volume of oxygen given off could have been measured, by collection in a graduated tube, thus difference in bubble size would not have mattered.
- Both readings for a given concentration of sodium hydrogen carbonate solution were made from the same dilution. The second reading was therefore made when the solution had already provided some carbon dioxide for photosynthesis during the first reading. Each reading at a given concentration of sodium hydrogen carbonate solution could have been done with a freshly made up dilution to ensure that the starting concentration of carbon dioxide available was the same.
- Calcium carbonate was deposited on the Elodea because distilled water was not used to make the sodium hydrogen carbonate dilutions. Use of distilled water would avoid this problem.

An improvement to the experiment would have been to collect some of the gas released and test it to check that it was oxygen. When collected into an upturned test tube the gas should have relit a glowing splint.
The effect of carbon dioxide concentration on the rate of photosynthesis could also have been studied at different light intensities and temperatures. A different water plant could be used. It would have be put in water otherwise the oxygen bubbles could not be counted or collected.

Books referred to:

Biology by DG Mackean
Biology for you by Gareth Williams
The Penguin Dictionary of Biology
A New Introduction to Biology by B. Indge, M. Rowland, M. Baker
Internet site: Learn.co.uk