Rate of Photosynthesis

Introduction

I am going to perform an experiment to test the rate of photosynthesis for different light intensities.

Photosynthesis is performed by plants only. It is the process they use to create glucose, the food that all living things consume, from sunlight. It occurs in the green cells of plants in the palisade layer of the leaf. The chemical equation for photosynthesis is

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

CO_2 is carbon dioxide, which the plant will take from the air via the leaves. H_2O is water, which the plant takes up through the roots. $C_6H_{12}O_6$ is glucose, the food the plant will burn when it respires. O_2 is oxygen, and although this is used during respiration enough of it is produced for there to be surplus amount, which secondary consumers (i.e. herbivores) can then use to respire (whilst they eat the plants).

All living things perform respiration and it takes place in every cell of the organism. The chemical equation for respiration is

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{Energy}$$

The rate of respiration for a plant rarely changes, whereas the rate of photosynthesis can be affected by four limiting factors. The amount of light the plant has access to (and the wavelength). The chlorophyll uses light energy to perform photosynthesis and it can only do this as fast as the light is arriving. The amount of carbon dioxide there is in its local atmosphere. There is only 0.03% of carbon dioxide in the air so it isn't readily available for the plants. The temperature of the plants surroundings is the third limiting factor. Chlorophyll is like an enzyme in this respect and it works best when it is warm, but not too hot.

The forth-limiting factor is the amount of chlorophyll a plant has. Even if all the other limiting factors are sated then the amount of chloroplasts in the palisade leaf cells will limit the rate of photosynthesis. Most of photosynthesis takes place in the top layer of the leaf, in the palisade cells (refer to leaf diagram). These cells are specially designed to absorb as much sunlight as they can by having a high concentration of chloroplasts. But a leaf can contain only so many chloroplasts and if these are all working to produce glucose then the rate of photosynthesis will balance out and stop rising.

Light intensity can be calculated using inverse square law, which states that if you double the distance you quarter the light intensity. The equation for light intensity is $1/d^2$ where d=distance.

We now know that photosynthesis has three main limiting factors and one final factor related to the plant and not the surroundings. These will have to be controlled or varied during my experiment to ensure that my test is fair and that I get some usable results. We also know that the plant produces two gases. The relevance of this will be explained later.

Plan

Method:

To test the rate of photosynthesis I am going to use a 10cm piece of Elodea (pond weed). The Elodea will be immersed in water and a halogen light will be pointed at it (imitating sunlight). The temperature of the water surrounding the Elodea will be affected by the light (which gets very hot) and the temperature of the room. In order to keep temperature change to an absolute minimum I will immerse the b oiling tube containing the Elodea in a large beaker of cool water, which will be changed for each distance. The carbon dioxide will be supplied by sodium hydrogencarbonate ($NaHCO_3$), which will be supplied to the boiling tube holding the Elodea once at the beginning. The Elodea will be left for five minutes before any readings are taken so it can come to equilibrium.

To measure the rate of photosynthesis I will count the bubbles produced by the plant over a five-minute period, recording the amount of bubbles produced every minute. The same piece of Elodea will be used for each distance and it follows that the same water in the boiling tube will also be used. This will effect the concentration of the carbon dioxide, as it will go down the longer the plant is p hotosynthesising. I will compensate for this by putting a lot of sodium hydrogencarbonate into the water surrounding the Elodea, so that it would be impossible for the plant to use it all.

The plant will then be moved to different distances from the light source so I can compare the rate of photosynthesis at the different light intensities (moving the light away from the plant will lower the light intensity).

Variables:

Temperature (fixed at 20^0C)
Amount of CO_2 (fixed at surplus amount)
Light intensity (variable)

Equipment:

A Halogen Lamp of 100w
A boiling tube
A large beaker 500ml
A stand (one metre tall)
Grips
Metre long rule graduated in cm

10cm long Elodea
Sodium hydrogencarbonate

I decided to use this equipment because it is all I need to complete the experiment successfully.

Measurements:

To ensure that I get an adequate amount of results I will repeat the experiment three times. I decided to go for three because it is a good number and it will enable me to get a reasonable average. Anymore would take too long to complete (I only have two hours in the laboratory) and any less would be too few.

The range of results will be:

5cm
10cm
15cm
20cm
25cm
30cm

Five separate distances are chosen because this will give me good range so I can compare them to each other. I chose these distances because they will me a good spread of results, which will enable me to compare the light intensities.

The first reading to be taken will be 80cm as this is the furthest and so the temperature of the water will be least affected. The final reading will be 5cm and all the readings will be taken in descending order. This is easiest because it saves messing about and all I have to do is move the jug and stand to the next distance.

Diagram:

Prediction:

I think that the rate photosynthesis will go down the further the plant gets from the light.

As I stated earlier photosynthesis has three limiting factors; temperature; light available and carbon dioxide available. It follows that if I change one of thes e factors photosynthesis will be affected. When the plant is close to the light photosynthesis will be at its greatest and many bubbles will be produced. The amount of light won't be a problem as there is an absolute surplus of it. Instead one of the other factors will limit the rate of photosynthesis so it won't be at its maximum or if it is it won't get any higher because the amount of chlorophyll will limit photosynthesis.

When the plant is twice the distance from the light the light intensity is quartered so I would expect the rate of photosynthesis to be quartered as well. I think this because none of the factors have been changed and I know from inverse square law that if you double the distance you quarter the light intensity. It follows that if the plant is receiving a quarter the amount light than it was to start with then its rate of photosynthesis would be quartered. For each distance this will be the same.

Investigation

I performed my experiment using the above method. No changes were made and the experiment was a success as we obtained some decent results. The only safety measure I needed to take was with the lamp, which got considerably hot whilst it was on, so care was taken not to touch it. The rest of the procedure presented no immediate risks.

There was a point during the investigation when I was struggling to obtain results. I had no choice but to ask for some assistance. My teacher gave me a new piece of Elodea and put some more sodium hydrogencarbonate in the medium. She also advised me to leave the Elodea for more than five minutes for it to come to equilibrium. With these adjustments my experiment went a little smoother, although some of my results were poor or out of the norm.

Results:

Table One

Distance from lamp	B.P.A. 1 minute	B.P.A. 2 minutes	B.P.A. 3 minutes	B.P.A. 4 minutes	B.P.A. 5 minutes
5cm	1	1	1	1	1
10cm	0	1	0	0	1
15cm	0	0	0	1	1
20cm	0	0	0	0	1
25cm	0	0	0	0	1
30cm	*	*	*	*	*

Table Two

Distance from lamp	B.P.A. 1 minute	B.P.A. 2 minutes	B.P.A. 3 minutes	B.P.A. 4 minutes	B.P.A. 5 minutes
5cm	7	8	8	9	8
10cm	5	6	5	7	5
15cm	4	3	5	3	4
20cm	2	2	3	2	3
25cm	1	1	1	1	1
30cm	0	1	1	1	0

Table one shows my first set of results, the ones that I felt were insufficient for a conclusion. The last row (30cm) has no figures because I terminated the experiment at that point.

Table two shows my second set of results, obtained after the adjustments had been made. As you can see the results are much more varied, if a bit random.

The two tables show the data in frequency form. B.P.A. stands for bubbles produced after x amount of minutes and by this I mean every minute I counted the bubbles produced in that minute (from 0-59seconds and 60-119secons etc). I decided this would give me a better spread of results without becoming ridiculous.

Analysis

Now I will process my results into two different tables that will show the light intensity (instead of distance from light source) and the amount of bubbles produced (rate of photosynthesis). To do this I will use the equation I mentioned in my introduction, inverse square law, $1/d^2$. The calculations I did are listed below:

For the first distance of 5cm=$1/5^2$=1/25 or as a decimal 0.04 x1000=40
For the second distance of 10cm=$1/10^2$=1/100 or as a decimal 0.01x1000=10
For the third distance of 15cm=$1/15^2$=1/225 or as a decimal 0.00444x1000=4.4
For the fourth distance of 20cm=$1/20^2$=1/400 or as decimal 0.0025x1000=2.5
For the fifth distance of 25cm=$1/25^2$=1/625 or as decimal 0.0016x1000=1.6
For the sixth distance of 30cm=$1/30^2$=1/900 or as a decimal 0.00111x1000=1.1

To show if there is a relationship between light intensity and rate of photosynthesis I will turn all the figures for each distance into averages. Here are my calculations:
For Table One:

(1+1+1+1+1)/5=1
(1+1)/2=1
(1+1)/2=1
1/1=1
1/1=1

For Table Two:

$$(12+9+11+13+10)/5=11$$
$$(8+9+6+7+9)/5=7.8$$
$$(4+3+5+3+4)/5=3.8$$
$$(2+2+3+2+3)/5=2.4$$
$$(1+1+1+1+1)/5=1$$
$$(0+1+1+1+0)/5=0.6$$

In mathematics this process is called finding the mean of the results.

Table Three below shows the data I have just coll ected for table two. Table Four below shows the information I have just collected for table two. You can now see why the first set of results I obtained was insufficient and I will make this clearer by drawing a scatter diagram displaying the information. The scatter graphs are on separate pieces of graph paper.

Table Three:

Light Intensity	Av. Bubbles Produced
40	1
10	1
4.4	1
2.5	1
1.6	1
1.1	*

Table Four:

Light Intensity	Av. Bubbles Produced
40	11
10	7.8
4.4	3.8
2.5	2.4
1.6	1
1.1	0.6

Looking at my results for table four I can see an obvious correlation between a reduction in light intensity and the amount of bubbles produced. Fortunately for me this is in perfect accordance with my original pr ediction and from this I can make a preliminary conclusion.

Graphs of Mean results:

Graph one displays the data in table three. You can now see why the results I obtained from this test were unusable. All I get for my troubles is a straight line running across the x-axis. You can see no patterns or trends.

Graph two shows the information from table four. This graph is very helpful as it shows a relationship between light intensity and the rate of photosynthesis. You can see that as the light intensity decreases so does the amount of bubbles produced. The line of best fit looks a bit jagged, however, it does a follow a pattern down.

Discussion:

My results are theoretically imperfect. The first result is fine, you can't fault the first term, but the second result doesn't quite follow my prediction. The light intensity has been quartered from 0.04 to 0.01, however the rate of photosynthesis hasn't even been halved. The second result should have been 2.75 bubbles produced, not 7.8.

However, after this first anomaly my results start to follow a trend and although it isn't clearly defined it is there. For light intensity 0.01 the amount of bubbles produced are 7.8 and for light intensity 0.0025 (one quarter of 0.01) the amount bubbles produced is 2.4, which is very close to one quarter of 7.8 (2). Now for light intensity 0.00444 the amount of bubbles produced is 3.8 and for light intensity 0.00111 (one quarter of 0.00444) the amount of bubbles produced is 0.6, which is very close to one quarter of 3.8 (0.95).

So there is a pattern that is very similar to what my prediction said would happen.

Conclusion:

The rate of photosynthesis increases with light intensity. This proves the correctness of my prediction.

I stated in my prediction that photosynthesis has three limiting factors, light, carbon dioxide and heat as well as all the water it needs. Three of these factors were controlled or stabilised so they could have no effect on the rate of photosynthesis. Only the light intensity was changed and therefore only the light intensity could affect the result.

The rate of photosynthesis increased because light is a key ingredient. Light is needed to start the reaction between the carbon dioxide and the water. The red and blue wavelengths of light are absorbed into the chlorophyll and it is there that the energy is used to activate the CO_2 and H_2O so that they react with each other.

So if there is no light then photosynthesis will not occur. If there is a lot of light then photosynthesis will occur in large amounts until it is limited by one of the factors I listed in my introduction. If there is a medium amount of light then photosynthesis will occur in moderate amounts.

I also discovered that the rate of photosynthesis is closely related to light intensity. By this I mean that when light intensity is quartered the rate of photosynthesis is also quartered or almost quartered.

Evaluation

Well, my experiment started of as a complete failure and I didn't get any results that were useful. I don't think that the method I was using was flawed because after I made the adjustments everything went smoothly. So I'm going to put the initial failure down to the plant although this seems a little unfair.

Once the plant was changed the experiment was successful and I came to some reliable results. The results aren't enough to give me a firm conclusion, because I only have set. However, I can formulate a sketchy conclusion on the evidence I did gain and from scientific knowledge.

The results I have are in accordance with my prediction to an extent. The first result was good but then the second result didn't follow the pattern I said would be observed. However, after this the results do follow the trend I said would be observed. I am going to say that the first result is anomalous because the results after the second result follow a pattern linked to the second result.

My one extremely anomalous result was the first one because that it fits no pattern within my results. The reason this is so could be because I misco unted the amount of bubbles or that there was too much light. I don't think that either of these reasons are very likely because I was careful when counting and an excess of light should boost photosynthesis, not lower it. Maybe the plant hadn't come to equilibrium when I started counting, which is certainly more possible. It could just be a strange factor that the plant displays at that intensity. The only way to see if any of my suggestions are correct is to perform the experiment a second time.

I think all my results are within a degree of accuracy. I was very vigilant when counting the bubbles and the clocks are tried and tested.

Improvements:

There are a few improvements I could to make to the experiment. The equipment was effective for the investigation and I wouldn't change it if I were to repeat the experiment. The method of counting of the bubbles is flawed because as I stated in introduction there are two gasses produced, oxygen and carbon dioxide. A better way to test for the amount of oxygen produced would be to use a gas tube, which could collect the gas. Then you could measure the amount of gas in the tube and to see if it was oxygen you could place a smouldering splint in it and see if it gets re -lighted.

This is the only adjustment I would make.

Further Work:

To further the investigation I could use different wavelengths of light. This would help to tell me what wavelengths of light the plant uses. I could also use different plants and see the effects light intensity has on these plants . This would tell me if all plants display similar properties.