An Assessment into the Effect of Water and Biochar on the Growth of Cherry Belle Radishes

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Abstract

The purpose of this research study is to experimentally determine the optimum growth conditions for Cherry Belle Radishes in regards to composition of biochar in the soil by volume and amount of water given per day. Information was gathered through internet searches and scientific papers. Experiments were performed to compare the effects of the two variables. Daily, water was added to each pot simulating conditions ranging from drought to heavy rainfall. The amount of water given daily was divided into five categories, 5 mL, 10 mL, 15 mL, 20 mL, and 25 mL. The amount of biochar in the soil was also divided into five categories consisting of 5%, 8%, 10%, 12%, and 15% by volume. All of the radish plants, 60 in total, were grown under grow lights indoors for 22 days. All of the trials were designed in accordance to the Central Composite Design data analysis method. Observations of final radish plant height, root length, weight, and percentage of germination were quantified using the two independent variables. It was found that the optimum growth conditions were 25 mL of water daily, and 10% biochar in the soil. The results of this experimental study will help farmers on both large and small scales improve crop productivity and soil quality, as well as help mitigate the effects of climate change.

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Introduction

The following discussion of Biochar describes some important background information and past research on the variables that will be affecting the experiment that is described below.

Biochar

Preparation and Types

Biochar is defined as a solid material that is made from the pyrolysis of biomass.[1] Pyrolysis is defined as decomposition brought about by high temperatures. Pyrolysis can be done in many ways, but includes the carbonization of biomass in the absence of oxygen to prevent combustion. Biochar can be made from many sources, including but not limited to corn stover, trees, dead wood, grasses, nut shells, agricultural and forestry residues, animal waste, and any other organic matter.[1] The most common source of Biochar in the United States is from agricultural and forestry residues. Figure 1 below shows the availability of biomass from existing crop residues in the United States by county on an annual basis.

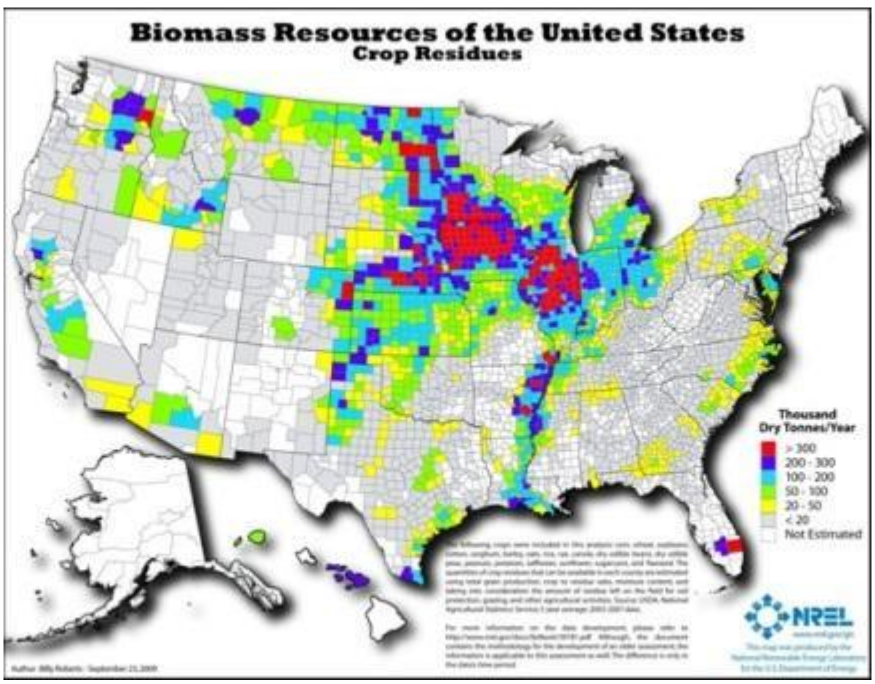

Figure 1. Biomass Availability in the United States from Crop Residues[2]

There are three different levels for testing the Biochar. The Biochar is considered level one if it has been tested for the most basic requirements and it only applies to Biochar that is made from unprocessed Biochar. The Biochar must also meet the carbon ratio minimums as well as have the correct proportions of hydrogen, carbon, and nitrogen.[1] Level two Biochar must meet some basic soil toxicity thresholds in addition to meeting all of the requirements for level one Biochar. All of these requirements must be met regardless of whether the Biochar was produced by processed or unprocessed feedstock. In addition, level two must meet soil enhancement chemicals of nitrogen, phosphorous, and potassium, as well as pass the electrical conductivity test.[1] For Biochar to be classified as level three, it must pass more advanced toxicity limits as well as meet all of the requirements outlined for level two Biochar. This Biochar needs to pass all of the requirements regardless of whether it was made from processed or unprocessed feedstock. The advanced toxicity is reported in regards to concentrations of volatile aromatic compounds. Advanced soil properties involve porosity and surface area of the Biochar.[1]

Applications

In order for the Biochar to be most effective, it should be located in the root zone of the plants.[3] For agricultural purposes, this includes the top 4-6” of soil. The soil surface is where the majority of the nutrient uptake takes place, as well as where most of the microbial activity takes place. Biochar should also be thoroughly mixed with the soil to ensure that wind and water erosion is decreased.[3] The Biochar should also be placed in a large enough area to ensure that the mature plant will be able to utilize the nutrients that the Biochar has to offer.

Biochar Effects on CO_2 Emissions

Biochar can also have an effect on the climate. The greenhouse gas, CO_2, has been steadily increasing in concentration in the atmosphere the last couple of decades, and now reaches over 400 ppm. Figure 2 shows the annual CO_2 atmospheric concentration as measured from the station at the Mauna Loa Observatory in Hawaii.[4]

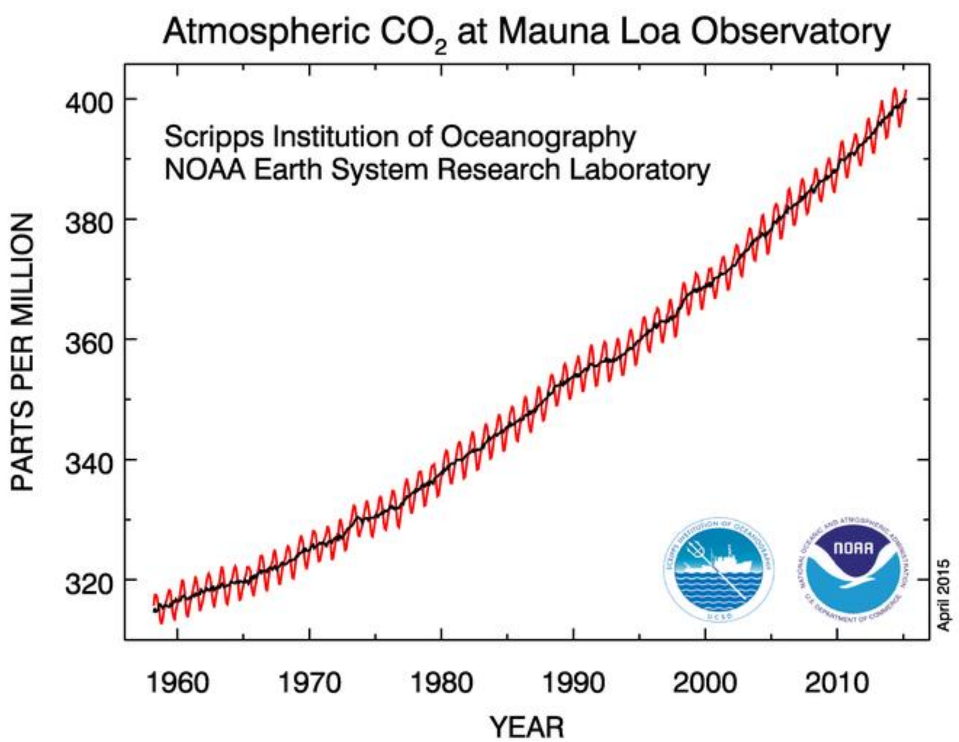

Figure 2. Annual Atmospheric CO_2 Concentration 1960-Present

The annual emissions of CO_2 can be reduced by 12% of the current anthropogenic emissions through the use of Biochar.[5] Figure 3 describes the annual CO_2 emissions per year.

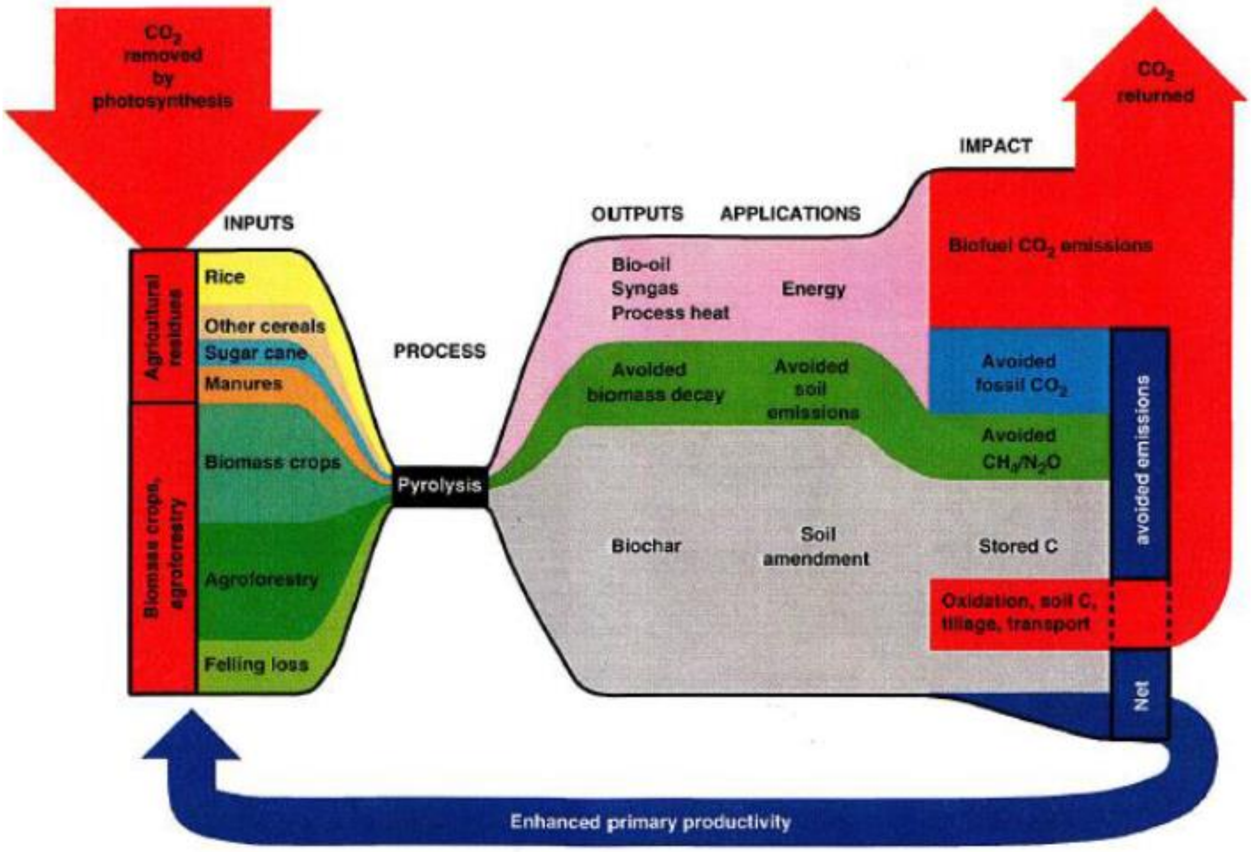

Figure 3. CO_2 Emissions in the Carbon Cycle through Biochar[5]

Biochar has many benefits including the fact that it is a source of renewable bioenergy, and the fact that it can improve agricultural productivity.[5] The biochar is able to store carbon that slowly decays. This slow decay returns a very small amount of CO_2 to the atmosphere in comparison to the natural decay of plants that do not undergo pyrolysis.[5]

Cherry Belle Radishes[6]

Cherry belle radishes are a variety of radish that are known for their crispness and early harvest time. They are best planted in soils that are less than 80 °F, and in areas that receive at least 6 hours of direct sunlight per day. In most locations, they are planted in both the spring and the early fall, as they do not tolerate the summer heat very well. They grow to be about ¾" in diameter, with tops that reach 4-6 inches above the soil. They are to be planted 3" apart in evenly spaced rows 6" apart. Cherry belle radishes are ready for harvest 25 days after planting in the spring, and as quickly as 22 days after planting in the fall. They have a bright scarlet outer skin with a white fleshy interior.

Plant Needs

Plants have a very specific need in regards to carbon and nitrogen and other major and minor elements. In this experiment, the biochar adds mostly carbon, and the compost adds mostly nitrogen. There needs to be a 10:1 ratio of carbon to nitrogen on average for plants to grow.[7,8] Some of the other elements that are required for plant growth are phosphorous, potassium, calcium, magnesium, and sulfur.[7,8] In total there are 16 elements that are needed for plant growth.

Other than chemicals, it is necessary for plants to have water and sunlight. Plants need these two ingredients in order to go through the process of photosynthesis. This is the process that converts carbon dioxide and water into starches and sugars that the plants use for energy.[7,8]

History of Cherry Belle Radishes

Radishes are a member of the *brassicaceae* family, and have the species name *raphanus sativus*. In the first few weeks of growth, they develop a tuber for means of storing water. Figure 4 shows the development of a radish plant from germination until the tuber is ready to harvest.

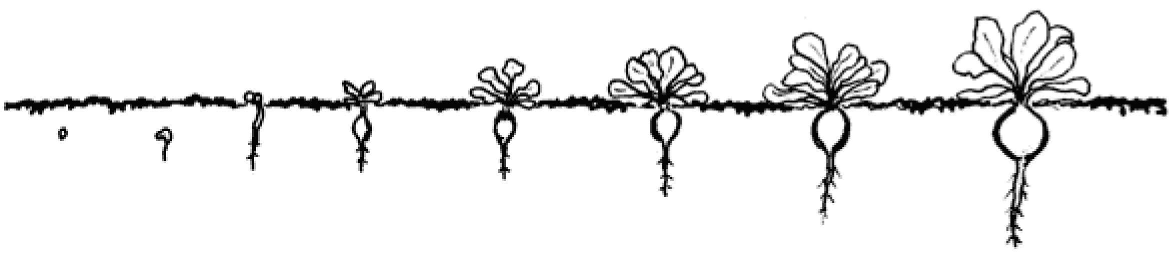

Figure 4. Radish Growth from Germination until Harvest[9]

If they are let to grow after the tuber is done developing, the tuber becomes more fibrous and tough. Over the winter, the leaves die and the water is used to keep the plant alive. When spring arrives, the tuber is almost gone, and the leaves of the plant start to grow again. The root system becomes more developed and the stem starts to grow longer, eventually growing flowers and seed pods that contain edible seeds in them. The full life stages of a radish plant are shown in Figure 5.

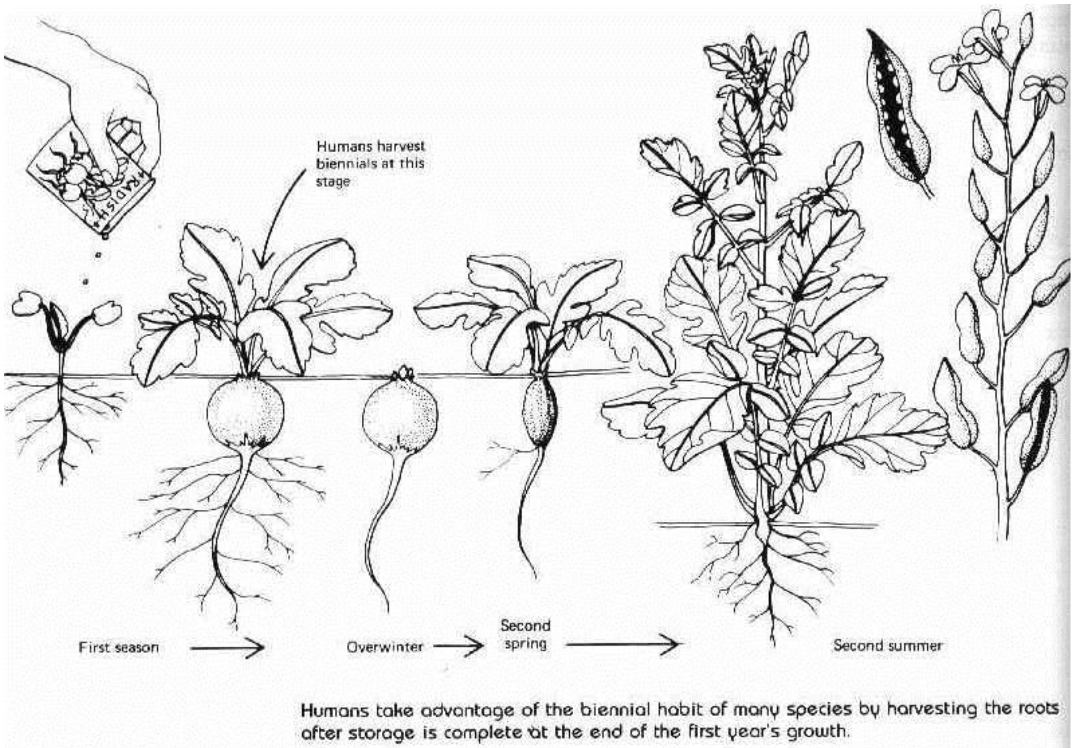

Figure 5. Complete Life Stages of a Radish Plant[10]

There are many reasons why radishes are a desirable plant for experimentation. The first of which is that they can be grown indoors with growing lights. They are also relatively fast growers, reaching maturity in just 22-25 days. Additionally, they are root vegetables, which grow in and directly come in contact with the biochar that is in the soil. Finally, radish seeds are readily available at local supermarkets and gardening stores. All of these reasons are why radishes were chosen in this experiment.

Methods and Materials

The following subsections describe the methods and materials used to perform the experimental study of the growth of radishes in biochar amended soils.

Independent Variables

There are two independent variables that are used in the experiment. These variables include the amount of water added and the amount of biochar in the soil. The amounts of water that are used in the experiment are 5 mL, 10 mL, 15 mL, 20 mL, and 25 mL per day. These numbers were chosen arbitrarily and were intended to represent a range of moisture levels from drought to heavy rainfall. The percentages of biochar that were added to each pot are 5%, 8%, 10%, 12%, and 15% by volume. These values represent a range of previously researched biochar compositions in soils that claim that a 10% volume composition is the best ratio to use for growing crops. The range of 5-15% by volume encompasses that optimal range and tests it.

All of the pots contained 50% top soil by volume, with the remainder being compost and biochar as described above. For example, if a pot contained 5% biochar by volume, it also contained 50% top soil and 45% compost by volume. The control in the experiment did not contain any biochar, and was 50% top soil and 50% compost by volume. Each of the variables in the experiment had two trials, for a total of 60 radish plants.

Dependent Variables

The dependent variables are the values that are measured at the end of the experiment. For this experiment, the dependent variables were the height of the plant above ground, the number of leaves, the length of the roots, the weight of the plant, how many of the seeds germinated, and how many of the plants developed tubers. Other observations were made such as the color of the stem of the plant and the visual moisture conditions of the soil. (e.g. was it saturated or dry?).

Materials

The following list describes the materials that were used to conduct the experiment.

- 60 Cherry Belle Radish seeds
- Biochar produced from yellow pine trees
- Organic Compost
- Top soil
- Tap water

Apparatus

The following list describes the apparatus that were used to conduct the experiment.

- 5 plastic seed starting trays
- 1 25ml beaker
- Sylvania Super Saver, Cool White Deluxe Light Bulbs, 34W (in light fixtures)

- 1 humidity and temperature meter (ACURITE-Indoor humidity Meter- #00613)
- 1 Lumen Meter (Hydrofarm-Digital Light Meter-LG17010)
- 5 aluminum mixing trays (disposal baking trays)
- 60 paper fiber compostable starter pots
- 1 1L plastic bottle for holding water
- 1 step stool for safe access to elevated working area
- 1 1L measuring cup

Experimental Conditions

The experiment was formed under the following conditions:

- Indoor temperatures ranging from 69-72 °C
- Indoor humidity ranging from 15-32%
- The top of the pots were approximately 30" from the light source
- An average of 820 lumens at all corners of the planting area

Experimental Procedure

The first step to set up the experiment requires a two week incubation period of the biochar/soil/compost mixture. The proper volumes of the biochar, soil, and compost were measured out in the 1 L measuring cup, with a total volume of 3 L per variable. For example, for the 10% biochar mixture, there were 1500 mL of soil, 1200 mL of compost, and 300 mL of biochar. These three components were mixed together in the disposable aluminum trays and mixed thoroughly by hand. It is important to label each one of the trays to avoid an error in the experiment. Each day for 14 days, the mixtures were churned by hand to insure even distribution of the components within the soil. Also, 250 mL of water was added each day to maintain soil moisture. The daily watering and mixing were essential to allow the biochar to absorb the nutrients that the compost and soil contained. If the biochar was not allowed to incubate, it could have been in the absorption process while the seeds were trying to germinate, which could have decreased the amount of seeds that germinated. It is not necessary to incubate the control, as the compost and soil do not have the same interaction as the biochar does with the soil and compost. Figure 6 shows the aluminum trays containing the different mixtures during the incubation period.

Figure 6. Biochar Incubation Trays

At the end of the 14 day incubation period, the compostable pots were filled with the soil in the arrangement indicated in Figure 7. Each of the 5 biochar composition variables and the control were laid out in the same manner in individual plastic trays.

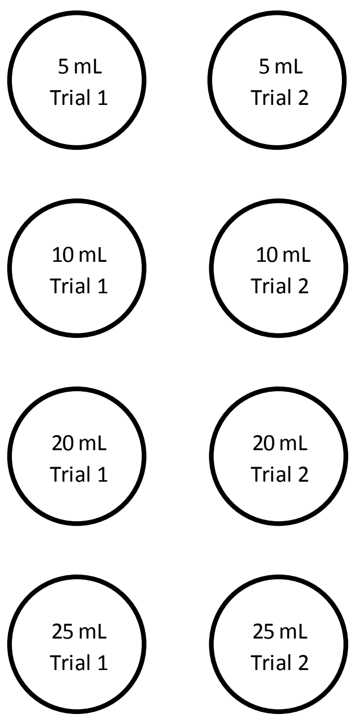

Figure 7. Radish Plant Layout

Once the setup is complete, the radish seeds are ready to be planted. One seed was planted per pot. The seed was placed in the middle of the pot on top of the soil, and either pushed ½" down into the soil, or ½" of soil was placed on top of the seed. After the planting is done, the seeds are ready to be watered. The plants were each watered once per day with the appropriate amount of water for 22 days. It is also important that the plants receive adequate light, so the lights were left on for 24 hours a day during the course of the experiment. The planted pots are shown in Figure 8.

Figure 8. Planted Radish Seeds in Pots

Data Collection

On the 22nd day of the experiment, the plants were watered like normal. After 8 hours had passed, the height of the plants was measured using a ruler, to the nearest mm. The number of leaves of each plant was noted, as well as the color of the stem of the plant. The pots were then easily torn away from the pots and the soil was removed. The soil was very carefully broken up in order to protect the plant and to avoid breaking the root. In order to remove the remaining soil from the root system, the plant was placed in a tub of water and gently rubbed to clean the roots. Then, the roots were dried on a paper towel to get rid of excess water. The length of the roots was measured, and the weight of the plant was taken to 4 decimal places on a digital scale. All of the data was entered in an Excel spreadsheet for analysis, which is summarized in the next section.

Data Reduction

Once all of the data were collected, it was analyzed for outliers. The averages of the trials were calculated, as well as the standard deviations. If the height or weight for the trial was not within three standard deviations of the average then it was eliminated. It is important to note that no outliers were found in this experiment.

Central Composite Design

Once the original design has been set up, it is essential to plot the trials in coded terms. Since there are two quantitative dependent variables, the interaction parameters of the experiment fall within a two dimensional plane. The limitation of having only two variables allows the data to be easily interpreted using a program like Microsoft Excel, and does not require more complex programming such as MATLAB, or other software that can easily manipulate 3 or more variables. Central composite design relates the independent and dependent variables through interaction parameters based on the results of the experiment. It relates multiple inputs to a single output. From these data, other results can be predicted by interpolating and extrapolating the experimental results.

Results and Discussion

After the data is examined for outliers, the statistical method of central composite design was implemented. The first step in the process is to develop the design. Two different analyses took place during the process: the amount of water given and the amount of biochar in the soil.

Table 1. Selection of Variable Magnitudes

	Variable	Low	Middle	High
A	Water Added (mL)	5	15	25
B	Biochar Composition (volume%)	5	10	15

Variable Effects on the Growth of Cherry Belle Radishes

The next step was to take the factorial for each respective set to find the main effects for each output variable. This was done by multiplying the response by the factorial. The average of the highs and the average of the lows were taken. The main effects graphs can be seen in Figures 9-12. In these figures, the largest slopes have the largest effect on the final height, root length, and weight.

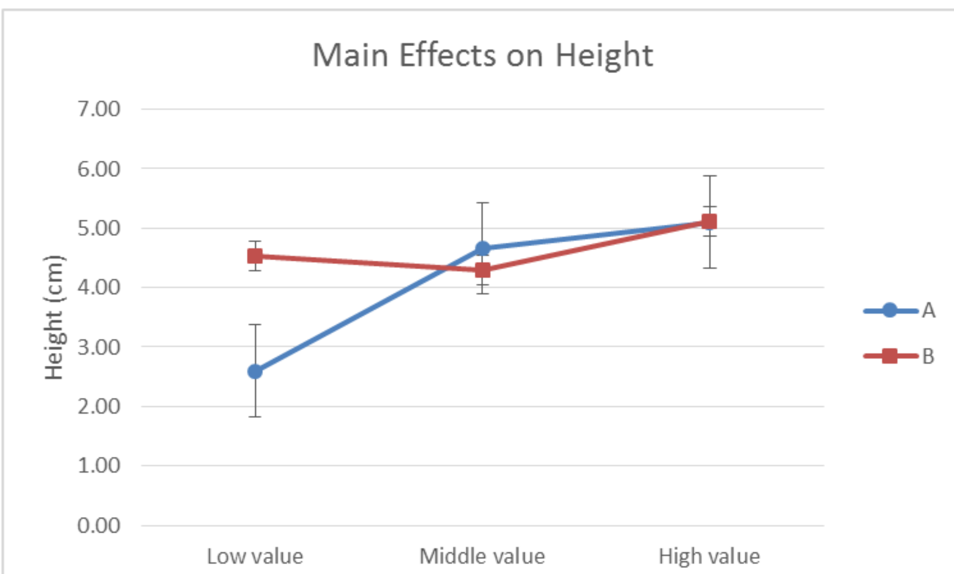

Figure 9. Height Effects on Radishes for Variables A and B

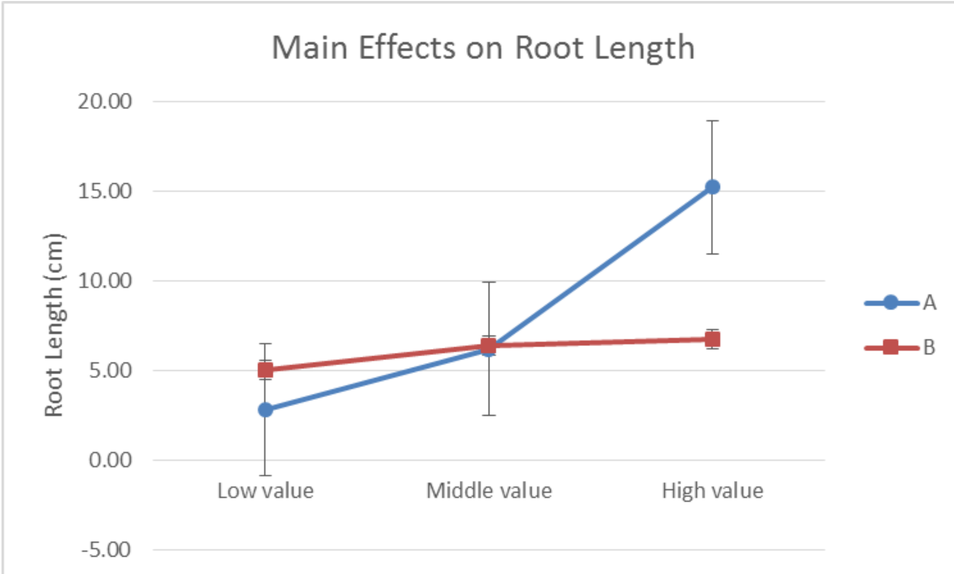

Figure 10. Root Length Effects on Radishes for Variables A and B

Figure 11. Weight Effects on Radishes for Variables A and B

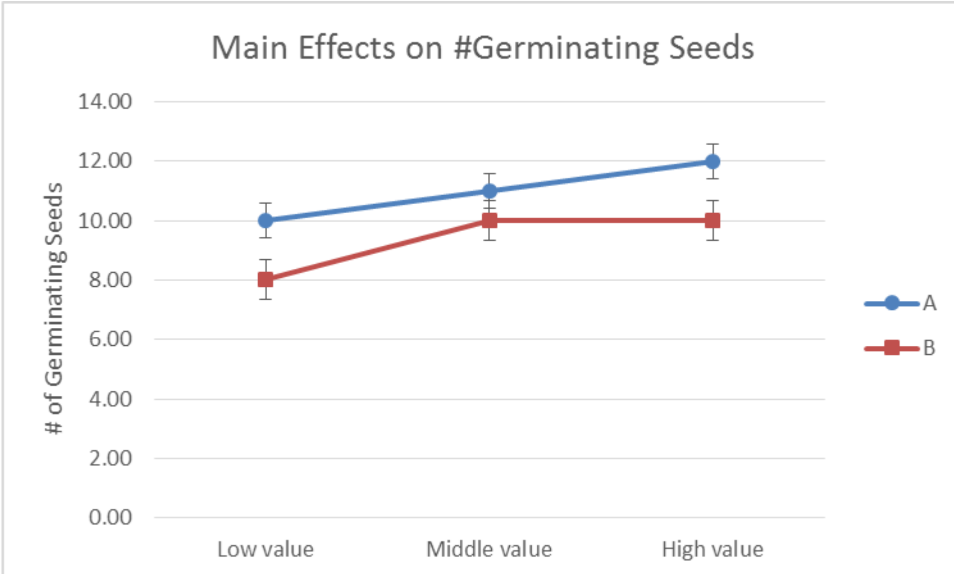

Figure 12. Number of Germinating Seeds Effects for Variables A and B

As shown above, line A dramatically increases as the amount of water increases from 5 mL to 25 mL for height, root length, and weight, but does not affect the amount of germinating seeds as dramatically, although there is still an increase.

For variable B, the results are not as dramatic as variable A, but some important trends can be noticed. For the weight of the plant, the root length, and the number of germinating seeds, the low value of biochar, 5%, has the least impressive results on the dependent variables. The results improve for the middle value where the biochar is increased to 10%, but the results either remain stagnant or decrease for the 15% biochar high value. For the plant height above the surface, the biochar actually lowers the final height of the plant. This is because the biochar has a stronger interaction where it directly comes in contact with the parts of the plant, such as the seed and the roots of the plant. Error bars are included to show the relative error of the calculations.

Observed Experimental Results

Table 2 depicts the optimum and worst growing conditions that were observed during the data collection stage of the experiment.

Table 2. Conditions for Optimum and Worst Growth of Cherry Belle Radishes

Optimal Conditions for Height	15%, 25 mL
Optimal Conditions for Root Length	10%, 25 mL
Optimal Conditions for Weight	10%, 25 mL
Optimum Conditions for Germination	10%, 25 mL
Worst Conditions for Height	10%, 5 mL
Worst Conditions for Root Length	5%, 5 mL
Worst Conditions for Weight	5%, 5 mL
Worst Conditions for Germination	5%, 5mL

Conclusions

In conclusion, the project indicates that the optimum growth conditions for Cherry Belle Radishes are 10% biochar and 25 mL of water daily. The worst conditions for radish growth appear to be only 5% biochar and 5 mL of water added daily. It is not surprising that the more water added to the plants the larger they grew. It is important to note that the biochar was only helpful to the plant only up to a certain concentration, and then the results started to decline. This could be because of the necessary carbon to nitrogen ratios a plant need to grow.

The results are proof that the experiments purpose was well fulfilled. It is recommended that further experiments are performed. Some possible experiments are described below in the *Recommendations* section.

Recommendations

In order to improve the experiment, several changes could be made. To get better averages with more statistically significant results, more trials should be conducted within each independent variable. For example, this experiment had two trials within each variable set, whereas five would be a better number. However, the limited space for this experiment and limited supplies did not allow for such an extensive experiment.

Additionally, it is recommended that the light intensity in the lab be increased. The light intensity in the lab was much less stronger than the sun, so the plants did not grow to their full potential and tubers did not develop. It would also be helpful to lengthen the time frame of the experiment to see longer term effects of the biochar and water on the plant growth.

It is also recommended that the growing pots used are not compostable ones, because some of them started to deteriorate towards the beginning of the experiment. It is also recommended that the experiment be conducted outside to contain a more natural environment, even if the experimental conditions are less controlled. Further research is required to gain a better understanding of the interactions of biochar with radish growth.

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Appendices

A. Raw Experimental Data

The following tables show the raw data that was collected when the growing period ended. The label "NA" in a table means that the value was not measurable or applicable.

Table 3. Control Experimental Data

Control (50% Soil - 50% Compost)									
Water	Trial	Observation							
		Height (cm)	Root Length (cm)	Weight (g)	# of Leaves	Color of Stem	Tuber?	Germination?	Other Observations
25 ml	Trial 1	5	24.2	0.2675	2	Light Red	N	Y	Muddy Soil
	Trial 2	5	55	0.2913	2	Deep Red	N	Y	Very Long Tap Root
20 ml	Trial 1	4.8	22.1	0.4103	3	Deep Red	N	Y	Muddy Soil
	Trial 2	5.2	18.6	0.3725	3	Deep Red	N	Y	Muddy Soil
15 ml	Trial 1	NA	NA	NA	NA	NA	N	N	Wet to the Bottom
	Trial 2	6.3	17	0.3968	3	Deep Red	N	Y	Soil was muddy
10 ml	Trial 1	2.8	6.7	0.1464	2	Deep Red	N	Y	Top 1" of soil was moist
	Trial 2	8.6	8	0.3844	4	Deep Red	N	Y	Soil was wet to the bottom
5 ml	Trial 1	2.1	3.7	0.1434	2	Light Red	N	Y	Top 1/2" of soil was moist
	Trial 2	3.3	5.5	0.1106	2	Light Red	N	Y	Top 1/2" of soil was moist

Table 4. 5% Biochar Experimental Data

50% Soil - 45% Compost - 5% Biochar									
Water	Trial	Observation							
		Height (cm)	Root Length (cm)	Weight (g)	# of Leaves	Color of Stem	Tuber?	Germination?	Other Observations
25 ml	Trial 1	4.5	7.1	0.2507	4	Red	N	Y	Soil Moist To Bottom
	Trial 2	5.2	7.3	0.185	2	Pink	N	Y	Soil Moist To Bottom
20 ml	Trial 1	3.4	5.1	0.0923	3	Red	N	Y	Soil Moist 1.75" Down
	Trial 2	5.6	7	0.3011	4	Deep Red	N	Y	Soil Moist 1.75" Down
15 ml	Trial 1	5.5	5.7	0.2433	2	Pink	N	Y	Soil Moist 1" Down
	Trial 2	3	4.6	0.1713	3	Red	N	Y	Soil Moist 1.25" Down
10 ml	Trial 1	NA	NA	NA	NA	NA	N	N	Soil Moist 1/2"
	Trial 2	NA	1.4	0.0605	NA	NA	N	Y	Never Made it Above Surface
5 ml	Trial 1	NA	1.8	0.0201	NA	NA	N	Y	Never Made it Above Surface
	Trial 2	NA	NA	NA	NA	NA	N	N	Soil is Dry

Table 5. 8% Biochar Experimental Data

50% Soil - 42% Compost - 8% Biochar									
Water	Trial	Observation							
		Height (cm)	Root Length (cm)	Weight (g)	# of Leaves	Color of Stem	Tuber?	Germination?	Other Observations
25 ml	Trial 1	5.2	6.1	0.2647	3	Pink	N	Y	
	Trial 2	4.5	8.5	0.2514	4	Pink	N	Y	
20 ml	Trial 1	3.2	6.3	0.1514	2	Red	N	Y	
	Trial 2	5.7	4.2	0.335	4	Pink	N	Y	
15 ml	Trial 1	2.2	5.4	0.2466	3	Red	N	Y	
	Trial 2	5.4	3.6	0.1699	2	Red	N	Y	
10 ml	Trial 1	3.4	4.1	0.2256	3	Light Pink	N	Y	
	Trial 2	3.3	2.3	0.121	2	Yellow/Green	N	Y	
5 ml	Trial 1	NA	1	0.0399	NA	NA	N	Y	
	Trial 2	NA	NA	NA	NA	NA	N	N	

Table 6. 10% Biochar Experimental Data

50% Soil - 40% Compost - 10% Biochar									
Water	Trial	Observation							
		Height (cm)	Root Length (cm)	Weight (g)	# of Leaves	Color of Stem	Tuber?	Germination?	Other Observations
25 ml	Trial 1	5.2	12.7	0.3892	3	Pink	N	Y	
	Trial 2	5.7	16.4	0.571	2	Red	N	Y	
20 ml	Trial 1	5.3	6.1	0.2609	3	Red	N	Y	
	Trial 2	5.3	10.4	0.3177	4	Light Pink	N	Y	
15 ml	Trial 1	5.2	4.6	0.242	3	Red	N	Y	
	Trial 2	3.8	4.1	0.1786	2	Red	N	Y	
10 ml	Trial 1	2.4	2.1	0.104	2	Green	N	Y	
	Trial 2	3.3	3.4	0.2063	4	Reddish	N	Y	
5 ml	Trial 1	2.4	2	0.096	2	Yellow	N	Y	
	Trial 2	NA	2	0.0286	NA	NA	N	Y	

Table 7. 12% Biochar Experimental Data

50% Soil - 38% Compost - 12% Biochar									
Water	Trial	Observation							
		Height (cm)	Root Length (cm)	Weight (g)	# of Leaves	Color of Stem	Tuber?	Germination?	Other Observations
25 ml	Trial 1	4.7	8.9	0.4707	3	Red	N	Y	
	Trial 2	4.4	7.8	0.2741	2	Red	N	Y	
20 ml	Trial 1	NA	NA	NA	NA	NA	N	N	
	Trial 2	4.5	7.4	0.2901	3	Red	N	Y	
15 ml	Trial 1	4.7	6.8	0.3348	3	Red	N	Y	
	Trial 2	4.3	5	0.2613	4	Red	N	Y	
10 ml	Trial 1	3.4	4.1	0.1425	3	Light Pink	N	Y	
	Trial 2	3	3.7	0.1921	4	Red	N	Y	
5 ml	Trial 1	NA	NA	0.0103	NA	NA	N	Y	
	Trial 2	NA	NA	0.0204	NA	NA	N	Y	

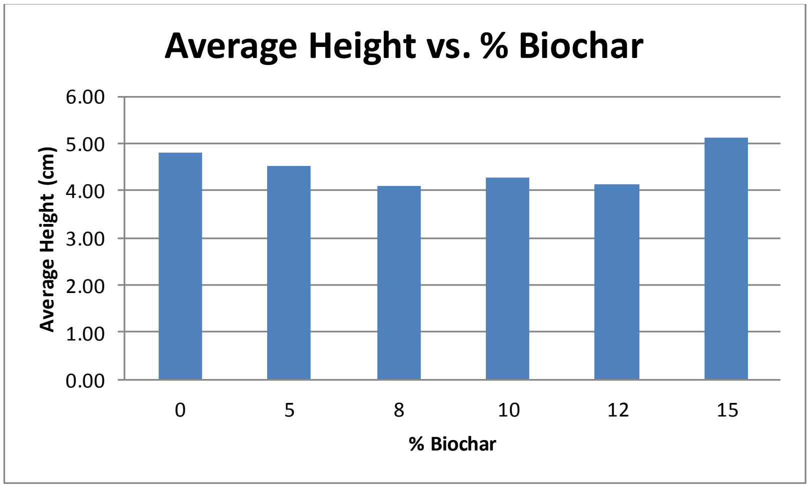
Table 8. 15% Biochar Experimental Data

50% Soil - 35% Compost - 15% Biochar									
Water	Trial	Observation							
		Height (cm)	Root Length (cm)	Weight (g)	# of Leaves	Color of Stem	Tuber?	Germination?	Other Observations
25 ml	Trial 1	5.6	20.3	0.2835	2	Light Pink	N	Y	
	Trial 2	6.2	8.5	0.3047	2	Light Pink	N	Y	
20 ml	Trial 1	3.7	5.9	0.2975	4	Light Pink	N	Y	
	Trial 2	6.6	5.8	0.2948	3	Light Pink	N	Y	
15 ml	Trial 1	5.7	6.6	0.346	2	Red	N	Y	
	Trial 2	5.2	4.7	0.2718	4	Light Pink	N	Y	
10 ml	Trial 1	4.3	5.1	0.1966	2	Light Pink	N	Y	
	Trial 2	3.7	4.1	0.1487	2	Light Pink	N	Y	
5 ml	Trial 1	NA	5.5	0.159	NA	NA	N	Y	
	Trial 2	NA	1	0.008	NA	NA	N	Y	

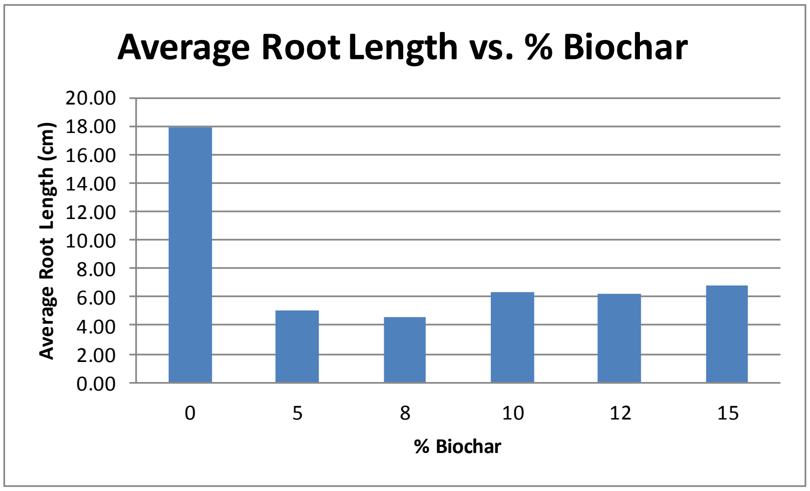
B. Data Tables and Graphs

The following tables and figures show the averages of the trials divided by dependent variable. The accompanying bar graphs show the graphical results of the tabulated values.

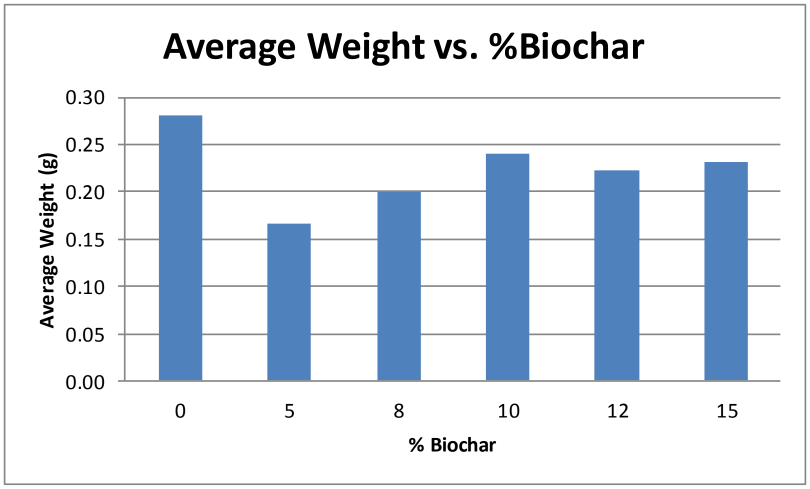
Average Height vs. % Biochar	
Composition	Average
0	4.79
5	4.53
8	4.11
10	4.29
12	4.14
15	5.13



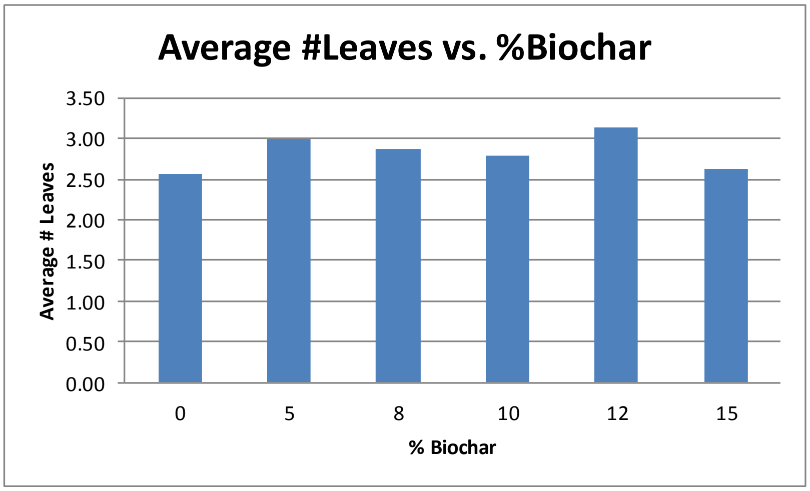
Average Root Length vs. %Biochar	
Composition	Average
0	17.87
5	5.00
8	4.61
10	6.38
12	6.24
15	6.75



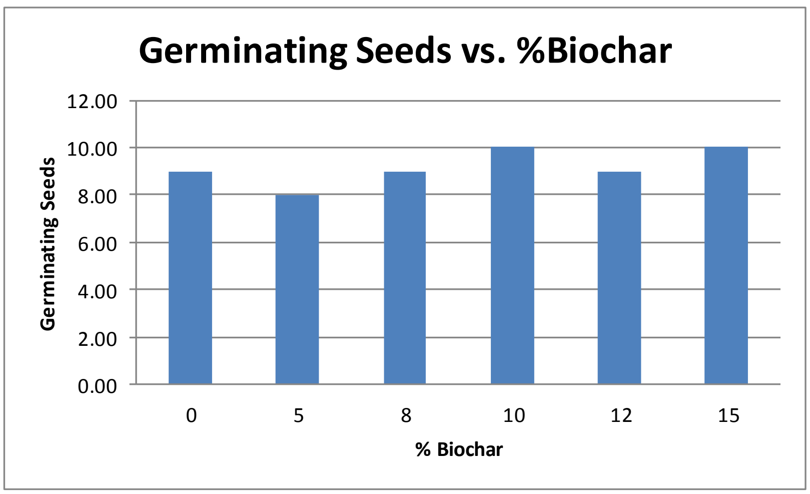
Average Weight vs. %Biochar	
Composition	Average
0	0.28
5	0.17
8	0.20
10	0.24
12	0.22
15	0.23



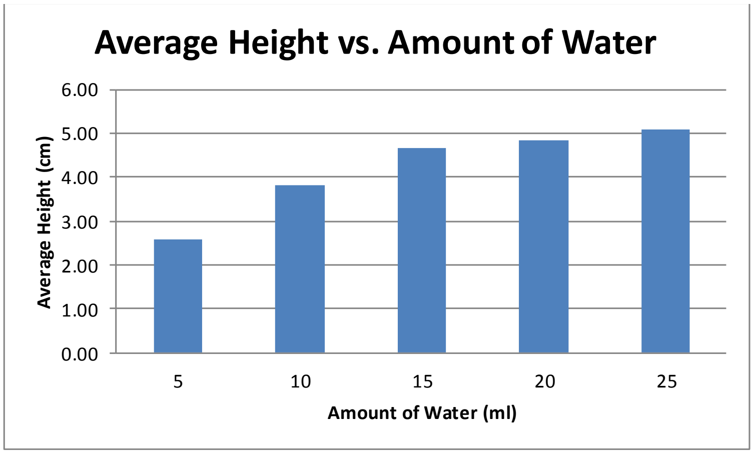
Average #Leaves vs. %Biochar	
Composition	Average
0	2.56
5	3.00
8	2.88
10	2.78
12	3.14
15	2.63



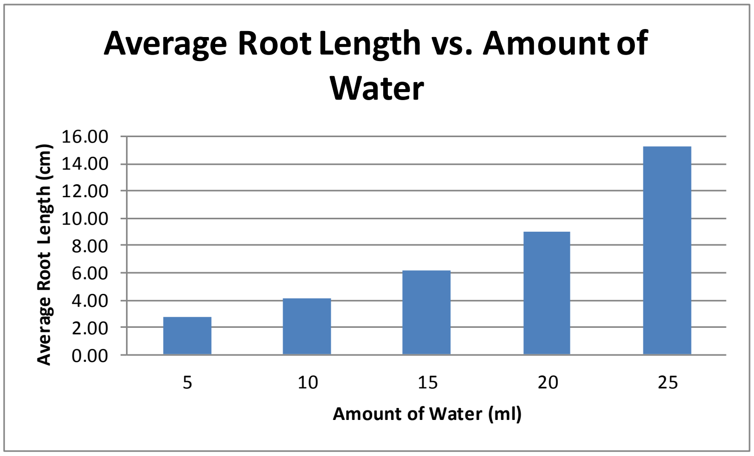
Germinating Seeds vs. %Biochar	
Composition	Average
0	9.00
5	8.00
8	9.00
10	10.00
12	9.00
15	10.00



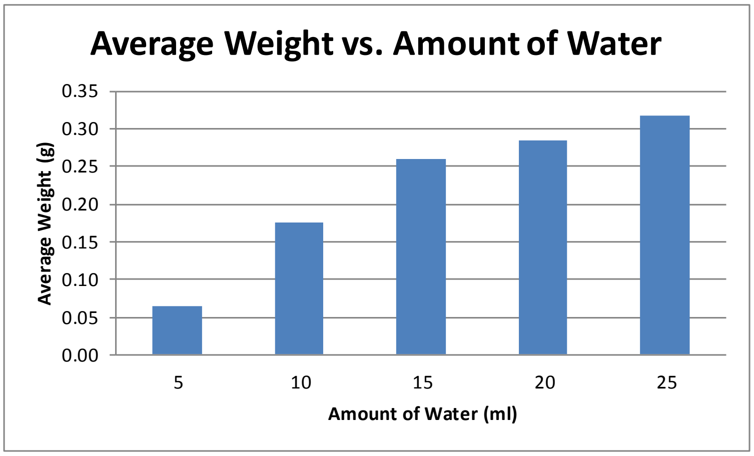
Average Height vs. Amount of Water	
Water (ml)	Average
5	2.60
10	3.82
15	4.66
20	4.85
25	5.10



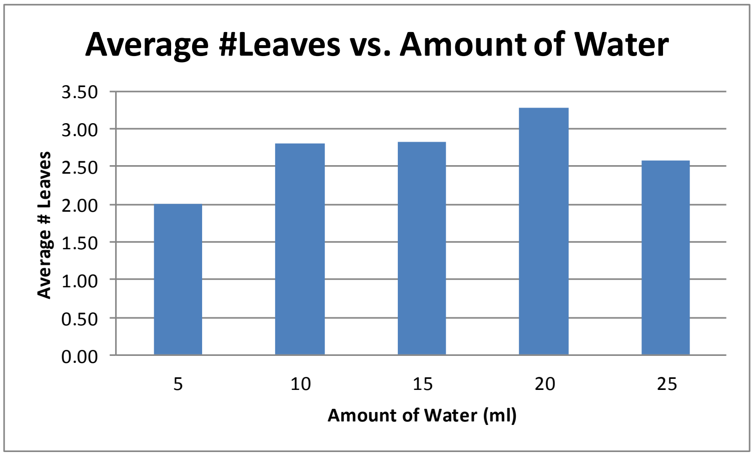
Average Root Length vs. Amount of Water	
Water (ml)	Average
5	2.81
10	4.12
15	6.19
20	8.99
25	15.23



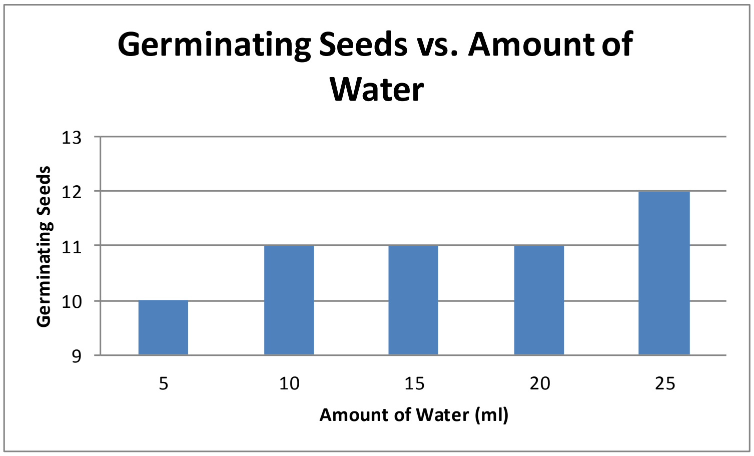
Average Weight vs. Amount of Water	
Water (ml)	Average
5	0.06
10	0.18
15	0.26
20	0.28
25	0.32



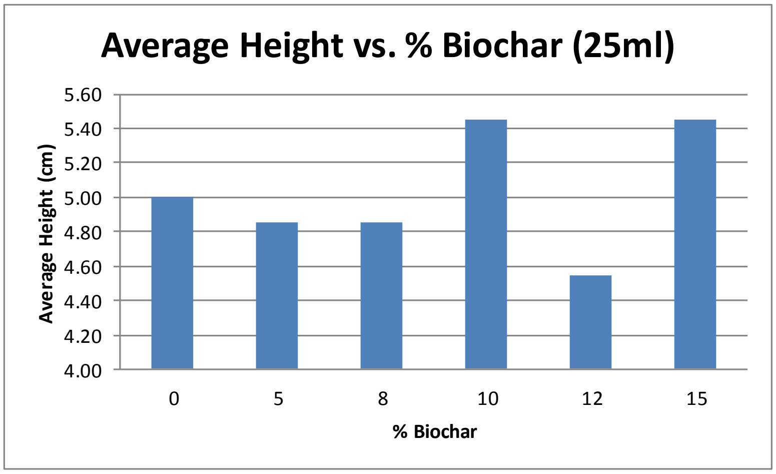
Average #Leaves vs. Amount of Water	
Water (ml)	Average
5	2.00
10	2.80
15	2.82
20	3.27
25	2.58



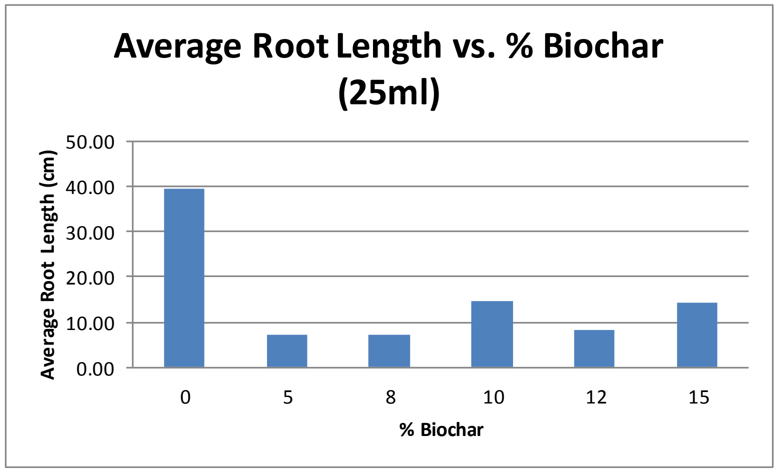
Germinating Seeds vs. Amount of Water	
Water (ml)	Average
5	10
10	11
15	11
20	11
25	12



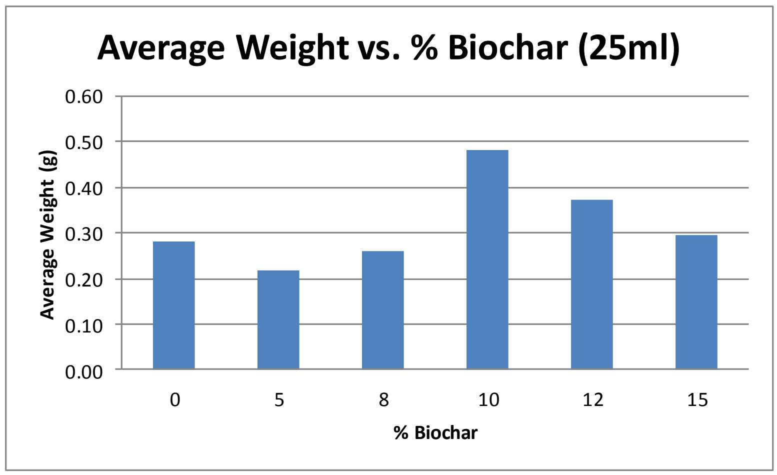
Average Height vs. % Biochar (25ml)	
% Biochar	Average
0	5.00
5	4.85
8	4.85
10	5.45
12	4.55
15	5.45



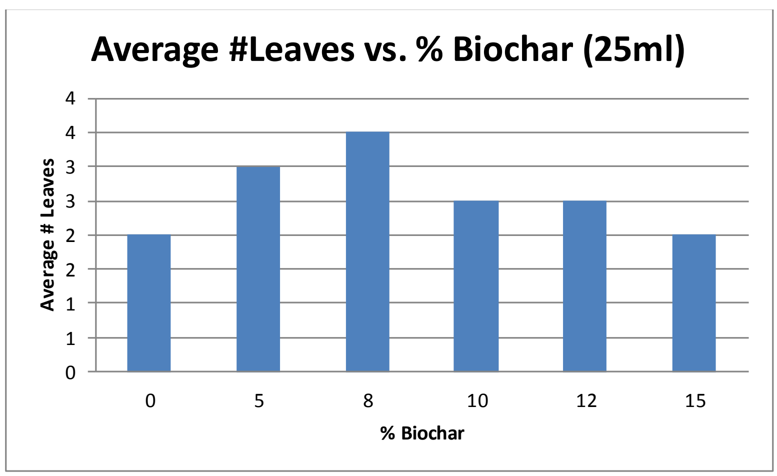
Average Root Length vs. % Biochar (25ml)	
% Biochar	Average
0	39.60
5	7.20
8	7.30
10	14.55
12	8.35
15	14.4



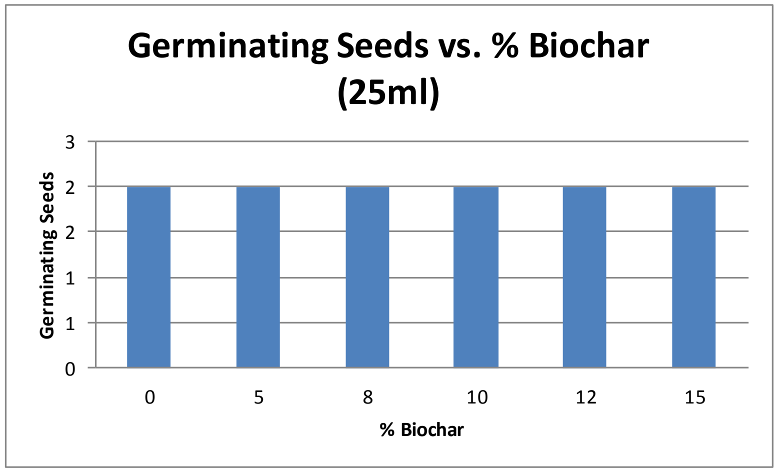
Average Weight vs. % Biochar (25ml)	
% Biochar	Average
0	0.28
5	0.22
8	0.26
10	0.48
12	0.37
15	0.2941



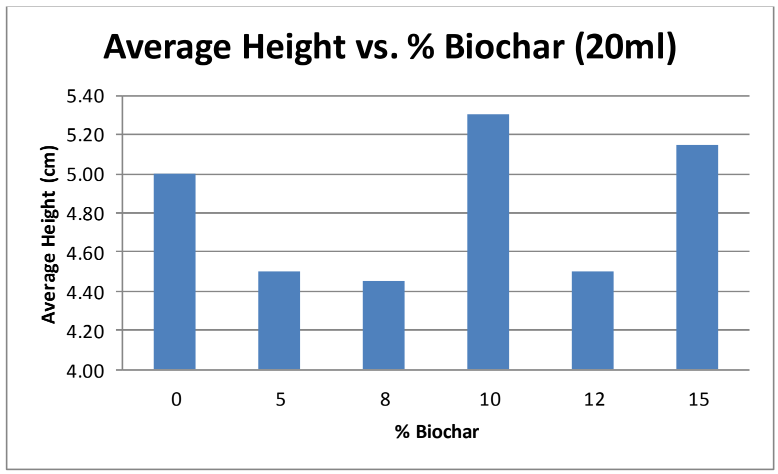
Average #Leaves vs. % Biochar (25ml)	
% Biochar	Average
0	2
5	3
8	4
10	3
12	3
15	2



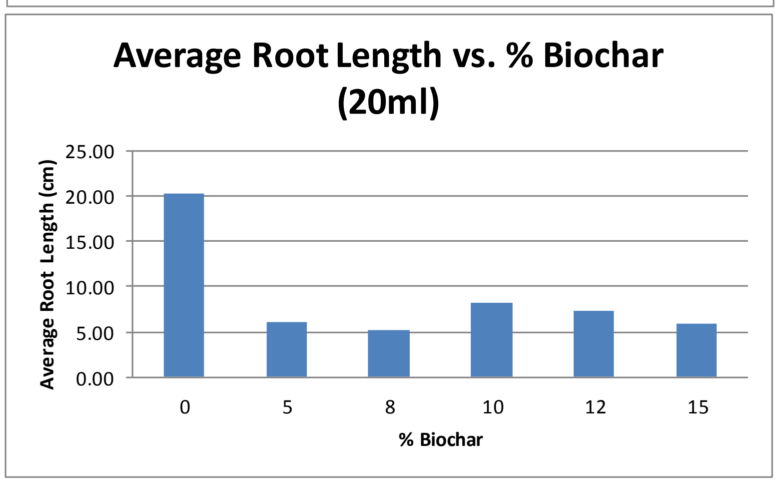
Germinating Seeds vs. % Biochar (25ml)	
% Biochar	Average
0	2
5	2
8	2
10	2
12	2
15	2



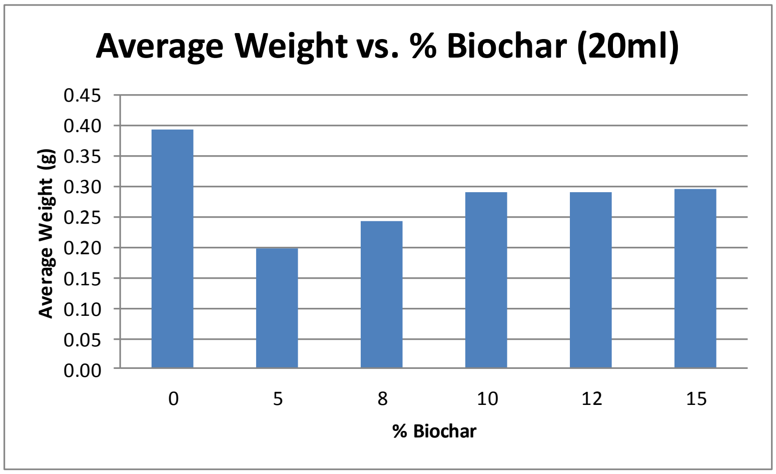
Average Height vs. % Biochar (20ml)	
% Biochar	Average
0	5.00
5	4.50
8	4.45
10	5.30
12	4.50
15	5.15



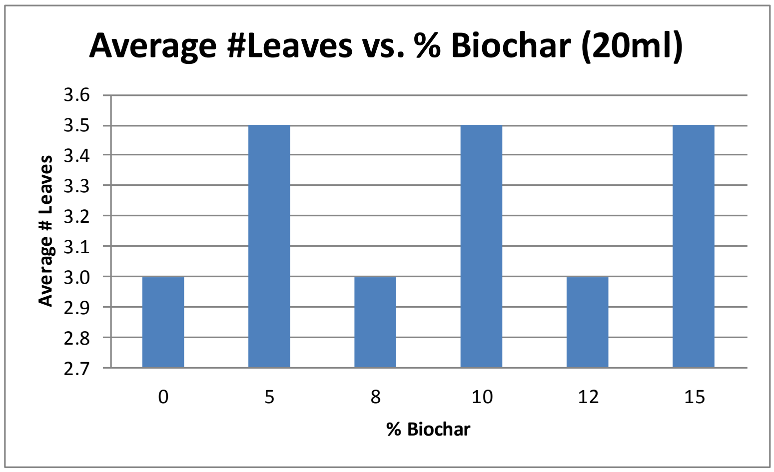
Average Root Length vs. % Biochar (20ml)	
% Biochar	Average
0	20.35
5	6.05
8	5.25
10	8.25
12	7.40
15	5.85



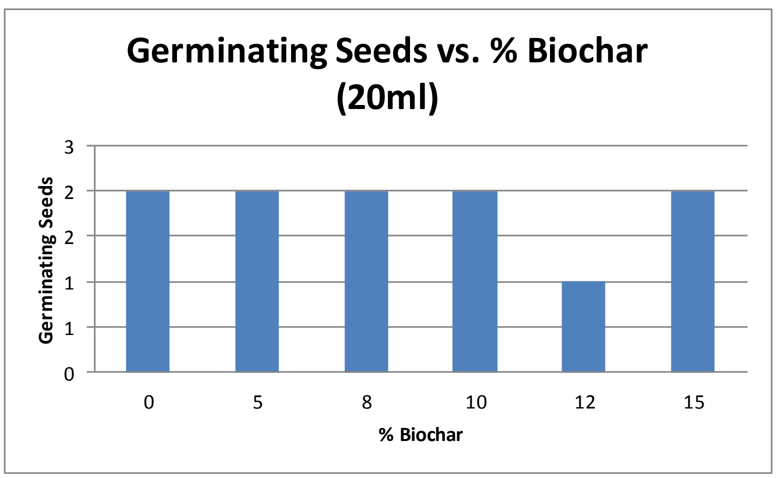
Average Weight vs. % Biochar (20ml)	
% Biochar	Average
0	0.39
5	0.20
8	0.24
10	0.29
12	0.29
15	0.29615



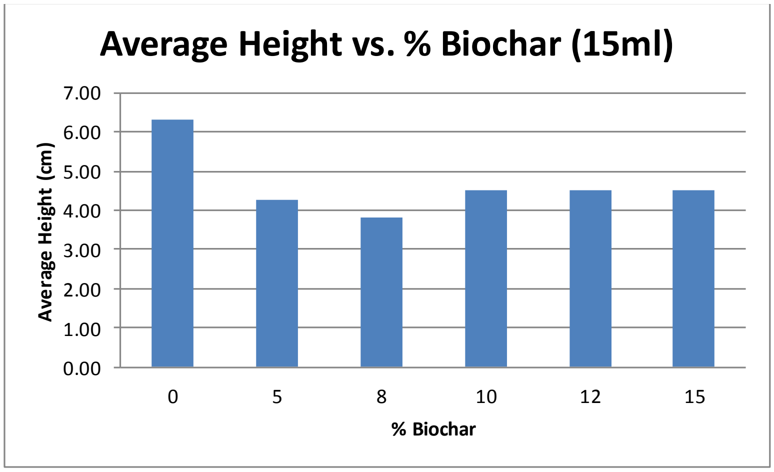
Average #Leaves vs. % Biochar (20ml)	
% Biochar	Average
0	3.0
5	3.5
8	3.0
10	3.5
12	3.0
15	3.5



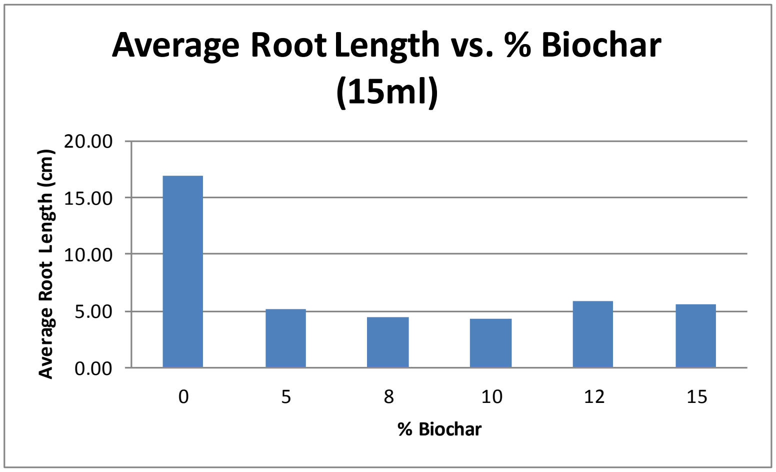
Germinating Seeds vs. % Biochar (20ml)	
% Biochar	Average
0	2
5	2
8	2
10	2
12	1
15	2



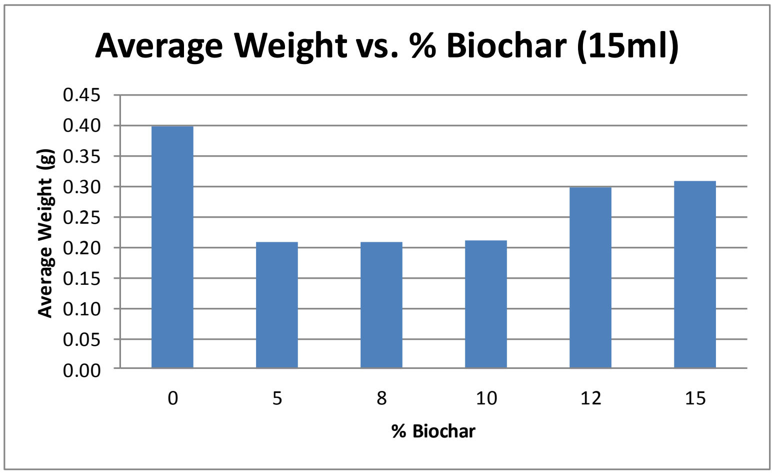
Average Height vs. % Biochar (15ml)	
% Biochar	Average
0	6.30
5	4.25
8	3.80
10	4.50
12	4.50
15	4.50



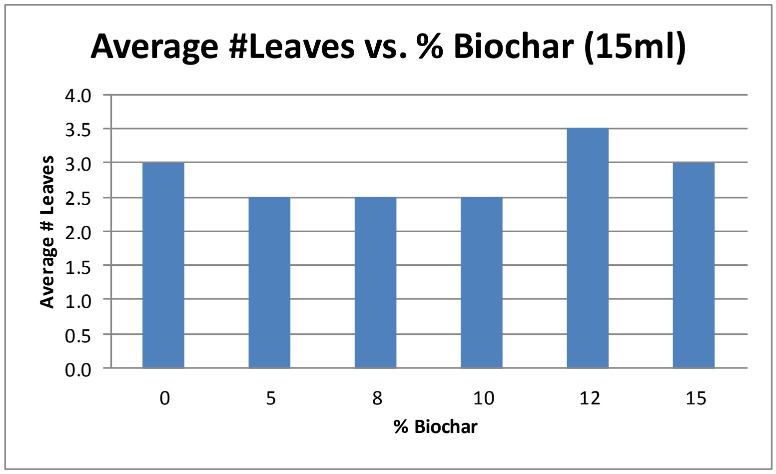
Average Root Length vs. % Biochar (15ml)	
% Biochar	Average
0	17.00
5	5.15
8	4.50
10	4.35
12	5.90
15	5.65



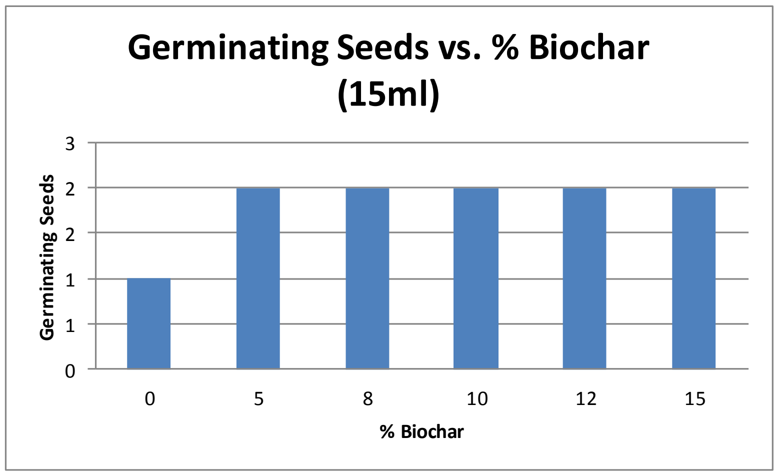
Average Weight vs. % Biochar (15ml)	
% Biochar	Average
0	0.40
5	0.21
8	0.21
10	0.21
12	0.30
15	0.31



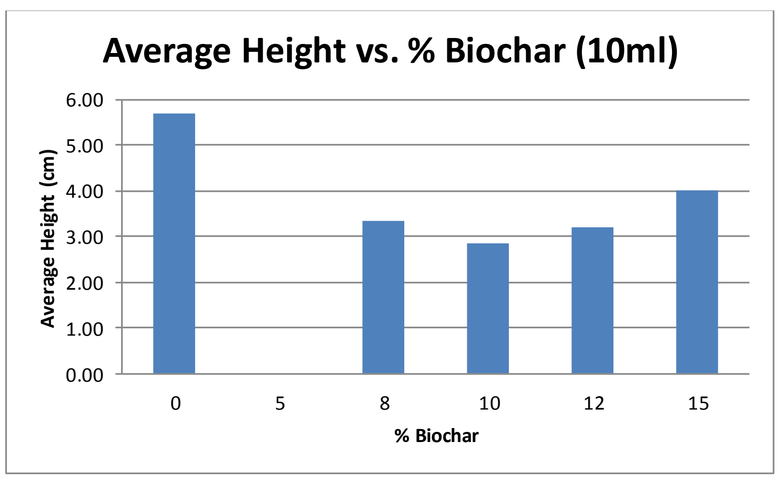
Average #Leaves vs. % Biochar (15ml)	
% Biochar	Average
0	3.0
5	2.5
8	2.5
10	2.5
12	3.5
15	3.0



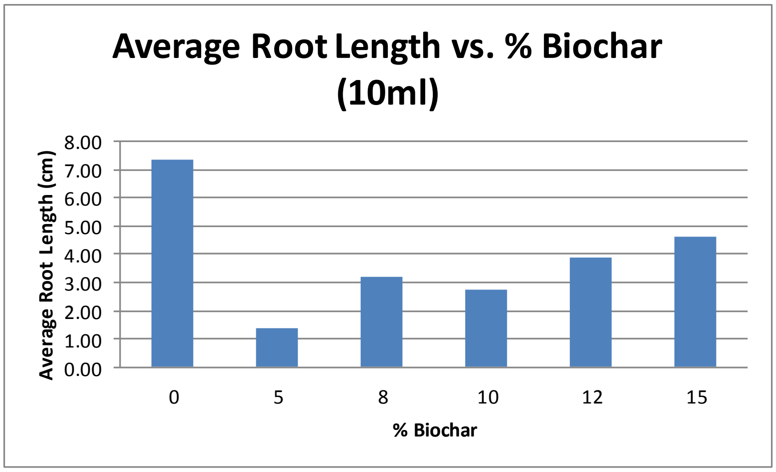
Germinating Seeds vs. % Biochar (15ml)	
% Biochar	Average
0	1
5	2
8	2
10	2
12	2
15	2



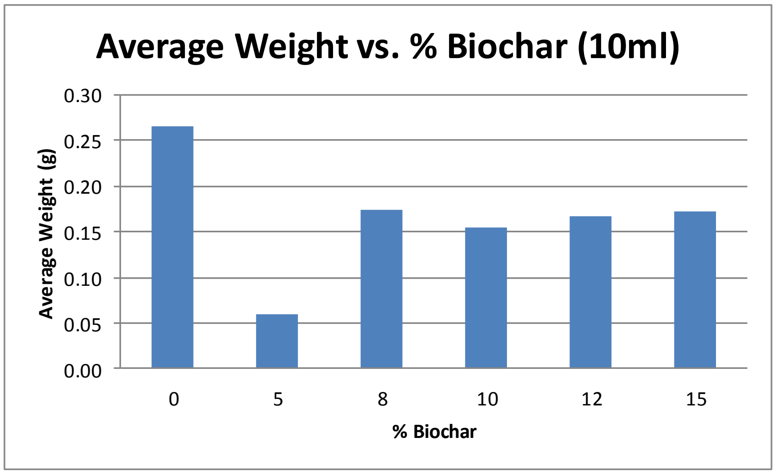
Average Height vs. % Biochar (10ml)	
% Biochar	Average
0	5.70
5	NA
8	3.35
10	2.85
12	3.20
15	4.00



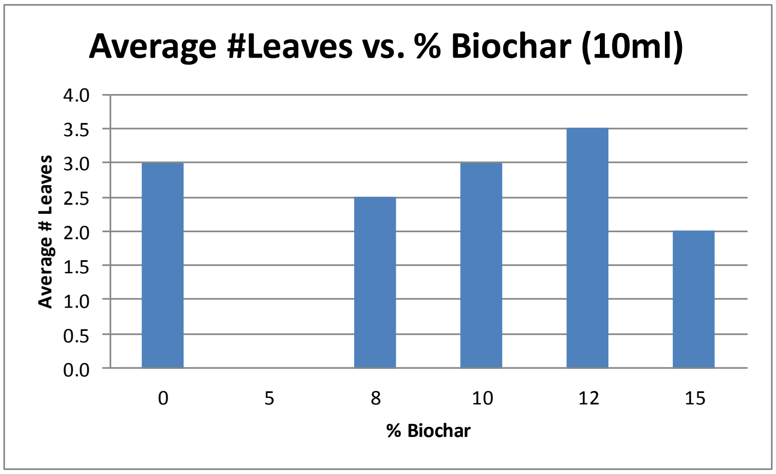
Average Root Length vs. % Biochar (10ml)	
% Biochar	Average
0	7.35
5	1.40
8	3.20
10	2.75
12	3.90
15	4.6



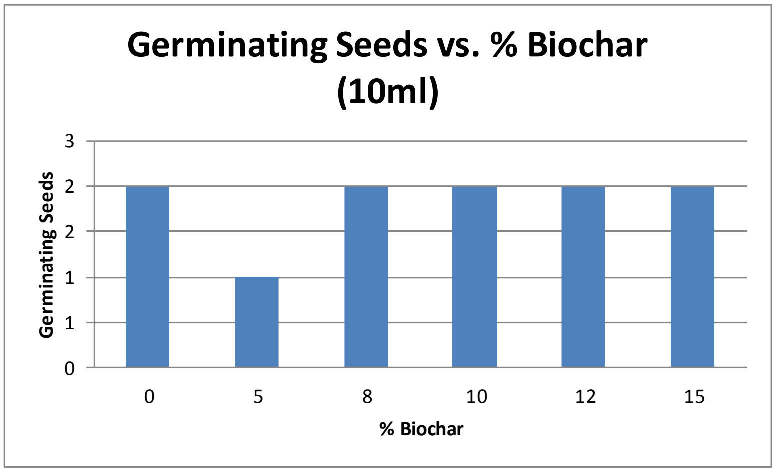
Average Weight vs. % Biochar (10ml)	
% Biochar	Average
0	0.27
5	0.06
8	0.17
10	0.16
12	0.17
15	0.17



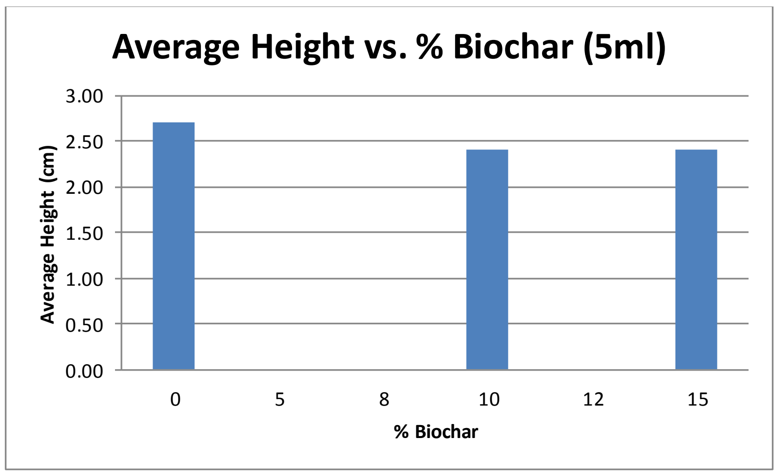
Average #Leaves vs. % Biochar (10ml)	
% Biochar	Average
0	3.0
5	NA
8	2.5
10	3.0
12	3.5
15	2.0



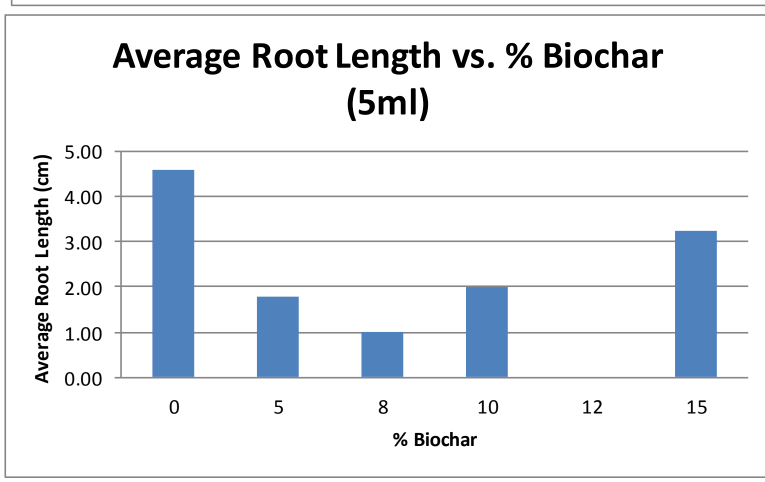
Germinating Seeds vs. % Biochar (10ml)	
% Biochar	Average
0	2
5	1
8	2
10	2
12	2
15	2



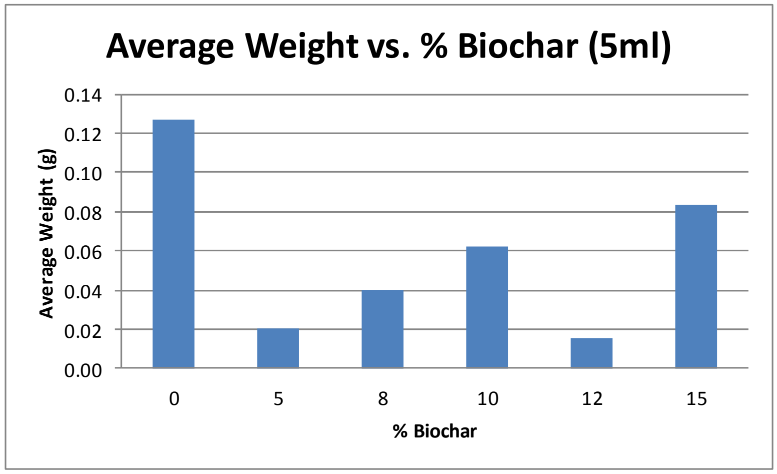
Average Height vs. % Biochar (5ml)	
% Biochar	Average
0	2.70
5	NA
8	NA
10	2.40
12	NA
15	2.40



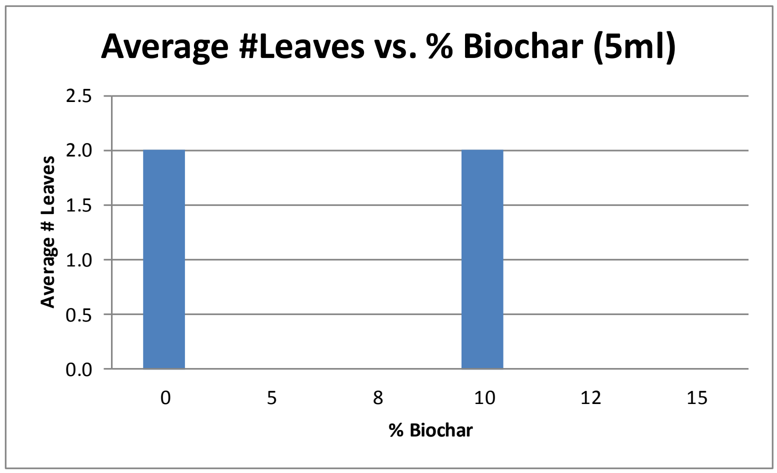
Average Root Length vs. % Biochar (5ml)	
% Biochar	Average
0	4.60
5	1.80
8	1.00
10	2.00
12	#DIV/0!
15	3.25



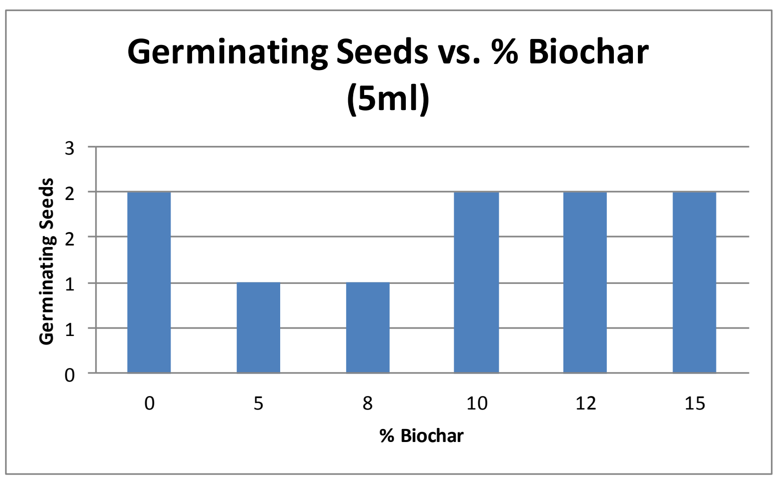
Average Weight vs. % Biochar (5ml)	
% Biochar	Average
0	0.13
5	0.02
8	0.04
10	0.06
12	0.02
15	0.08



Average #Leaves vs. % Biochar (5ml)	
% Biochar	Average
0	2.0
5	#DIV/0!
8	#DIV/0!
10	2.0
12	#DIV/0!
15	#DIV/0!



Germinating Seeds vs. % Biochar (5ml)	
% Biochar	Average
0	2
5	1
8	1
10	2
12	2
15	2



C. Example Calculations

The following examples show how some of the values in the data analysis were calculated.

Average

The average is defined as the sum of the variables divided by the number of variables added.

$$Average = \frac{1}{n}\sum_{i=1}^{n} a_i = \frac{1}{n}(a_1 + a_2 + \cdots + a_n)$$

The standard deviation is the square root of the sum of the value minus the average, quantity squared, divided by the number of values, N.

$$\sigma = \sqrt{\frac{\sum(x - Average)^2}{N}}$$

This value was multiplied by three and then added and subtracted to the average to get a range. Each data point was then analyzed. Any points that fell outside the three standard deviation range would then need to be ejected. Note that no data points were rejected from this experiment.