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Plant Reactions to Different Spectrums of Light

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Table of Contents

Abstract

Growing plants under LED lights has been studied thoroughly throughout recent years to improve plant production due to the increasing population. This experiment intended to expand this research by finding a more accurate light combination that would grow plants as good as or better than natural light. It was tested whether plants grown under lights with a red, blue, green ratio of 9:6:3 would grow better than plants grown under other combinations or normal, white light. Radishes were grown in five groups, including white light, under different light combinations and compared via their plant height, root length, and color. An ANOVA showed no difference in plant height and root length between the groups, though standard error bars showed a slight difference in plant height. Two groups' plants' color was darker than the other three groups, showing healthier plant signs. However, these plants were shorter in height. Further study showed that the plants were too tall, meaning the conclusions were insufficient. The plants also died which limited the accuracy and amount of data collected. The experiment did not reveal anything significant and further testing should be followed with more test subjects and different health measures.

Plant Reactions to Different Spectrums of Light

The world's population has quadrupled over the past century, rising from 1.8 billion to 7.3 billion people (Elferink & Schierhorn, 2016). With this rise in population comes an increased need for more food. To meet these demands, society must improve the yield and growth rates of plants or cultivate more land (Elferink & Schierhorn, 2016). However, implementing any of these plans will cost money and could damage the environment by depleting the earth's nutrients.

One new technological advancement that farmers have used to solve this problem is the use of artificial growth lights, specifically the cheap Light Emitting Diodes (LED) (Darko et at., 2014). LEDs have recently been used to help improve plant production and replace natural light (Darko, Heydarizadeh, Schoefs, & Sabzalian, 2014). For decades, scientists have tried to define the best light setup for optimal plant growth by mimicking the plant absorption spectrum (Darko et al., 2014).

The plant absorption spectrum mainly consists of red light, specifically normal red light and some far-red light, since it allows the plants to grow and mature (Hopkins, 2006). Normal red light is one of the factors that starts a plant's germination, and all red light helps the plant develop and mature (Halleck, 2018; Hopkins, 2006). This is why many plants grow extraordinarily well under monochromatic red LED lights, with some claims even saying that red light allows plants to grow better than natural light (Rabara, Behrman, Timbol, Rushton, 2017).

In spite of these claims, other studies show that plants grown under red light only may cause nutritional deficiencies and wilting (Darko et al., 2014). This is because blue light aids in the plant gas exchange, closing and opening stomata (Halleck, 2018). If there is not enough blue light, the plant may shut down vital plant functions in order to grow in height to reach the sun (Halleck, 2018). To stop the plant from shutting down, both light spectrums are needed (Darko et al., 2014; Halleck, 2018). This is why many grow lights combine red and blue lights.

Furthermore, NASA conducted an experiment that determined the effect of green light on plants by comparing a group of radishes grown under white light (with green light) to a group of radishes grown under combined red and blue light (without green light). The "results showed darker red color under the red and blue LEDs, [indicating] a higher concentration of anthocyanin, a powerful antioxidant that can combat some of the effects of cosmic radiation" (Dunbar, 2012, paragraph 13). This may lead one to believe that green light restricts plant growth. However, other experiments that added some green light to combined red and blue lights saw enhanced plant growth (Darko et al., 2014; Halleck, 2018). This may be because some green light is absorbed by plants through accessory pigments, giving some aid to plant functions (Halleck, 2018).

The results from the experiments above contradict each other, and need further clarification. This experiment attempted to support one of the claims above and find a specific light ratio that maximized Cherry Belle radish development. Cherry Belle radishes were chosen because radishes are a fast-growing plant that humans can eat, and the Cherry Belle variation is one of the smaller, more common, and fastest growing varieties of the all the radishes (Anderson, 2013). It was hypothesized that the radishes would grow the best under lights with a red:blue:green ratio of nine:six:three because the radishes would need more red light to satisfy the many functions that require red light and less green light since the plants do not absorb green light.

The experiment included five different groups, each consisting of eight Cherry Belle radishes, four in one pot. The control group was grown under eighteen warm white LED Christmas lights; this group was called Group C (control). One of the groups, called Group R (regular), was grown under nine red and nine blue LED Christmas lights. Another group was grown under nine red, six blue, and three green LED lights; this group was Group H (hypothesis). The next group, Group S (same), was grown under six red, six blue, and six green lights. The last group had twelve red lights and six blue lights and was called Group A (alter).

Every other week the radishes' heights and widths were measured and each pot was given the same amount of watts, soil, fertilizer, and water. All of the pots were in the same room, under the same temperature, and under a cardboard box to reduce the chance of unwanted light reaching one of the plants (Fox, personal communication, October 4, 2018).

Methods

The sharp tip of the utility knife was not touched. An adult was in the room to make sure the process was done correctly and safely. Hands were washed before and after touching the plants, soil, or fertilizer. Once the radishes started growing, hands were thoroughly washed before and after interaction with the radishes.

Materials

- 50 red LED C3 Home Accents Holiday Christmas lights 16 feet and 4 inches in lighted length
- 50 blue LED C3 Home Accents Holiday Christmas lights 16 feet and 4 inches in lighted length

- 50 green LED Home Accents Holiday C3 Christmas lights 16 feet and 4 inches in lighted length
- 50 warm white LED Home Accents Holiday C3 Christmas lights 16 feet and 4 inches in lighted length
- 10 clay standard pots with holes in them 5 inches in diameter and 4 inches deep
- 5 cardboard boxes 16 inches wide, 12 inches long, and 12 inches high
- 9 millimeter blade utility knife
- 1 gallon of tap water
- One seed packet of 200 Cherry Belle radish seeds
- One 24 ounce spray bottle
- 1 pound of MiracleGro all purpose fertilizer
- 8 quarts of soilless potting mix
- One 30-centimeter ruler to measure the distances to prepare the materials for the plants and to measure the radishes
- One tablespoon to measure out the soil
- One large mixing bowl
- One regular black Sharpie marker
- 5 rubber bands, 2 inch in diameter
- 5 plant trays 10-inch diameter and 2 inches deep
- 10 ounce bottle of dish soap
- A kitchen scale with a capacity of 1000 grams, used to measure the mass of soil in grams
- One weigh boat

- A roll of black duct tape, 3 inches in width
- An extension cord
- A bucket, 6 inches deep and 12 inches in length and width

Procedures

The eighteen of the lights on the warm white Christmas lights were pushed together so all the lights were facing the same way and were at the same length. A rubber band was wrapped around these lights to keep the lights in place. This light group was for the control group.

Nine of the lights on the red Christmas lights' wire were removed where every other light was removed. These lights were removed starting from the end of the wire and going to the middle. Nine of the lights from the blue Christmas lights' wire, that were right next to each other, were removed and put into the empty spots in the red Christmas lights' wire. These eighteen red and blue lights were pushed together and wrapped with a rubber band like done with the white lights. The finishing wire had lights that alternated from red to blue. This was the group of lights for Group R.

On the other end of the red Christmas lights' wire, nine of the red lights were taken out using the same method as done in the last part. Six lights were removed from the blue Christmas lights' wire and two lights were removed from the green Christmas lights' wire. The removed lights were put into the empty spots in the red Christmas lights' wire, following the pattern red, blue, red, green, red, blue. After pushing the lights together evenly, a rubber band was wrapped around the lights three times, making up the lights for Group H.

On the blue Christmas lights' wire, blue lights were removed and put in to follow the pattern blue light in, blue light out, blue light out, until the eighteenth light spot was reached. Six of the lights were taken out of the green Christmas lights' wire. These lights, along with six of the red lights taken out of the red Christmas lights' wire were put into the blue lights' wire, following the pattern blue, green, red. These lights were pushed together and wrapped with a rubber band using the same procedure shown with the white lights. This was the light group for Group S.

On the other end of the blue Christmas lights' wire, lights were taken out using the same method that was done on the other end of the blue lights' wire. Twelve of the red lights that were removed from the red lights' wire were placed into the blue lights' wire, arranged in a pattern of blue, red, red. These lights were pushed together evenly and wrapped with a rubber band three times. This last group of lights made up group A.

On each cardboard box, the flaps that fold to make the bottom were cut. This became the bottom of the cardboard box. On the top of each cardboard box, the flaps were folded together and taped with duct tape. Then a hole (two inches in diameter) was cut in the center of the duct taped flaps (6.0 inches in from the edge of the box) with the utility knife. This is where the lights went to light the radishes.

Each pot was washed with dish soap and warm sink water to remove bacteria. Then each pot was soaked in room temperature sink water for half an hour to keep them from drawing moisture from the plants (Bradley, 2006). Since each pot had a hole on the bottom of it to drain excess water (Maguire, 2013), the pots were placed in buckets that were six inches deep so that the water would stay in the pots.

Once the pots finished soaking, six cups of soil, a half cup of water, and two tablespoons of fertilizer were put into a large mixing bowl. These components were mixed together with bare hands until the soil became evenly moist. Afterward, the hands were washed, then the weigh boat was put on the kitchen scale and the scale was calibrated to read zero. The soil mixture was poured into the weigh boat until the scale read one-hundred twenty grams. The soil mixture in the weigh boat was poured into one of the empty pots. The soil was repeatedly weighed and poured into pots until there were no empty pots. When the bowl ran out of soil, a new mixture was prepared, and the weighing procedure began again.

Once this was finished, hands were washed thoroughly. The right index finger was used to make four one-inch deep holes in each pot. Each hole was one inch from the center and at least one inch from each other, being evenly spaced around the center. After the holes were made, a seed was planted in each hole. These holes were covered back up with the soil removed when making the holes.

On a tile floor, two pots were placed on the ground, side by side, on top of a plant tray. One of the cardboard boxes was flipped over the two pots where the hole was on top. The two pots were centered underneath the hole. This was repeated four more times with the other eight pots and four other cardboard boxes. Each cardboard box was an inch apart.

The first cardboard box was Group C. This name was written on the box with a Sharpie. The white lights were placed on top of the cardboard box, in the hole, where the christmas light wires were facing up and the lights were facing down. The light circle was taped to the edges of the hole to keep it stable.

The next cardboard box was labeled Group R, using a Sharpie. The taped bunch of red and blue lights on the red Christmas lights' wire was taped to the hole in the cardboard box with the same technique used with the white lights. The same thing was done with the next cardboard box using the bunch of lights on other end of the red lights' wire, except the box was labeled Group H.

The fourth box was labeled Group S. The taped circle of red, blue, and green lights on the blue Christmas lights' wire was taped to the exposed hole in the cardboard box with the same procedure as stated in the previous paragraph. The taped circle on the other end of the blue lights' wire was taped to the hole in the last cardboard box with the same method as used before. This last box was labeled Group A.

The red Christmas lights' cord was plugged into the extension plug-in on the blue Christmas lights' wire. Then the blue Christmas lights' cord was plugged into the extension plug-in on the white Christmas lights' wire. Lastly, the white Christmas lights' cord was plugged into an extension cord, which was plugged into the electrical socket in the wall. Every night, at 10 PM, the extension cord was removed from the electrical outlet.

Every morning, at 6 AM, hands were washed thoroughly then all cardboard boxes were lifted up gently. Each plant was checked for mold, fuzzy leaves, or insects. If there were fuzzy things growing on a leaf, the fuzzy leaf was cut off with pliers, then thrown away in the trash. If there were insects, they were removed by picking them off the leaves. The soil was then touched to check the moisture. If the soil felt dry, twenty milliliters were added to the pot. If the plant was overwatered, the pot was lifted up to allow the excess water to flow out of the pot through the holes and into the plant tray (Bradley, 2012). When all of the water had drained, the two pots were placed on the ground and the excess water in the tray was poured into the sink. The tray was then placed back under the pots. If the soil was moist and not dry, then the plants were sprayed with water four times with the spray bottle. When the watering was done, the removed cardboard boxes were placed back over their respective plants, centering on the two pots. Once done, the white Christmas lights' cord was plugged back into the electrical socket.

Once the seedlings had grown, every day, at 6 PM, the cardboard boxes were gently removed and all of the plants' heights were measured in centimeters with the ruler. The removed cardboard box was replaced to where the lights were centered in the middle of the pots. This was repeated until the stems stopped growing.

The seedlings stopped growing and died, so the radishes did not develop fully. Root length was determined at the end of the experiment, but no other data was collected, resulting in incomplete data.

Results

During the experiment, radishes were grown under different light conditions to test whether a plant grown under lights with a red:blue:green ratio of 9:6:3 would grow the best. The plants' heights were recorded in centimeters over a period of ten days-from the day of the seedling sprouted to the day the plants stopped growing. The color of the stems was also looked at to determine the healthiness of the plants. At the end of the experiment, root length was measured in centimeters. Since all the plants died, no other data was recorded.

Based on the mean and median for height measurements, Group R had a greater mean and median than Group H, and Group A and Group S were lacking far behind them (see Appendix A). Group C had a wide range of height values compared with the rest of the groups, with a range of 6.73 on the last day. Most of the days, Group R had the highest mean and Group A had the lowest mean. On the last day height was measured, Group R had a mean of 10.27

centimeters, Group H had a mean of 10.08 centimeters, Group S had a mean of 8.545 centimeters, Group C had a mean of 8.495 centimeters, and Group A had a mean of 8.38.

The raw data of the root lengths showed opposite trends, with Group S having the longest root length and Group R having the shortest root length. (see Appendix B). Looking at the raw data, there does not seem to be any group's whose root length is longer than the others. The mean calculations of each group show very little difference between Group H, Group R, and Group C. It also shows very little difference between the mean calculations of Group A and Group S. The ranges varied a lot within the groups, with Group S and Group R having the highest ranges. Standard deviation formula:

$$\sqrt{\frac{\sum(x-\bar{x})^2}{n-1}}$$

where x is an individual data point, $\bar{x}$ is the mean of the data, and n is the number of plants in the group.

Standard Error formula:

$$\frac{\sigma}{\sqrt{n}}$$

where σ is the standard deviation and n is the number of plants in the group. Example for Group H: $\frac{1.337}{\sqrt{7}} = 0.5$

The standard deviation of plant heights for Group H was 1.337 and the standard error was 0.5. Group R had a standard deviation of plant heights of 1.422 and a standard error of 0.5. Plant heights of Group C had a standard deviation of 2.478 with a standard error of 0.876. The standard deviation of plant heights for Group A was 0.83 and the standard error was 0.31. Group S had a plant height standard deviation of 1.838 and a standard error of 0.65. All five group's plant height data are displayed in a bar graph with standard error bars in *Figure 1.* Group R and Group H overlapped, and Group C, Group A, and Group S overlapped. Nevertheless, both Group R and Group H didn't overlap Group C, Group A, or Group S, showing a possible height difference between the groups R and H and the groups C, A, and S.

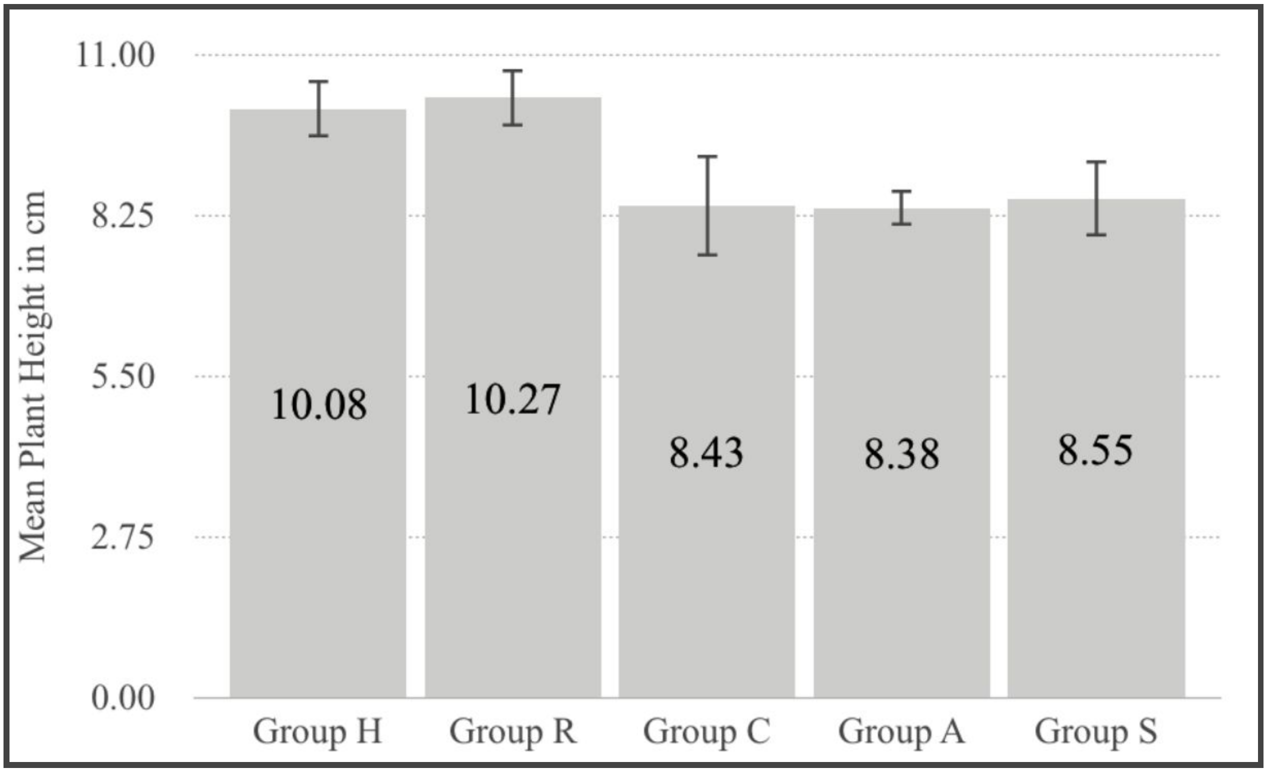

Figure 1: Mean Plant Height on Last Day

Despite these error bars, an ANOVA between the plant heights yielded different results. Given an F factor of 2.293 and a p-value of 0.08, there is no significant difference to suggest that any of these groups' plants' heights are different from one another.

The standard deviation of root length for Group H was 1.15 with a standard error of 0.435. Group R's root length data had a standard deviation of 1.81 and a standard error of 0.64.

Group C had a standard deviation of 1.19 and a standard error of 0.42 for root length. The standard deviation of root length for Group A was 1.57 with a standard error of 0.59. Group S had a root length standard deviation of 2.37 and a standard error of 0.838. These five group's root length data is represented in a bar graph with standard error bars in *Figure 2.* All of these bars overlap, meaning no significant difference actually occurred.

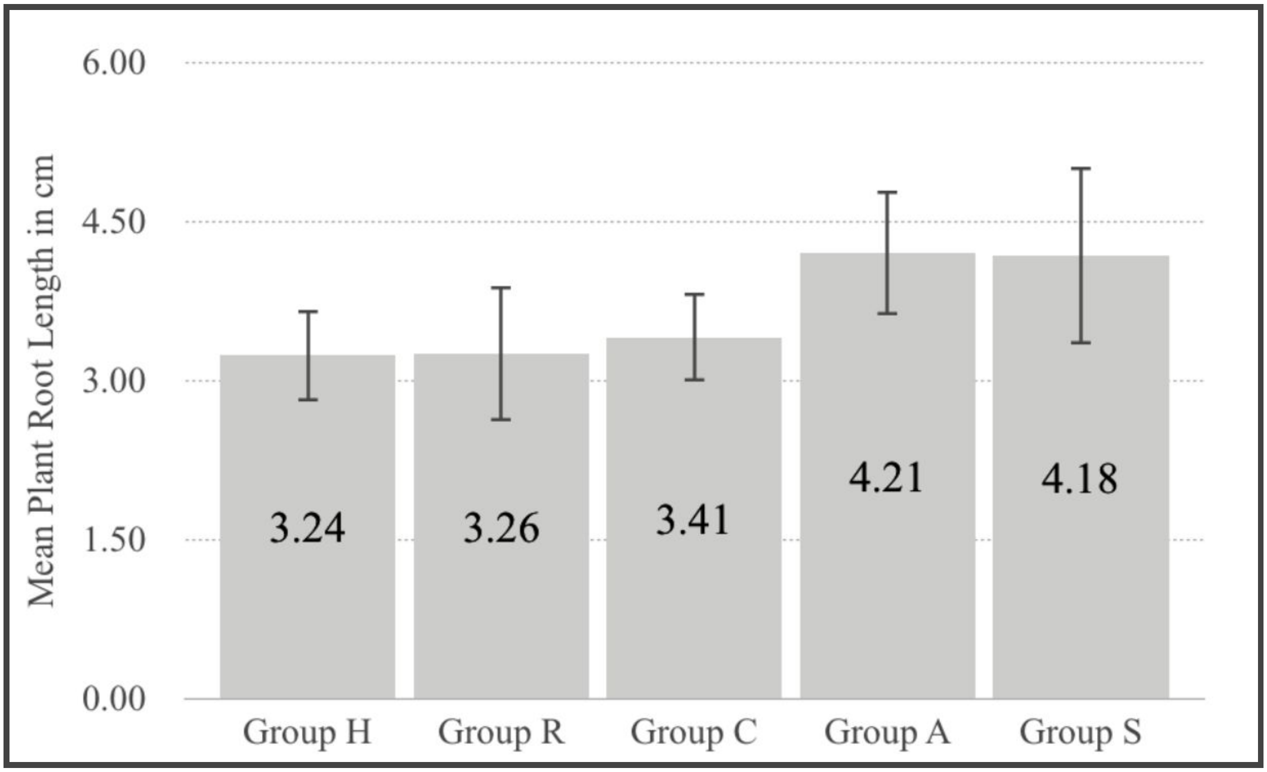

Figure 2: Mean Plant Root Length

Running an ANOVA produces the same results. With an F-value of 0.63 and a p-value of 0.644, no significant variance between the data to suggest that any group had a longer or shorter root length than another.

The color of the stems were also recorded. All of the plants started turning yellow towards the end of the experiment. Many of the stems started to fall and wilt. Though Group R, H, and C had the highest heights, the plants were more susceptible to falling over and had a light green color. Group S and Group A had shorter heights but had green, sturdy stems.

Discussion

Throughout four weeks, radishes were grown under different light situations where the heights were measured and the color of the stems was observed. Each different light group had a different ratio between the colors red, blue, and green. Root length was measured at the end of the experiment. No further data was collected due to the plants' death, which gives only a limited amount of data to work with.

It was hypothesized that Group H, the group with a red, blue, green ratio of 9:6:3, would grow the best due to the bit of green light and blue light that would help the plant perform its functions properly. This hypothesis was rejected due to the standard error bars revealing no plant height difference between Group R and Group H and no root length difference between any of the groups. This hypothesis was further rejected with the results from the ANOVA tests revealing there to be no statistical difference between plant height and root length. Group H also had stems that were light-colored and very flimsy, showing that the plants did not have enough structural support and were very weak.

Though Group H did not grow the best, the standard error bars revealed a difference between the height means of Groups R and H and the height means of Groups C, A, and S. However, the ANOVA tests and the standard error bars for root length did not reveal any differences. The stems of Groups A and S were stronger and darker-colored than that of Groups R and H. This might mean Group A and S grew better than the other groups though they were short plants.

This confusing data and the reason the plants died happened as a result of lack of light on the plants. The Texas A&M AgriLife Extension Service Center (personal communication, January 2, 2019) stated that the plants were too tall. This happened because the LED lights were too far away from the plant to get sufficient light. In order to try to get more light, the plant grew to an excessive height and limited its own functions (Halleck, 2018). This shows that Group S and A had better light conditions than Group H, R, and C. However, this may have resulted because of the way the lights were set up, with Groups S and A closest to the electrical socket and the other groups getting their electricity from a wire connected to the lights of Group S and Group A. More tests and data would be needed to confirm whether Group S and A had a better light combination or more energy from the wall, so the test still leads to no conclusions.

These results also show that height is an inadequate variable to judge on the health of the radishes. Height should still be calculated but should not be heavily relied on to determine a plant's health. Other factors, like color, biomass, stem strength, root length, and leaf number should be studied more closely to give a more accurate determination for plant health.

The AgriLife Extension Service Center also stated that the plants were too moist. This was caused because of the experimentation of how much water to put in the plants. Many times the plants were waterlogged or too dry. The random water differences from one day to the next also affected the plants' growth and probably had an affect on their death.

To further this research, this experiment should be repeated with a larger sample size of at least twenty radishes per group. The radishes should be given less water and the lights should be much closer to the plant. Each light wire should be plugged into their own socket so that the electricity given to each group will be even. According to Halleck (2018), air circulation, such as fans, should also be included to give the plants a feel for an “outside” environment. This will allow the plant to grow more stable due to the “windy” conditions and the circulation of carbon dioxide into and out of the area. Future analyzation of this type of experiment should not depend on height and should incorporate color, root length, biomass, stem strength, and leaf number. If height is calculated, it should be compared with the accepted population height of that plant.

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Appendix A

Day 1: Plant Height Stats

	Group H	Group R	Group C	Group A	Group S
Mean	3.05 cm	3.13 cm	2.19 cm	1.85 cm	1.72 cm
Median	3.28 cm	3.43 cm	1.76 cm	1.64 cm	2.43 cm
Range	1.29 cm	2.52 cm	4.44 cm	3.99 cm	3.13 cm

Day 2: Plant Height Stats

	Group H	Group R	Group C	Group A	Group S
Mean	6.02 cm	6.34 cm	5.17 cm	4.63 cm	4.92 cm
Median	6.32 cm	6.14 cm	4.76 cm	5.29 cm	5.51 cm
Range	2.20 cm	3.19 cm	5.81 cm	6.52 cm	6.00 cm

Day 3: Plant Height Stats

	Group H	Group R	Group C	Group A	Group S
Mean	7.70 cm	8.03 cm	6.88 cm	6.01 cm	6.69 cm
Median	8.01 cm	7.84 cm	6.65 cm	7.02 cm	7.36 cm
Range	3.35 cm	3.99 cm	5.93 cm	7.72 cm	6.51 cm

Day 4: Plant Height Stats

	Group H	Group R	Group C	Group A	Group S
Mean	8.49 cm	9.4 cm	7.78 cm	6.76 cm	7.73 cm
Median	9.065 cm	9.235 cm	6.945 cm	7.78 cm	8.27 cm
Range	4.61 cm	3.78 cm	5.67 cm	8.1 cm	6.99 cm

Day 5: Plant Height Stats

	Group H	Group R	Group C	Group A	Group S
Mean	8.985 cm	9.9 cm	8.04 cm	7.93 cm	8.38 cm
Median	9.325 cm	9.715 cm	7.24 cm	8.29 cm	8.875 cm
Range	5.09 cm	3.75 cm	5.57 cm	2.74 cm	6.12 cm

Day 6: Plant Height Stats

	Group H	Group R	Group C	Group A	Group S
Mean	9.275 cm	10.24 cm	8.59 cm	8.06 cm	8.49 cm
Median	9.82 cm	10 cm	7.9 cm	8.19 cm	8.64 cm
Range	5.19 cm	3.48 cm	6.00 cm	2.61 cm	6.06 cm

Day 7: Plant Height Stats

	Group H	Group R	Group C	Group A	Group S
Mean	9.50 cm	10.63 cm	8.655 cm	7.79 cm	8.74 cm
Median	9.94 cm	10.57 cm	7.87 cm	8.38 cm	8.97 cm
Range	6.32 cm	3.35 cm	6.61 cm	4.23 cm	6.29 cm

Day 8: Plant Height Stats

	Group H	Group R	Group C	Group A	Group S
Mean	10.10 cm	10.38 cm	8.46 cm	8.42 cm	8.755 cm
Median	9.98 cm	10.10 cm	7.58 cm	8.66 cm	9.01 cm
Range	4.14 cm	4.27 cm	6.52 cm	2.20 cm	5.89 cm

Day 9: Plant Height Stats

	Group H	Group R	Group C	Group A	Group S
Mean	10.08 cm	10.27 cm	8.495 cm	8.38 cm	8.545 cm
Median	9.89 cm	10.35 cm	8.07 cm	8.41 cm	8.835 cm
Range	4.11 cm	4.62 cm	6.73 cm	2.41 cm	5.33 cm

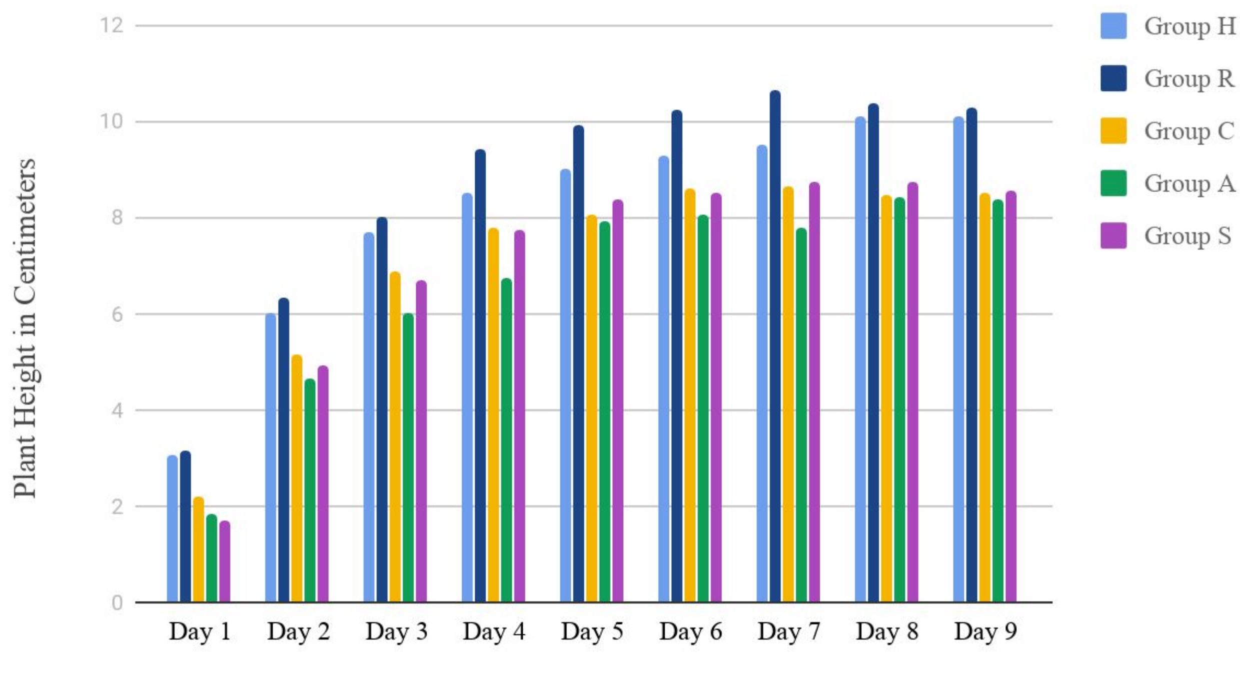

Figure 3: Mean Plant Height Over Time

Appendix B

Root Length Data

Group H	3.61 cm	4.53 cm	4.65 cm	2.32 cm	3.36 cm	1.51 cm	2.70 cm	
Group R	2.11 cm	7.05 cm	4.12 cm	2.13 cm	2.80 cm	3.29 cm	1.03 cm	3.54 cm
Group C	2.23 cm	3.13 cm	3.29 cm	1.86 cm	5.12 cm	3.01 cm	5.13 cm	3.52 cm
Group A	2.83 cm	6.39 cm	4.36 cm	3.29 cm	6.00 cm	4.39 cm	2.19 cm	
Group S	3.02 cm	2.91 cm	6.39 cm	1.51 cm	2.02 cm	3.99 cm	8.52 cm	5.06 cm

Root Length Stats

	Group H	Group R	Group C	Group A	Group S
Mean	3.24 cm	3.26 cm	3.41 cm	4.21 cm	4.18 cm
Median	3.36 cm	3.045 cm	3.21 cm	4.36 cm	3.505 cm
Range	3.14 cm	6.02 cm	3.27 cm	4.20 cm	7.01 cm