The Effect of Light Intensity on the Rate of Photosynthesis of *Elodea canadensis*

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21 November 2019

Personal Engagement

I began gardening a few months ago, first starting out with simple flowers and vegetables. But I noticed that there seemed to be irregularities in the growth depending on where I would plant the seeds. I continued to notice this pattern over the following weeks as the plants on one side of my yard began to thrive while the ones on the other side couldn't. Eventually, I noticed that the side that was growing seemed to be receiving more sunlight throughout the day, which led me to wonder if the lack of light was the reason for the plants not growing as well. I thought back to my 11th-grade IB Biology class, where we found that the color of the light was very impactful on the rate of photosynthesis and plant growth which led me to believe that the intensity of light would also impact photosynthesis. In a pilot experiment, I developed a setup that would test this theory. I created a contraption that would allow me to measure the amount of oxygen produced by utilizing the rising properties of air, permitting any liquid above it to displace the air below, allowing me to record the total amount of oxygen produced through photosynthesis.

Introduction

Photosynthesis is the process that plants undergo in order to produce glucose, or chemical energy, for the plant. The inputs of photosynthesis are carbon dioxide, water, and light. Once these inputs pass through the light reactions, the Calvin cycle, and the electron transport chain the products that remain are glucose and oxygen (Ensminger 2020). This would suggest that if you were to reduce any of the inputs, it would act as a limiting factor and the overall photosynthesis chemical reaction would be reduced from what it usually would be. This begs the question: To what extent does light intensity (100%, 25% and 35%) affect the volume of oxygen (mL) produced through photosynthesis in *Elodea canadensis*? I hypothesize that as the light intensity decreases, the volume of the oxygen produced will also decrease because the light will act as a limiting reactant in photosynthesis (Ensminger 2020). A limiting reactant is the reactant that is completely used while there is a surplus of the other reactants. However, if there

was more light, it wouldn't be a limiting reactant because it would not be limiting the photosynthesis of the plant. For this experiment, the Independent variable is the intensity of light: 100%, 35%, and 25%. I decided on these levels by first considering the different areas that plants may be placed. For example, if the plant were to be outside it would follow the 100% intensity results. However, if it were placed inside a house it may conform more to the other two levels of variable (35% and 25%). The dependent variable will be the volume of oxygen produced by the *Elodea canadensis*. This will allow me to conduct a one-way ANOVA test in order to find if the light intensity is a significant factor in affecting the rate of photosynthesis. The control variables will be the temperature, the amount of light shined on the samples (before they pass through the filters), the length of the *E. canadensis* plant, the materials used for the experiment, and the time that the experiment is conducted. I will control the temperature and light by having all three levels of IDV going at the same time and in the same location. I will control the length of the *E. canadensis* by only using a specific length for the experiment (20.3 cm). I will control the materials used for this experiment to ensure that none of the trials have and variation due to equipment. Finally, I will control the time of the experiment by starting the experiment, collecting data, and ending it all at the same time for all three levels. I will also make sure to have the same time for all five trials.

Materials

1. Beakers, 3 (1L)
2. Clear Plastic Wrap
3. Distilled water
4. Double sided tape
5. Elodea (*Elodea canadensis)*
6. Graduated cylinder (100 mL)
7. Scotch Tape
8. Sewing needle
9. Small River Rocks
10. Syringe 65mL
11. Window Tint Roll (25%)
12. Window Tint Roll (35%)

Procedure

1. Suspend one 20.3 cm *Elodea canadensis* stem in a 1-liter beaker so the bottom is touching the bottom of the beaker.
2. Carefully pour the small river rocks into the beaker until you reach the 200 mL of the beaker.
3. Make sure the *Elodea canadensis* is anchored by the rocks.
4. Place a ring of double-sided tape inside of the beaker so that the bottom of the tape is at the 700 mL line.
5. Fill up the beaker with distilled water to this line of tape.
6. Take a large sheet of plastic wrap (30.48 cm x 30.48 cm) and attach it to the tape ring, but make sure the make the surface of the plastic is tight.
7. Make sure that there are no air bubbles under the plastic, adding more water as necessary, or removing water if there is some water above the plastic.
8. Manually remove any bubbles using your hands if necessary.
9. Using a 100mL graduated cylinder, pour 100mL of water onto the plastic surface.
10. Repeat steps 1-9 for the two other 1 L beakers.
11. Cut out a piece of 25% window tint.
12. Cover the top of one beaker with 25% window tint.
13. Set the beaker out in an area that receives sunlight. I will be doing it in my backyard.
14. Repeat steps 11-13 but with 35% tint on one of the beakers and leave the other without a tint (control group).
15. The next day, at the same time, remove the tint from the top of the beaker, if necessary.
16. Using a syringe, collect the water that is above the plastic wrap and transport it into a 100mL graduated cylinder.
17. Record the how much the water has decreased from the initial 100mL volume and record this value.
18. Pour the water back into the beaker.

19. Cover the beaker with the tints, if necessary.
20. Repeat steps 15-17 for two more days.
21. At the end of the trials, remove everything from the beaker.
22. Dispose of the plastic wrap, tape and *Elodea canadensis*.
23. Place the window tint to the side for reuse on other trials.
24. Place the river rocks back into a bag to be reused.
25. Pour water into a plant.
26. Repeat steps 1-25 for four more trials for an altogether total of 15 days.
27. Dispose of the plastic wrap, elodea, and tape.
28. Put the pebbles in a bag and clean the beakers.

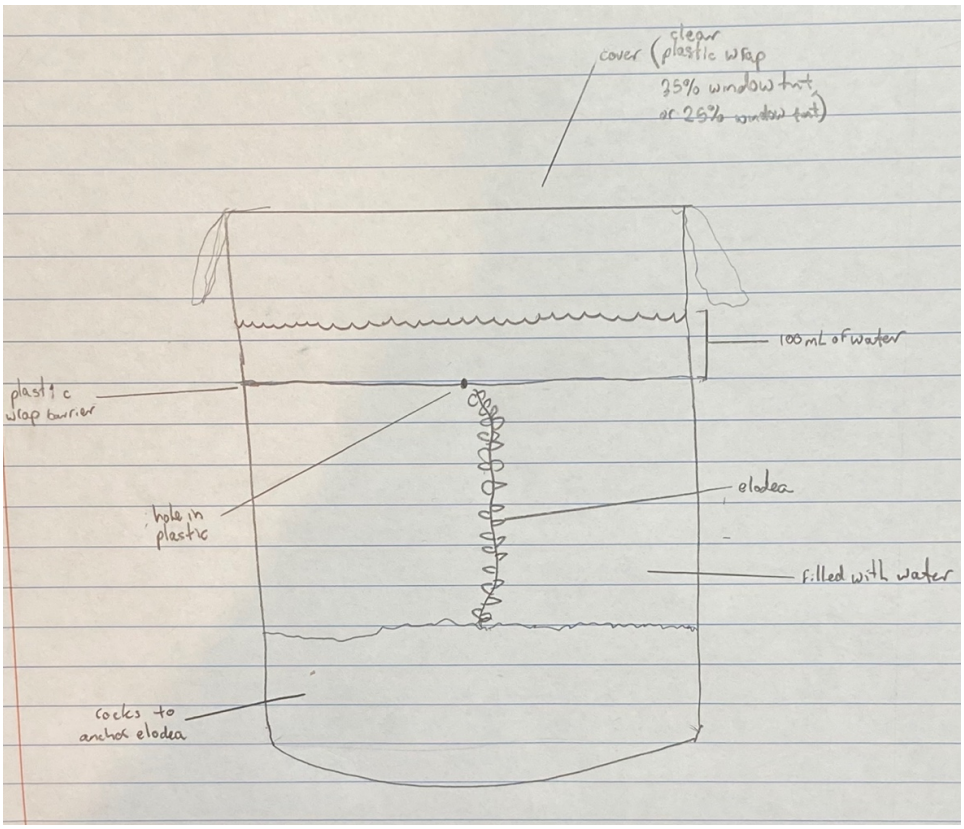

Figure 1 - This is a drawing of the setup for my data collection, illustrating all the parts of the design.

Analysis

Table 1: Raw Data – Five trials of Volume of Oxygen measured everyday released by 20.3cm Elodea canadensis plants in a 1L Plastic Beaker with 700mL of Distilled Water with no Light Filter Placed Over it.

Time passed (hours)	Volume of Oxygen (mL ± 0.5mL)				
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
24	31.0	33.0	37.0	29.0	30.0
48	64.0	58.0	65.0	60.0	58.0
72	91.0	86.0	94.0	88.0	87.0

Table 2: Raw Data – Five trials of Volume of Oxygen measured everyday given off by 20.3cm Elodea canadensis plants in a 1L Plastic Beaker with 700mL of Distilled Water with a 35% Light Filter Placed Over it.

Time passed (hours)	Volume of Oxygen (mL ± 0.5mL)				
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
24	10.0	11.0	14.0	9.0	10.0
48	21.0	20.0	22.0	19.0	16.0
72	32.0	29.0	34.0	27.0	26.0

Table 3: Raw Data – Five trials of Volume of Oxygen measured everyday given off by 20.3cm Elodea canadensis plants in a 1L Plastic Beaker with 700mL of Distilled Water with a 25% Light Filter Placed Over it.

Time Passed (hours)	Volume of Oxygen (mL ± 0.5mL)				
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
24	8.0	8.0	9.0	6.0	6.0
48	18.0	14.0	19.0	13.0	13.0
72	26.0	21.0	26.0	19.0	20.0

<u>Qualitative Observations</u>

- Water drops on the outer parts of the beaker and on plastic wrap for all trials due to evaporation.
- Elodea in 35% tint trials began to turn yellow on the third day for trials 2, 4, 5.
- The air bubbles collected against the plastic wrap, plant, and rocks for all trials.

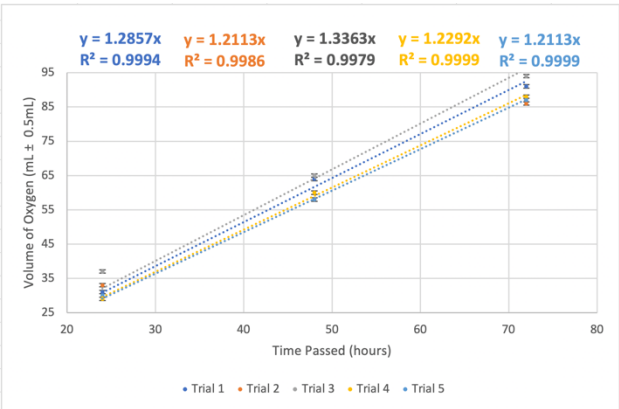

Figure 2 – Five trials of Volume of Oxygen measured everyday given off by 20.3cm Elodea canadensis plants in a 1L Plastic Beaker with 700mL of Distilled Water with no Light Filter Placed over it.

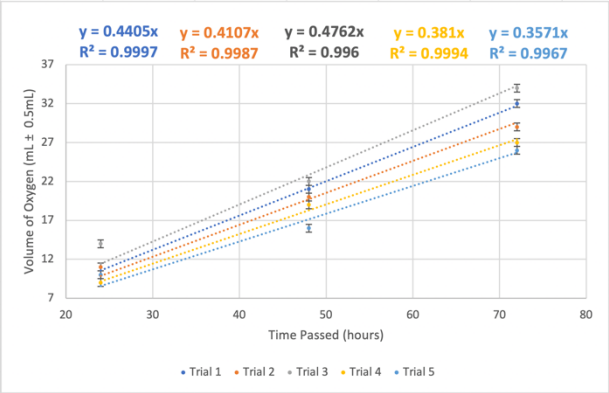

Figure 3 - Five trials of Volume of Oxygen measured everyday given off by 20.3cm Elodea canadensis plants in a 1L Plastic Beaker with 700mL of Distilled Water with a 35% Light Filter Placed Over it.

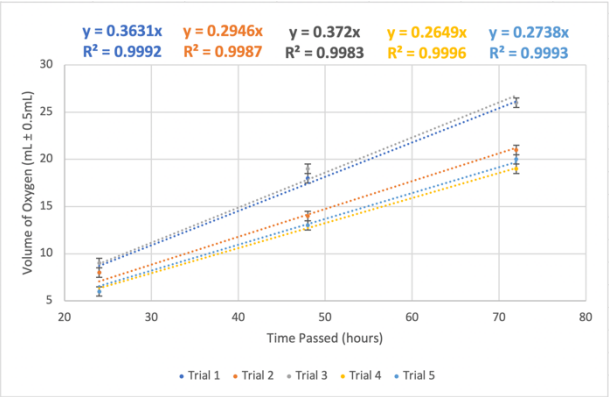

Figure 4 – Five trials of Volume of Oxygen measured everyday given off by 20.3cm Elodea canadensis plants in a 1L Plastic Beaker with 700mL of Distilled Water with a 25% Light Filter Placed Over it.

I processed my data by analyzing the individual rates of oxygen release for each of the 5 trials for all three levels of independent variable (100% light, 35% light, 25% light) and then taking the average of the slopes of the graphs to conduct a statistical test on. I then found the standard deviation for the three levels of independent variable to see the spread of the collected data.

Table 4: Processed Data – Rates of Oxygen Release and Standard Deviation Five trials of Volume of Oxygen measured everyday given off by 20.3cm Elodea canadensis plants in a 1L Plastic Beaker with 700mL of Distilled Water with no Light Filter, 35% Light Filter, and 25% Light Filter Placed over it.

Light Intensity	Rate of Oxygen Release (mL/hour)							
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Standard Deviation	Coefficient of Variation
100%	1.3	1.2	1.3	1.2	1.2	1.3	0.055	0.044
35%	0.44	0.41	0.48	0.38	0.36	0.41	0.047	0.12
25%	0.36	0.30	0.37	0.27	0.27	0.31	0.050	0.16

Values are rounded to two significant figures to maintain consistency with raw data.

Sample Calculations for the Average in Microsoft Excel:

=average (trial 1: trial 5)

Average oxygen release rate in 100% light intensity:

=average (1.2857:1.2113) = 1.26 mL/hour (rounded to 3 significant figures to keep precision with raw data values)

Sample Calculation for the Standard Deviation in Microsoft Excel:

=STDEV (trial 1: trial 5)

Sample Calculation for Standard deviation of oxygen release rate in 100% light intensity:

=STDEV (1.2857:1.2113) = 0.0549 mL/hour (rounded to 3 significant figures to keep precision with raw data values)

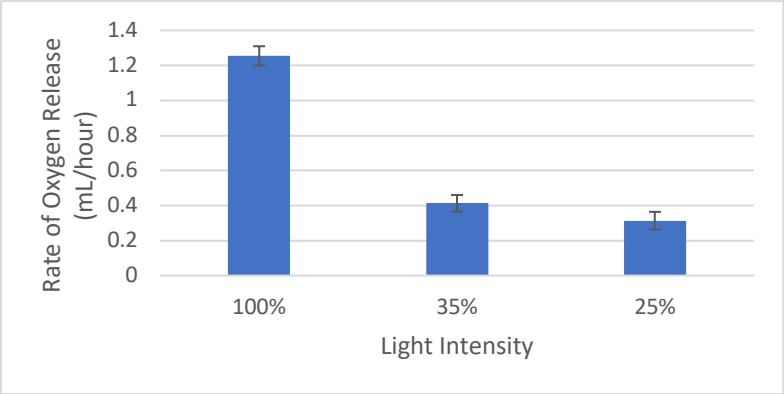

Figure 5 – Bar Graph of the Average Growth of the Average Rate of Oxygen Release by Elodea canadensis plants in a 1L Plastic Beaker with 700mL of Distilled Water with no Light Filter, 35% Light Filter, and 25% Light Filter Placed over it with Error Bars showing the Standard Deviation of Each Light Intensity Level.

In the graph we can see that the standard deviation bars overlap for the 35% and 25% light intensity trials. This may suggest that there is a chance that the difference is simply up to random chance, however, the bars do not overlap too much which would make it less likely to be random change. In the case of the 100% light intensity trials, the error bars do not overlap with the other levels which means that the difference is most likely to be statistically significant. To verify these results, I have decided to conduct a one-way ANOVA test. The reason an

ANOVA test will be carried out is because there are three levels of independent variable. More specifically, a one-way ANOVA test will be carried out because there is only one independent variable (light intensity) and only one dependent variable (rate of oxygen release). If I find that there is a statistical difference after the ANOVA test, I will carry out a Tukey Test to find the extent of the difference between each level of independent variable.

Null Hypothesis: There is no relationship between the light intensity (100%, 35%, and 25%) shined on the Elodea canadensis and the rate at which it expels oxygen. Any variation is due to random chance and there is no statistical difference between the values influenced by the light intensity.

Alternate Hypothesis: There is a relationship between the light intensity (100%, 35%, and 25%) shined on the Elodea canadensis and the rate at which it expels oxygen. Any variation is not due to random chance and there is a statistical difference between values influenced by the light intensity.

Sample Calculation for One-Way ANOVA Test in Microsoft Excel:
On the data tab at the top select data analysis. Then select “ANOVA: Single Factor” and click “OK”. In the input range select your average growth values for all trials organized in rows. Then select a cell and input it into the output range and click “OK”

Table 6: Processed Data – Screenshot from Microsoft Excel showing one-way ANOVA Test

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	5	6.2738	1.25476	0.00300923
Row 2	5	2.0655	0.4131	0.00222613
Row 3	5	1.5684	0.31368	0.00254438

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.6731791	2	1.33658955	515.411652	2.3218E-12	3.88529383
Within Groups	0.03111896	12	0.00259325			
Total	2.70429806	14				

The p-value is 2.3218×10^{-12} with 14 degrees of freedom. This is lower than the critical 0.05 p-value so we would reject the null hypothesis. Therefore, there is a statistically significant difference between light intensity and release of oxygen in Elodea over 72 hours. We now have to conduct a Tukey Test to find how each level of light intensity varies between each other.

Table 7: Processed Data – Tukey Test Carried out on 20.3cm Elodea canadensis plants in were in a 1L Plastic Beaker with 700mL of Distilled Water with no Light Filter, 35% Light Filter, and 25% Light Filter Placed over it.

Light Intensity	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inference
100% vs 35%	36.9573	0.0010053	p<0.01
100% vs 25%	41.3228	0.0010053	p<0.01
35% vs 25%	4.3655	0.0236444	p<0.05

I began processing my data by taking the slopes from the graphs of the volume of oxygen over time. These slopes represent the rate at which oxygen was leaving the Elodea canadensis plants which allows for us to compare the levels of independent variable. I did this by using a single factor ANOVA test and found that there was a p-value of 2.3218×10^{-12}, far below the critical 0.05 p-value. I decided to reject the null hypothesis because of this and conducted a Tukey Test to find the extent to which the results of each level of IDV varied from each other. I concluded that there was a significant difference between all the variables, with the 100% light trials varying the most of all. Nevertheless, all comparisons between the independent variables had a p-value less than 0.05 meaning that there was a substantial difference that is not be from random error or variation. Moving on, the error bars on the bar graph above represent the standard deviation of the processed rates. For the 100% light trials the standard deviation was 0.0549, for the 35% trials it was 0.0472 and finally for the 25% trials it was 0.0504. These values represent the average standard deviation from the mean for each point. We can note that their values are fairly small, meaning that there was not much deviation from the mean and that the experiment tended to follow a constant pattern throughout. Additionally, after calculation of the coefficient of variation, we can see that the standard deviation in the 35% and 25% light intensity trials is large, with values of 0.12 and 0.16 respectively. This suggests

that there was more variation in these trials compared to the 100% light intensity trial, which only had a coefficient of variation of 0.044. Nevertheless, the r-squared values in this lab are extremely high, hinting that the data conformed tightly around the line of best fit. The r-squared values in this lab did not go under 0.99 at any point which suggests that the data was very precise with minimal variability. It also tells me that the rates of oxygen release accurately represented my raw data as the slopes of the graph regression lines had such high r-squared values. In this lab, the processed data was only rounded to two significant figures which may be concerning. The gathered data were rather small, meaning that rounding due to significant figures could have a much larger impact on the results of the lab compared to an experiment that may consist of larger values. Furthermore, the equipment uncertainty was 0.5mL, which seems high when it comes to measuring smaller quantities as low as 8.0mL. However, as the experiment progressed the values reached as high as 94.0mL meaning that the uncertainty would impact the results less. Regardless, these higher values are limited to the 100% light intensity trials, meaning that there is more variability from the equipment uncertainty in the 35% and 25% light intensity trials. A way to fix this issue would be to measure the volume using a 10mL graduated cylinder, which only has 0.1mL of equipment uncertainty. This would render the data more accurate and strengthen the overall procedure.

Evaluation

In this experiment, I set out to answer the question: To what extent does light intensity affect the volume of oxygen (mL) produced through photosynthesis in *Elodea canadensis*? I used 100%, 35%, and 25% light intensity values to determine if there was in fact a difference. I found the rates to be 1.3 mL/hour for the 100% trials, 0.41 mL/hour for the 35% trials, and 0.31 mL/hour for the 25% trials. I subsequently conducted an ANOVA test to determine if there was a statistical significance between these values or not. I found that the difference between these rates was in fact noteworthy, so I continued to a Tukey Test to find how significant the difference was between each level of variable. I found that there were large significant

differences between all of the levels, with every light intensity pair in the Tukey Test having a p-value less than 0.05. These conclusions support my hypothesis as well. I predicted that as the light intensity decreased, less oxygen would be released from the plant. This phenomenon is caused by light acting as a limiting reactant in photosynthesis. When there is less light, the rate of photosynthesis will be less, and more oxygen will be released. Light enters the plant in the form of photons, which absorbed by the chlorophyll a in the thylakoid membranes of a chloroplast located in a plant cell. These photons are then used to break apart water, converting each water molecule into an O_2 molecule and a H^+ ion. The hydrogen ions are then combined with carbon dioxide with the help of ATP and NADPH to help form a sugar that can be used by the plant for energy. The trials with less light intensity absorbed less photons, meaning less oxygen was yielded from the water split (Molnar and Gair 2020). However, there were many other factors that weakened the results of the experiment. First, the plants in the 25% trial began to yellow in some of the trials. This is because the amount of light the plant was receiving was not enough to sustain life in the plant. As a result, there was a reduction in the amount of oxygen produced, causing the results to vary more than other levels of light intensity as we can see by the 0.16 coefficient of variation. This is a systematic error. We could fix this by using different light intensity values to ensure that the plant did not die. For example, it could be better to use values such as 100%, 80% and 60% to ensure that the plants survived but also that the values are far enough apart to negate random chance. Another source of error was the buildup of bubbles in the rocks and on the plant. Thus, the collected data of volume of oxygen released was less than the actual oxygen released by the elodea and caused the calculated rates of oxygen release to be less that what the actual value is. Because some of the data are so small, the values would be greatly impacted. This is a systematic error. To correct this error, we could use a vibrating dish to make the bubbles rise to the top. The sudden movements from the vibrating dish would detach the bubbles from the rocks and plant allowing for the air in the bubbles to be displaced by the water above, leading to a more accurate recording of the data.

My final source of error is evaporation. With the experiment carried out in my backyard, the water was exposed directly to the sun. Some of this water evaporated and stuck to the top which led to a smaller collected oxygen value. Similar to the previous error, the fact that there are small values in the data makes the impact of these error even more. This is also a systematic error. The problem could also be reduced if we conducted the experiment indoors with an artificial light. This would result in a cooler environment, preventing evaporation from occurring. Although there would still be some evaporation, it would be less. In conclusion, based on the data I collected and processed, the light intensity the *Elodea canadensis* is placed under does affect the rate of photosynthesis. As the light intensity increases, the rate of photosynthesis increases. In the future, we could use a PASCO Oxygen concentration device in order to gather more accurate data and negate the errors that took place in this experiment. This would allow us to gather more accurate information with a higher level of precision due to a smaller equipment uncertainty.

Works Cited

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