The Impact of Light on Plant Growth

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ABSTRACT

As we strive to send humans on further and longer space missions, finding ways of sustaining an entire crew with fresh food produced on site will substantially reduce resupply costs and bring the concept of self-sustaining colonies one step closer to reality.

In this paper, we examined the possibility of growing plants (we chose clover due to its compact size) under magenta and blue LED light compared to natural sunlight.

Firstly, we monitored root systems and nodules development under magenta light, blue light and natural sunlight respectively, the growth media being agar-agar due to its transparency that enabled us to better observe the roots. A key part in achieving root nodulation was played by the nitrogen-fixing Rhizobia bacteria.

Subsequently, we narrowed our analysis to the best LED light color (that proved to be magenta) in comparison to natural sunlight, also replacing agar with potting soil. We then studied plant health by examining chlorophyll level with the help of near-infrared imagery, as well as the overall growth by programming a Raspberry Pi computer to take pictures periodically.

Finally, magenta light proved to be the best choice in terms of root development & chlorophyll level, as this paper further aims to present.

1. INTRODUCTION

The feasibility of growing plants in space for human consumption has been proven thanks to multiple experiments performed on the ISS over the past decade. [1,2,3] Thus, there are already some cultivation methods, such as hydroponics [4], which have already been adapted to accommodate plants in a microgravity environment. [5,6]

Our aim was to improve upon these methods by finding light conditions which would favor faster growth. It is widely known that light is one of the most important factors in the proper development of plants, being a crucial resource for photosynthesis. [7]

Figure 1: Setting up our experiment

However, research shows that plants mainly absorb the blue and red parts of the electromagnetic spectrum, while light from other sections proves less important [8].

This begs the following questions: what are the effects upon the development of plants when exposed solely to red and blue light and is the energy provided by these narrower parts of the electromagnetic spectrum enough to ensure satisfactory growth in a controlled environment? [9] Answering these questions could help scientists build plant growth modules for use in space which would be both more efficient from an energy consumption point of view while also providing better yearly production.

Our experiment was designed with these inquiries in mind and a specific focus on the influence of continuous exposure to magenta light on growth rate. This was achieved by comparing clovers grown by us in a controlled environment under magenta light to control samples placed in sunlight, and blue light respectively. Note that in the Munsell color system, magenta is called red purple. The additive secondary color magenta, as noted before, is made by combining violet and red light at equal intensity; it is not present in the spectrum itself. [10]

2. RESEARCH METHOD

Figure 2: Root Nodules

2.1. Root development. Nodulation.

The first stage of our experiment consisted in **assessing the effect of light on root nodulation**. For this purpose, we have set up 3 trials: one under **magenta light**, one under **blue light** and another one exposed solely to **sunlight**.

The growth media was **agar** [11], a nutrient rich gelatin, thus the tubes were sealed throughout the **7-week** experiment period, the plants in agar not needing additional water. The growth media and seedlings were inoculated with **Rhizobia** [12,13], a nitrogen-fixing bacteria that forms a symbiotic relationship with legumes. As a result, nodules are formed on the plant root, within which the bacteria can convert atmospheric nitrogen into ammonia that can be used by the plant. [14]

2.2. Chlorophyll analysis. Growth process.

In the second stage, we designed a simple experiment which allowed us to examine the development of clover plants in a controlled environment. After planting in **potting soil**, two tubes were chosen as the control group and set next to a window, where we made sure they could receive **sunlight** through the whole day (approximately 14 hours), while the other two tubes were set in a cardboard box illuminated by a **magenta LED lamp**. Note that the box was well sealed from any outside light and was only opened for inspection at night, so as to minimize any contamination of our data. Additionally, whenever we watered the plants, we made use of lab equipment such as disposable gloves in order to keep the ideal conditions.

Figure 3: Inspecting the plants with a magnifying glass

Figure 4: Image Captured by the Pi Camera

Throughout the experiment, data was autonomously gathered by two **Raspberry Pi computers equipped with cameras** [15] carefully aligned so as to get the best view of the seedlings within the tubes (see figure 4).These were programmed to take photos daily, giving us a complete picture of our plants' evolution all throughout the runtime of our experiment.

In order to be sure any differences observed in the growth of the clovers from each of the two groups have been determined solely by the color light they were exposed to, we eliminated all potential uncertainty from other variables by exposing both groups to the same environment, where temperature and humidity were tightly controlled and provided both trials with the same amount of water daily. [16] What's more, during nighttime, the LED lamp was turned off, thus ensuring both clover batches received equal light exposure. With this setup, the clover seedlings were left to grow for **7 days**, after which the data was analysed.

3. RESULTS AND DISCUSSIONS

3.1. Root development. Nodulation.

During this first stage of the experiment, the magenta and blue light tubes were under close monitoring, as the three figures below suggest. [17]

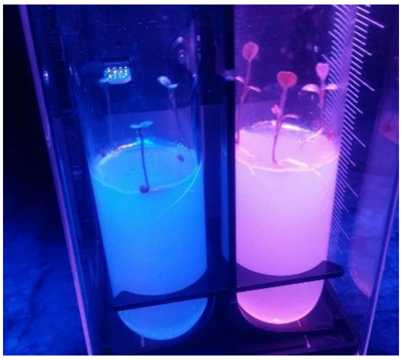
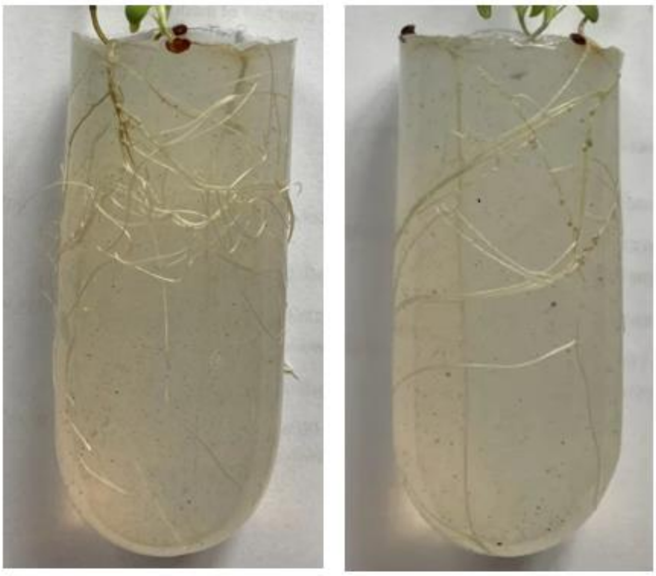


Figure 5: Tubes in Blue / Magenta Light. Beginning growth stage

Figure 6: Emergence of the first nodules (14 days after planting), Magenta light tube

Figure 7: Tubes in Blue / Magenta Light. Advanced growth stage

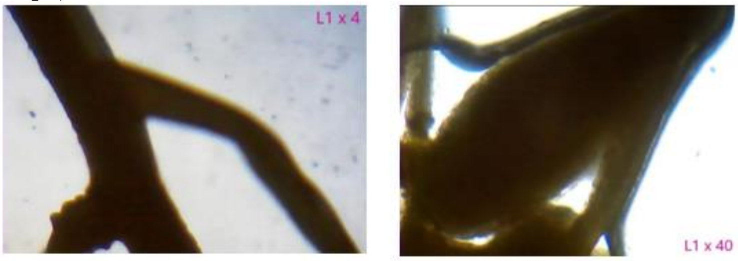
At the end of this first stage of the experiment, the plants were removed from the tubes in order to begin the analysis of the root systems, which, as the image comparison below shows, are clearly more developed for the plants that had access to magenta light.



Magenta Light **Blue Light**

Figure 8: Root System Comparison (after removing the plants from the tubes)

What is more, we counted the **root nodules** and came to a result of **26 in blue light** and **32 in magenta light**, which were also larger in size (See figure 9 for a better view of the nodules, as seen through a microscope).



Magenta Light Root Nodule Magnified x4 **Magenta Light Root Nodule Magnified x40**

Figure 9: Nodules through Microscope

On the other hand, the plants exposed exclusively to sunlight did not achieve root nodulation.

Seeing as the magenta light clearly surpassed the other candidates, as we were originally expected, we then proceeded with the second part of our analysis in order to study clover in magenta light from a different perspective, that of growth and overall health based on the plant's pigment.

3.2. Chlorophyll analysis. Growth process.

Coming from the Greek words “chloros” (green) and “phyllon” (leaf), **chlorophyll** is a pigment that can be found in plants and that, together with light, contributes to the process of photosynthesis. [18,19] Therefore, the chlorophyll level is an indicator that can accurately assess plant health.

In order to apply this theory, we used the Raspberry Pi **near-infrared camera** [20] in order to take pictures of the clovers at the end of the experiment. We then processed the resulted images with the help of the infragram.org platform and concluded that **the plants that were exposed to magenta light have a higher chlorophyll level**. [21] See Figure 10 below for the comparison between the chlorophyll level of the plants that have been exposed to **magenta light (left)** and those exposed to **sunlight (right).**

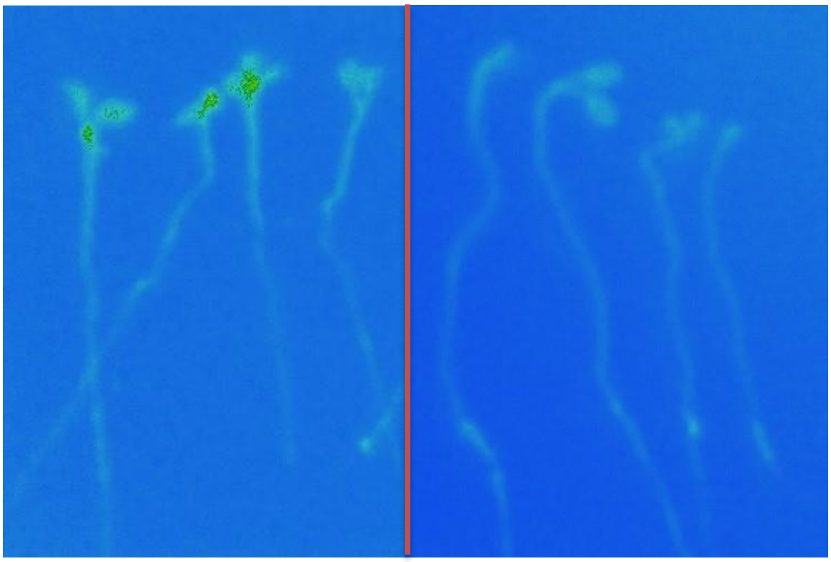


Figure 10: Plant Health. Chlorophyll Analysis. (Magenta vs. Sunlight)

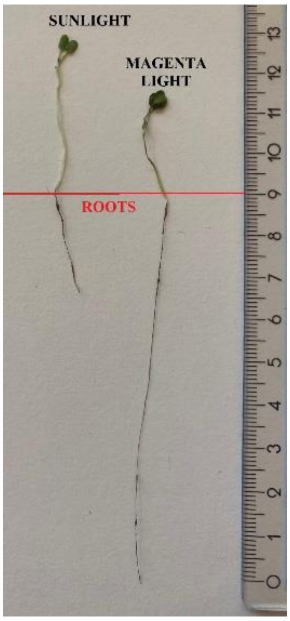


Figure 11: Growth Comparison

The health was also studied by analyzing **raw images** (See figure 11). In this way, we can clearly state that the plants in magenta light are stronger, having such a sustainable root just one week after planting. Examining the figure, we find that **the root of that plant that had magenta lighting is 7 cm longer than the other**, which though has a 1.5 cm longer stem. Still, without support from a strong root, the plants that had access to sunlight were bound to wither. That is because, of course, roots keep a plant in place, but more importantly they take up air, water, and nutrients from the soil and move them up into the leaves, where they can interact with sunlight to produce sugars, flavors, and energy for the plant, thus being the lifeline of the plant [22]. Moreover, the subject on the left (natural sunlight) has a white-light green frail stem whilst the one on the right has a **dark green pigment, which is a sign of healthier growth**.

It shall not be forgotten to mention that our second experiment run for a 7-day window, which is why the plants were yet to achieve root nodulation in this case. From our first experiment, we noticed that the plants generally started forming nodules two weeks after planting, so longer than our second time window. Still, we decided to end our trial since root nodulation was not the purpose of our second experiment, already being discussed in the first section.

Please feel free to access the following link for a short video plotting the **key events in plant growth** – a parallel between the magenta light tubes and those in natural light.

4. CONCLUSION

Finally, we came to the end of our research project that started with just an equation in mind: ***W - G = R + B = M (Magenta)*** [23]. In the end, our idea proved to be successful, **magenta light clearly surpassing all its combatants in terms of root nodulation and healthy growth**, as it is evident from Section 3: Results and Discussions. Still, in order to rigorously confirm our findings, we will be sure to repeat the experiments in the near future. Moreover, we plan on **further extending our analysis** by not only studying chlorophyll, but also the **flowers** that the seedlings are bound to produce if the experiment time window is bigger. [24]

On a practical level, the application prospects of our research are notable, especially in terms of **future space missions**, where the astronauts will no longer be able to operate mainly with pre-packaged food and the need of producing **fresh nourishment** will be imperative. [25]

Figure 12: Our set-up

Figure 13: Watering the plants

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By working on this project, we gained knowledge on advanced topics, we developed our research, programming & analysis skills and team spirit, and, we dare say, got a small insight on what it's like to be a scientist.

Last but not least, we would like to show our immense gratitude to our amazing Physics teacher Ioana Stoica for providing us with useful materials and suggestions, and encouraging us to participate in such a prestigious competition.

REFERENCES

[1] https://www.nasa.gov/content/growing-plants-in-space

[2]https://www.nasa.gov/feature/nasa-astronaut-paints-a-picture-of-success-growing-plants-in-space

[3]https://www.esa.int/Education/Teachers_Corner/Astrocrops_-_Growing_plants_for_future_space_missions_Teach_with_space_PR43

[4] https://www.freshwatersystems.com/blogs/blog/what-are-hydroponic-systems

[5] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6607005/

[6] https://www.space.com/37258-gardening-plants-space-station.html

[7] https://royalsocietypublishing.org/doi/10.1098/rstb.2013.0243

[8]https://www.researchgate.net/figure/The-electromagnetic-spectrum-and-a-typical-spectral-reflectance-curve-for-healthy-plant_fig1_266218822

[9] https://www.gardeningknowhow.com/garden-how-to/design/lighting/red-light-vs-blue-light.htm
[10] https://owlcation.com/humanities/Understanding-the-Munsell-Color-System
[11]https://www.tandfonline.com/doi/pdf/10.1080/02571862.1993.10634661?fbclid=IwAR1OBQ3vzOnc7S7-EQkjZB0fV6gjWGesPgJAxWSjs8kvHNYL-twGSMu3AIM
[12] https://www.frontiersin.org/articles/10.3389/fsufs.2020.619676/full
[13] https://www.intechopen.com/chapters/59280
[14] https://www.nature.com/scitable/knowledge/library/biological-nitrogen-fixation-23570419/
[15] https://www.raspberrypi.com/documentation/accessories/camera.html
[16] https://ocj.com/2021/07/understanding-primary-factors-driving-plant-growth/
[17] https://magnitude.io/
[18] https://education.nationalgeographic.org/resource/chlorophyll
[19]https://www.nature.com/scitable/topicpage/photosynthetic-cells-14025371/#:~:text=Chlorophyll%2C%20the%20primary%20pigment%20used,chloroplasts%2C%20which%20contain%20the%20chlorophyll.
[20] https://www.impopen.com/introduction-near-infrared-nir-spectroscopy
[21] https://infragram.org/
[22]https://www.dekooktips.com/advices/readers-ask-how-do-stems-and-roots-help-a-plant.html#:~:text=More%20importantly%2C%20roots%20are%20the,and%20energy%20for%20the%20plant.
[23] https://www.physicsclassroom.com/class/light/Lesson-2/Color-Subtraction
[24] https://www.backyardnature.net/fl_clovr.htm
[25] https://www.nasa.gov/audience/foreducators/5-8/features/F_Fresh_Ideas.html

BIOGRAPHIES OF AUTHORS

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- Born August 8, 2005 (age 16)
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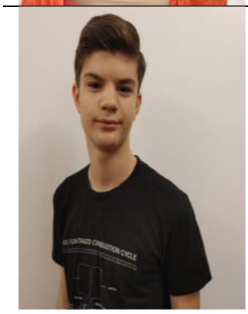

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