The effect of different light intensities on the rate of photosynthesis by Cabomba carolinensis

Research question

How does the predicted rate of photosynthesis at different light intensities made by a simulator compare with that of a living plant (*Cabomba carolinensis*)?

Comment [PB1]: Ex: Focussed research question

Introduction

Aquatic plants can be used to demonstrate oxygen evolution in the process of photosynthesis. In theory, when an aquatic plant is placed in a solution containing a source of carbon dioxide (CO_2), in the presence of light of appropriate intensity, the plant will photosynthesise and produce bubbles of oxygen-containing gas. These bubbles can be counted and the rate of bubbling can serve as an indication of the rate of photosynthesis. When the light intensity is increased, the rate of bubble production should increase. Decrease the light intensity and the rate of bubbling should decrease. Remove the light source altogether, or move it to a distance beyond which the energy levels are to small for photosynthesis, and the bubbling should cease.

Comment [PB2]: Ex: Set in a scientific context

Light is essential for photosynthesis. Green plant cells that are placed in the dark will not photosynthesis. An increase in light intensity will produce an increase in the rate of photosynthesis until a level of light intensity is reached [normally 38% [1]] above which the rate does not increase because the light saturation point has been reached and another factor (CO_2 concentration or temperature) is limiting.

In this experiment, the light intensity is changed, by decreasing the light intensity. The rate of photosynthesis should decrease and therefore the amount of oxygen bubbles should decrease.

Hypothesis

I think that if the light intensity is very low, then the number of bubbles of oxygen produced will also be very low, because the plant obtains light energy from photons being absorbed by pigments in photosystems, and this energy is what drives the photosynthetic process. At low light intensity, water will not undergo photolysis and therefore will not produce O_2 as a by product. As the light intensity increases, more electrons are energised in the reaction centre of the photosystem, and so more photolysis occurs to replace the high energy electron, thus releasing more oxygen which can be detected as more bubbles. [2]

Comment [PB3]: Ex: Hypothesis developed

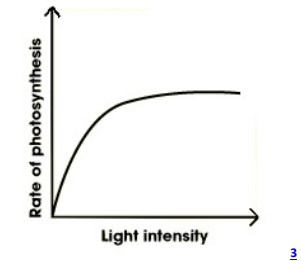
At the highest light intensities it is possible that the number of bubbles will plateau, as photosynthesis can be limited by several factors: light intensity, temperature, and carbon dioxide concentration. The rate of photosynthesis is unlikely to continue increasing even with high light intensities because e.g. carbon dioxide concentrations may not be optimal.

Photosynthesis also requires CO_2 to be present as a solution of dissolved CO_2.

Light is absorbed by chlorophyll during photosynthesis, in the blue/green spectrum. White light provides these wavelengths, so using a normal light bulb (white light) without filters is sufficient.

Comment [PB4]: Ex: Control

Simplistic graph to show relation of light intensity and CO2 concentration on photosynthesis rates



[3]

[1] http://fhs-bio-wiki.pbworks.com/w/page/12145771/Factors%20effecting%20the%20rate%20of%20photosynthesis
[2] 'Steps in Photosynthesis ' p278-280: Clegg, Biology for the Diploma, 2007, Hodder Education.
[3] http://www.bbc.co.uk/schools/gcsebitesize/science/add_aqa_pre_2011/plants/plants2.shtml

The simulation program: Water Weed

This simulation permits the experimenter to modify light intensity, carbon dioxide levels and the colour of the light. The screen shot below shows the virtual set up.

Comment [PB5]: Ex Screen shot useful

[4]

Variables

Independent variable – The light intensity (varying from a scale of 1 – 10, unknown units)

Dependent variable - The number of bubbles produced over a known period of time (O_2 production)

Comment [PB6]: Ex: Control

Controlled variables	**How is it being controlled?**
Type age and weight of water weed	The water weed used in this experiment was unknown. It was assumed that it was healthy and that the amount of weed used in each run is constant or it would not give consistent results.
Temperature of the CO_2 solution	This was unknown and could not be controlled. It was assumed that the temperature remained constant and was at an optimum level.
Time of bubble collection	This should always be the same and of a reasonable length to provide stat data, A time of 30 seconds was pre-programmed into the simulation. The speed could be at normal time or x 5 so the faster simulation speed was used to quicken data collection. It was assumed that this did not influence the results given.
External light intensities	These could not be controlled and no data was provided. It was assumed that the simulation was carried out in dark conditions to provide optimum results.
Sodium hydrogen carbonate concentration	This could be controlled using an arbitrary scale of 1 – 10. The simulation gave no indication of the solution composition or Molarity. The level used in this experiment was 2 to ensure that the CO_2 was not in excess simulating a limiting factor.
Size of bubbles	From observations during the simulation these appeared to be of a regular size and were released from the plant at fairly regular intervals.

Method

The parameters were set on the simulation as follows:

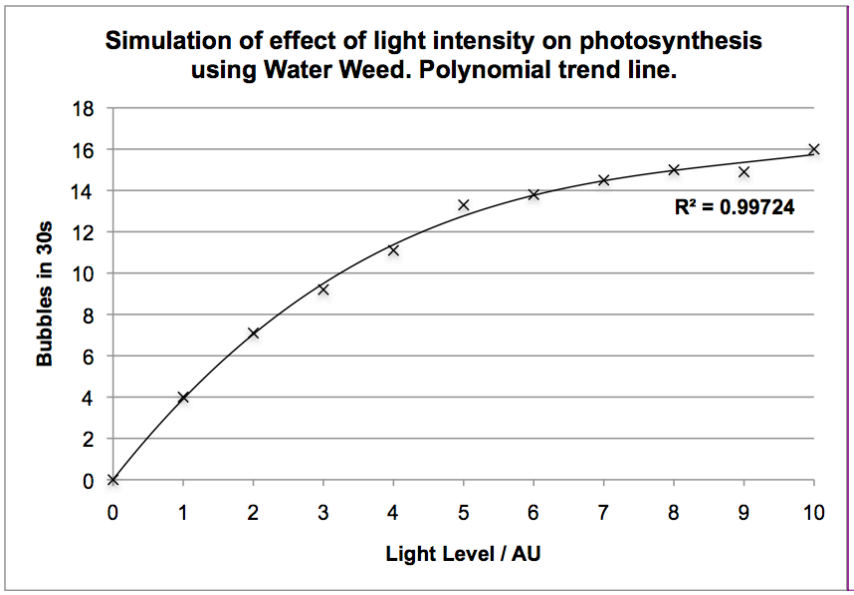
[4] http://www.saddleworth.oldham.sch.uk/science/simulations/waterweed.htm

- CO_2 level = 2
- Light filter white
- Speed of simulation x5 though the timer of the simulation gives readings to 0.1s precision

Data was collected from light levels 1 -10.
10 repeats were carried out at each light level.

The result of the ten repeats on the simulator run at different light levels.

Light level	Number of bubbles produced in 30 seconds (+/-0.1 seconds)										
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	0	4	6	9	12	14	14	15	15	14	15
2	0	4	7	9	12	12	13	15	15	15	17
3	0	4	7	10	10	13	13	15	14	14	16
4	0	4	7	9	11	14	14	13	14	15	16
5	0	4	7	9	11	12	15	15	16	16	16
6	0	4	7	9	12	14	14	14	16	14	15
7	0	4	8	9	11	13	14	15	14	15	18
8	0	4	8	9	11	14	13	15	15	16	15
9	0	4	7	9	10	13	13	15	14	14	16
10	0	4	7	10	11	14	15	13	17	16	16
Mean	**0**	**4**	**7**	**9**	**11**	**13**	**14**	**15**	**15**	**15**	**16**
St Dev	**0**	**0**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**1**



Conclusion

As the light levels are increased there is an increase in oxygen (bubble) production from photosynthesis of the plant. This increase slows down progressively at higher light levels. This result suggests that my hypothesis was correct.

Standard deviation was calculated to determine the reliability of the experiment. It can be seen on the graph that the higher the light level, the greater the standard deviation, showing that the data becomes a bit less reliable as the light

Comment [PB7]: An: Raw data presented appropriately

Comm: Conventions respected

Comment [PB8]: An: Appropriate analysis

An: Processing can be followed

An: Successful processing

Comment [PB9]: An: Processed data graphed appropriately

Comms: conventions respected

Comment [PB10]: An: Data correctly interpretted

Comment [PB11]: Ev: Conclusion supported by the data

intensity increases. However, at all light intensities the standard deviation was relatively small in comparison with the mean, being at the most 14% of the mean value (for light level 2).

The plateau seen to develop would result from the low level of CO_2 used in the experiment. The theory suggests that eventually this would become a limiting factor, which the simulation replicates.

Comment [PB12]: An: Uncertainties and their impact considered.

Comment [PB13]: Ev: Relates results back to scientific context

Comment [PB14]: Ev: Some weaknesses identified and improvements suggested

Evaluation

Weaknesses	Improvements
No intermediate values could be assessed	The simulation does not allow assessment of any values outside the pre-programmed values. This is an area that could be explored in the laboratory. It would be useful if this could be changed.
Units of light and CO_2 concentration were in units of 1-10. There was no indication of how this is related to a laboratory situation and what the solutions and the light levels actually were. These variables cannot be controlled and may not provide sufficient data to comment fully or provide the variation in an experiment that would normally be carried out. No trial runs can be carried out.	More detail about light units, solutions etc. Allow fine adjustments of variables. Provide more information.

Investigating photosynthesis in a living plant

Cabomba is an aquatic plant genus, one of two belonging to the family Cabombaceae. It can grow up to 2.5cm per day. *Cabomba* plants require good light and warm water temperatures (from 18-32°C). They like high CO_2 levels in the water, which should be rich in macro- and micronutrients.[5]

Variables

Independent variable – The light intensity (varying from high to low) in Lux

Dependent variable - The amount of bubbles produced over a known period of time (O_2 production)

Comment [PB15]: Ex: Thorough attempt to control the experiment.

Controlled variables	How is it being controlled?
Type and age of water weed	The water weed used in this experiment was Cabomba. As quoted on SAPS website[6] this is a reliable producer of oxygen during photosynthesis. The water weed was obtained from a good supplier (Blades) who ensure the plants are healthy when shipped, with short lead times. On receiving the plant it was maintained in an ideal environment (20°C) and with a constant light source. The plant was used within a week of receiving it to ensure optimum results. It was not possible to get an accurate age of the plant but the whole specimen appeared healthy and green!
Weight (amount) of Cabomba	After two trial runs (see trial experiment section) it was established that the ideal weight range of Cabomba was 0.7-0.8g. This enabled the number of bubbles produced during the experiment to be counted accurately. If a greater amount of the plant is used the there is a far greater chance of human error in counting, due to a faster rate of bubble production. This is probably due to the increased leaf area and therefore increased surface area for light absorption.
Temperature of the room	The experiment will be carried out in a darkened room. The main experiment will be carried in one series of data collections therefore the temperature of the room should remain constant. This will be monitored by a thermometer, placed on the bench near the apparatus.
Temperature of the sodium hydrogen carbonate solution	A data logging device will be used to monitor this. A heat shield is placed between the light source and the beaker containing the solution. This should minimize temperature rises.
Time of bubble collection	This should always be the same and of a reasonable length to provide stat data. A time of 30 seconds was used as this enabled data collection and a

[5] http://en.wikipedia.org/wiki/Cabomba

[6] http://www.saps.org.uk/secondary/teaching-resources/190-using-cabomba-to-demonstrate-oxygen-evolution-in-the-process-of-photosynthesis-

	workable experiment time. This was also the same data collection time of the simulation experiment being run alongside. (see evaluation)
External light intensities	As this experiment was to observe the effects of a specific light source on Cabomba , it was essential to eliminate all other light sources. The experiment was carried out in a dark room ensuring the lamp was the only source of light.
Sodium carbonate concentration	The sodium hydrogen carbonate solution was 0.2M. This was a high concentration to ensure the dissolved CO2 was always in excess and would not influence the results.
Size of bubbles	It is not possible to control the size of the bubbles produced from the plant during photosynthesis. A clean cut to the stem of the plant may aid this but there will be a small amount of variation, it is unclear whether this will influence bubble count.

In this experiment, the light intensity is changed by moving the light source away from the plant. This decreases the light intensity with distance. Therefore as the light source moves away from the plant, the rate of photosynthesis decreases and the amount of oxygen bubbles should decrease. [7]

Apparatus

- 1 litre glass beaker
- Elodea glass funnel
- Test tube
- Plasticine (3 small balls)
- Glass shield (approx 30 x 30 cm)
- Light (60 W bulb)
- Retort stand and clamp
- Ruler (1m)
- Pasco data logger
- light intensity sensor
- temperature sensor
- 0.2 M sodium hydrogen carbonate [CLEAPSS Hazcard 95C]
- *Cabomba* water weed
- Balance (error ± 0.01g)
- Weighing boat (30ml)

Method

1. Weigh approximately 0.7 - 0.8g Cabomba. Ensure that the plant stem has an even cut to the stem

2. Set up the apparatus as shown in the above diagram, with the Cabomba placed in the funnel cut stem upwards.

3. With the light source at 0 cm from the Cabomba , leave for 15 minutes.

4. Count the amount of bubbles released from the plant for 30 seconds and record. Repeat for a total of 5 data collections. Measure the light intensity and temperature of the sodium hydrogen carbonate solution at each data collection time.

5. Move the light source in 5cm increments from the Cabomba, (waiting for 15 minutes after each movement of the light source) and repeat as in 4 above at all distances.

Minimum distance = 0m
Maximum distance = 1m

Trial Experiments

Two trial experiments were carried out prior to the main experiment. These identified areas of the experiment, which were then changed to optimise, as much as possible, the final experimental run.

Trial run 1

This was carried out with the light source at 0cm from the plant. No heat shield was used. After 30 minutes the temperature of the sodium hydrogen carbonate had risen by 3.7°C. This was an unacceptable rise and the number of bubbles produced rose with the temperature increase. This indicated that an increase in temperature probably causes an increase in photosynthesis. A heat shield was used subsequently.

Trial run 2

Comment [PB16]: Ex: Safety factors considered otherwise the investigation does not present a major safety risk.

Comment [PB17]: Ex :Environmental issue. Correct disposal of pond weed needed to avoid introduction of alien species.

Comment [PB18]:
Ex:
•Is this technically possible?
•Control: Period of adaptation

Comment [PB19]:
Ex:

•Sufficient data

•Control: Temperature monitored

Comment [PB20]: Ex: Clear methodology; Good approach

[7] http://www.saps.org.uk/secondary/teaching-resources/190-using-cabomba-to-demonstrate-oxygen-evolution-in-the-process-of-photosynthesis-

This run was used to calculate the amount of time needed before readings were taken. Allowing the plant to adapt to the new levels for an optimum time prior to reading is crucial. This run was carried out under normal laboratory conditions. It was found that when the light source was moved away from the plant the light readings fluctuated widely showing that the experiment needs to be carried out in a dark room to prevent sources of light, other than the intended light source, to influence the results.

A heat shield was also used in this experiment. As can be seen in the results table for Trial 2, after 30 minutes the temperature had risen but this was deemed acceptable.

The weight of Cabomba to be used in the main experiment was 0.7-0.8 g to allow manageable bubble counting.

Trial run data are shown in the appendix.

Main experiment

Carried out as in the method described earlier.

- Weight of Cabomba = 0.86g ±0.01g
- Temperature of room = 20°C
- Temperature of the water 21.3-22.3°C
- 5 repeats for each distance

Precision

Ruler ± 0.05cm or 5 x 10^{-4}m

Temperature ± 0.01°C

	Bubbles per 30s ±0.01s									
Distance / m	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0
Light / lx	**5**	**13**	**20**	**35**	**60**	**160**	**240**	**250**	**262**	**262**
	0	1	2	2	3	5	9	16	29	40
	0	1	2	3	4	5	9	17	30	40
	0	1	1	2	3	6	10	16	29	41
	0	1	1	2	3	5	9	16	29	41
	0	1	2	2	3	6	9	16	30	42
	Bubble min^{-1}									
Distance / m	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0
$1/d^2$	4.94	6.25	8.16	11.11	16.00	25.00	44.44	100.00	400.00	
Light / lx	**5**	**13**	**20**	**35**	**60**	**160**	**240**	**250**	**262**	**262**
	0	2	4	4	6	10	18	32	58	80
	0	2	4	6	8	10	18	34	60	80
	0	2	2	4	6	12	20	32	58	82
	0	2	2	4	6	10	18	32	58	82
	0	2	4	4	6	12	18	32	60	84
Mean	**0**	**2**	**3**	**4**	**6**	**11**	**18**	**32**	**59**	**82**
St Dev	**0**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**2**

Comment [PB21]: An: Qualitative observations

Comment [PB22]: Ex: Control

Comment [PB23]: Ex: Control

Comment [PB24]:
Comm: Unambiguous

Comm: Conventions respected

Comment [PB25]: An: Uncertainties presented

Comment [PB26]: An: Processed data presented

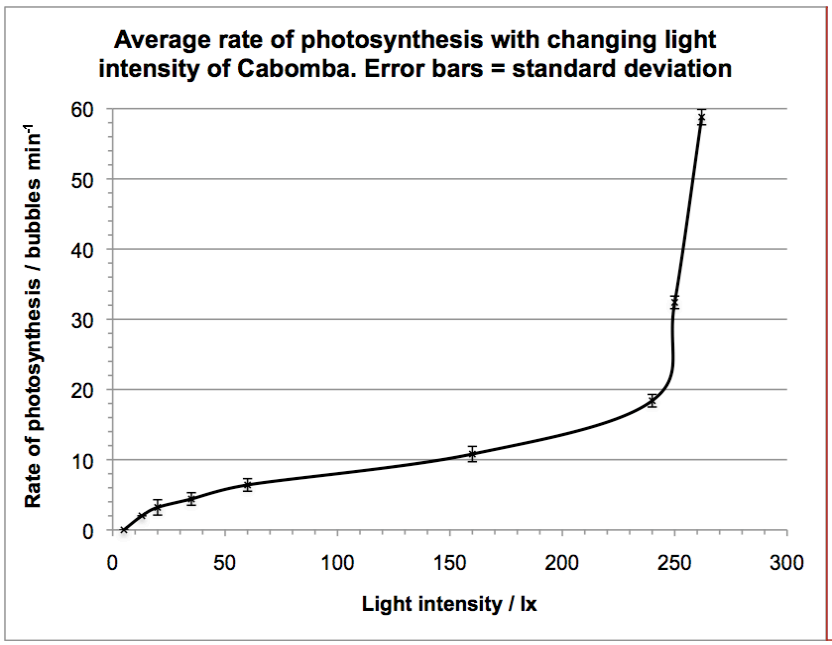
An: Appropriate processing

An: Successful processing

Comment [CB27]:

Comm:
•Unambiguous

•Conventions respected

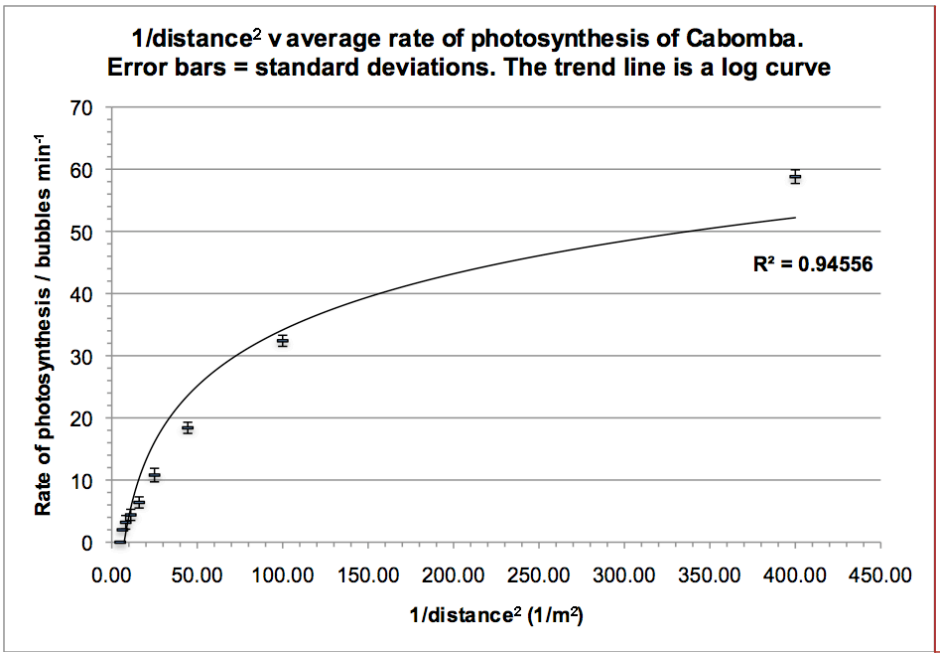


Comment [PB28]: An: Appropriate graph.

Comment [CB29]: Comm: Correct conventions

This graph does not look like the prediction or the simulation. The light intensity should decrease with the square of the distance from the plant. Plotting 1/distance^2 against the rate of photosynthesis gives the following graph, which does resemble the predicted curve and that of the simulation.

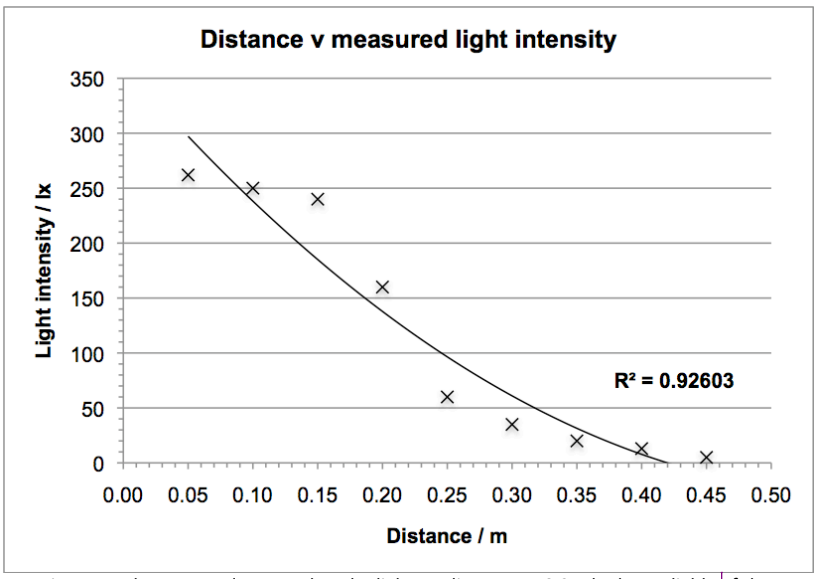
Comment [PB30]: Ev: Evaluation of data correct



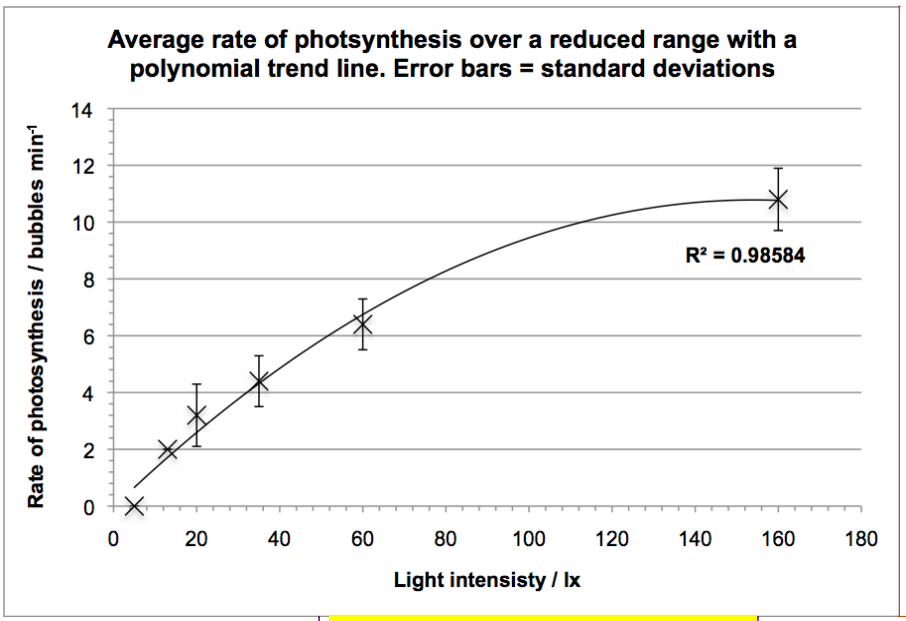
Comment [PB31]: An: Appropriate and successful data processing

Comment [CB32]: Comm: Correct conventions

It was decided to investigate the light readings. These should obey the inverse square law, the light intensity should decrease with 1/distance^2.



This does approximate to the expected pattern but the light readings up to 0.2m look unreliable. If the rates of photosynthesis are plotted against light intensity measured from 0.2m onwards we get the following graph:



This does closely follow the predicted curve. The error, therefore, could be in the light readings.

Conclusion

The simulation does act as a good model for the real rates of photosynthesis provided the living system to which it is compared is properly controlled and the measurements are precise and reliable. The rate of photosynthesis does rise

Comment [CB33]: Comm: Conventions respected

Comment [PB34]: An:
•Appropriate processing
•Appropriate graphical presentation
•Uncertainties displayed

Comment [PB35]: An: Correct interpretation of the data. However, the student should explain what the "expected pattern" is i.e. an exponential decline plotted like this.

Comment [PB36]: An:
•Appropriate graphical presentation
•Uncertainties displayed

Comment [CB37]: Comm: Conventions respected

Comment [PB38]: An: Data interpreted correctly

Comment [PB39]: Ev: Conclusion supported by the data

with increased light intensity to reach a plateau where other limiting factors affect it. In this case levels of dissolved CO_2 could be the limiting factor.

Evaluation

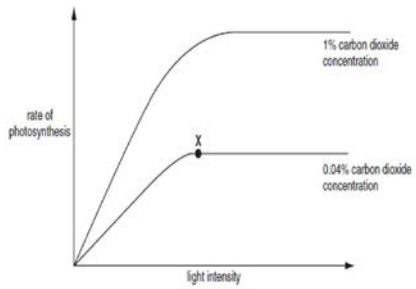
The data looks reliable in all cases there are high R^2 values for the trend lines indicating a good fit. The standard deviation values are also very low compared to their means indicating consistent data. Interestingly both the simulation and the live experiment show higher values for standard deviations at the higher light intensities.

The data for the measured light levels was considered unreliable for measurements taken less than 0.2m from the plant. In trial run 2 a large amount of fluctuation of the light measurements had been observed. The light probe used (Pasco Pasport Light Level Sensor[8]) has an accuracy of ±10% and three levels of sensitivity. Though 262lx is well within the range of the highest level of sensitivity it could be that the sensor was not set on the appropriate scale. This may explain the fluctuation. Further trail runs with the sensor may be needed to judge the appropriate level of sensitivity.

As the bubble size could not be controlled an alternative method for determining the rate of photosynthesis could be tried using a dissolved oxygen probe or a pressure to measure the build up of oxygen or alternatively a pH probe to measure the change in pH as the dissolved CO_2 is consumed.

Development

The rate of photosynthesis does level off at a certain light intensity, this could be due to another limiting factor affecting the maximal rate of photosynthesis. This could be the concentration of dissolved carbon dioxide. To confirm this the same experiment could be tried at different concentrations of dissolved CO_2 with the following predicted outcome[9]:



Comment [PB40]: Ev: Overall conclusion supported by the data.

Comment [PB41]: Ev Data evaluated correctly

Comment [PB42]: Ev

•Another possible interpretation is that the plant is sensitive to the rise in temperature.

•Likely source of error considered.

Comment [PB43]: Ev: Sensible suggestion

Comment [PB44]: Ev: Appropriate extension suggested.

[8] http://www.pasco.com/prodCatalog/PS/PS-2177_pasport-light-level-sensor/index.cfm
[9] http://www.proprofs.com/quiz-school/story.php?title=plant-revision

Appendix

TRIAL 1

CONSTANTS

WEIGHT OF CABOMBA 0.77g 60W bulb NO LIGHT SHIELD

DISTANCE OF LIGHT FROM CABOMBA 0 CM

Run	Time of run (s)	No of bubbles produced	Temperature (°C)	Time from start of experiment (min)
1	30	27	18.7	0
2	30	26	18.7	0
3	30	26	18.7	0
4	30	27	18.7	0
5	30	27	18.7	0
1	30	36	20.4	15
2	30	36	20.4	15
3	30	36	20.4	15
4	30	37	20.4	15
5	30	37	20.4	15
1	30	48	22.4	30
2	30	47	22.4	30
3	30	47	22.4	30
4	30	48	22.4	30
5	30	48	22.4	30

NOTE Experiment stopped as heat shield required

TRIAL 2

CONSTANTS

WEIGHT OF CABOMBA 0.77g 60W bulb LIGHT METER GLASS SHIELD

Run	Time of run (s)	No of bubbles produced	Light intensity (lx)	Temperature (°C)	Distance of light from source (cm)
1	30	9	25.6	16	0
2	30	8	25.6	16	0
3	30	8	25.6	16	0
4	30	8	25.6	16	0
5	30	7	25.6	16	0
1	30	9	262	16.7	0
2	30	9	262	16.7	0
3	30	10	262	16.7	0
4	30	10	262	16.7	0
5	30	10	262	16.7	0
1	30	15	Fluctuates	16.8	10
1	30	18	262	18	0
2	30	19	262	18	0
3	30	20	262	18	0
4	30	21	262	18	0
5	30	22	262	18	0

Note Fluctuating light levels between 20 and 25 rapidly so experiment stopped.
Results in blue area were taken after 30 minutes of photosynthesis

Comment [PB45]:
An: Raw data from trials set out appropriately

Comment [CB46]:

Comm:

•Unambiguous

•Conventions respected. Uncertainties not give but they are given with the results of the main experiment.