Subject: Environmental Systems and Societies

Internal Assessment

Research Question: How does 25g of biochar mitigate the effect of different masses (6.2 mg, 12.4 mg, and 24.9 mg) of Cadmium Chloride on the growth of *Triticum aestivum* (Wheatgrass) in 250 grams of soil by measuring biomass?

Word Count: 2,203

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Background

Soil is a major component of our ecosystem, it forms the outermost surface of the Earth and it interacts with major processes that occur in our ecosystem[1]. It is non-renewable, meaning that it takes years for soil to regenerate[2]. Soil is formed from minerals, water, air, and organic matter and it is a medium for plants to grow, it absorbs and purifies water, it is a habitat for small living organisms and it recycles nutrients to stabilize plant growth[3].

The world is currently facing the environmental issue of soil degradation due to contamination. Soil degradation is the reduction in the quantity and the quality of soil and it can be caused naturally, for example, due to wind or runoff[4]. However, it can also occur due to anthropogenic activities, for instance, urbanization, deforestation, and overgrazing. According to the WWF, half of the topsoil on the Earth has been lost in the past 150 years[5].

Soil degradation can also be caused due to soil contamination. Soil contamination is the release of heavy metals in our environment, especially the release of heavy metals in soil. Heavy metals (HMs) are non-biodegradable substances that accumulate in the environment.

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[1] Rutherford, Jill, and Gillian Williams. *Ib Environmental Systems and Societies*. 12 Mar. 2015. Accessed 9 Dec. 2023.

[2] Rutherford, Jill, and Gillian Williams. *Ib Environmental Systems and Societies*. 12 Mar. 2015. Accessed 9 Dec. 2023.

[3] Rutherford, Jill, and Gillian Williams. *Ib Environmental Systems and Societies*. 12 Mar. 2015. Accessed 9 Dec. 2023.

[4] "Soil Degradation | UNDRR." *Www.undrr.org*, 7 June 2023, www.undrr.org/understanding-disaster-risk/terminology/hips/en0005#:~:text=Soil%20degradation%20is%20the%20physical. Accessed 10 Dec. 2023

[5] World Wildlife Fund. "Soil Erosion and Degradation." *World Wildlife Fund*, 2023, www.worldwildlife.org/threats/soil-erosion-and-degradation. Accessed 10 Dec 2023.

adverse effects on soil, water, and ecosystems. For example, soil toxicity, reduction in biodiversity, and bioaccumulation. Some examples of them are Cadmium (Cd), Zinc (Zn), Lead (Pb), Copper (Co), and Magnesium (Mg).

While the Indian economy is developing and growing, two-thirds of the population still relies on agriculture as a primary source of income, and agriculture produce accounts for 19% of the GDP[6]. Heavy metal contamination can lead to upsetting results for farmers leading to lower yield available and thus resulting in a loss of income. India's population primarily relies on wheat and the contamination of heavy metals can pose serious threats to the health of the human population of India as continuous exposure of Hm. Biomagnification is a biological process wherein these chemicals accumulate in the body's tissue.

Through industrial waste, cadmium enters the soil in the form of Cadmium. Since cadmium is a toxic metal it affects soil quality, food safety, and human health due to bioaccumulation[7]. It is a primary contaminant in the past that has caused the Itai-Itai disease in Japan[8] which causes extreme pain in bones and renal tubular dysfunction[9]. The concentrations were chosen from a previous experiment.The amount of heavy metals that are found in the polluted soil

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[6] "Achieving Aatmanirbharta in Agriculture." *Pib.gov.in*, pib.gov.in/FeaturesDeatils.aspx?NoteId=151185&ModuleId%20=%202. Accessed 10 Dec. 2023.

[7] "Bioaccumulation and Biomagnification: Increasingly Concentrated Problems!" *Catalina Island Marine Institute*, 21 Mar. 2021, cimi.org/blog/bioaccumulation-and-biomagnification-increasingly-concentrated-problems/#:~:text=Bioaccumulation%20is%20the%20process%20by. Accessed 10 Dec. 2023.

[8] Khan, Muhammad Amjad, et al. "Soil Contamination with Cadmium, Consequences and Remediation Using Organic Amendments." *Science of the Total Environment*, vol. 601-602, Dec. 2017, pp. 1591–1605, www.sciencedirect.com/science/article/pii/S0048969717314341, https://doi.org/10.1016/j.scitotenv.2017.06.030. Accessed 12 Dec. 2023.

[9] Nishijo, Muneko, et al. "Causes of Death in Patients with Itai-Itai Disease Suffering from Severe Chronic Cadmium Poisoning: A Nested Case–Control Analysis of a Follow-up Study in Japan." *BMJ Open*, vol. 7, no. 7, 1 July 2017, p. e015694, bmjopen.bmj.com/content/7/7/e015694, https://doi.org/10.1136/bmjopen-2016-015694. Accessed 12 Dec. 2023.

and are the normal (12.4), half (6.2), and double (24.9)[10] concentration in 3.5 Kg were used to understand the limit to the Biochar effectiveness[11].

Biochar is a carbon-rich material that is produced from a variety of biomass including, woody material, manure, and straws[12]. The inclusion of biochar in this study is because the application of biochar has been found effective in increasing plant productivity.[13] However, it is not a popular solution that is used, therefore, this experiment aims to achieve the following objectives.

The experiment has the following objectives:

1. To analyse how Heavy Metal contamination can affect Wheatgrass growth.
2. To analyse how effective Biochar is in mitigating the effect of Cadmium.
3. To analyse if Biochar is effective, cheap, and reliable for solving local and global issues.

Research Question:

How does 25g of biochar mitigate the effect of different masses (6.2 mg, 12.4 mg, and 24.9 mg) of Cadmium Chloride on the growth of *Triticum aestivum* (Wheatgrass) in 250 grams of soil by measuring biomass?

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[10] Athar, Rana, and Masood Ahmad. "HEAVY METAL TOXICITY: EFFECT on PLANT GROWTH and METAL UPTAKE by WHEAT, and on FREE LIVING AZOTOBACTER." *Water, Air, and Soil Pollution*, vol. 138, no. 1/4, 2002, pp. 165–180, https://doi.org/10.1023/a:1015594815016. Accessed 29 Dec. 2023.

[11] Athar, Rana, and Masood Ahmad. *Water, Air, and Soil Pollution*, vol. 138, no. 1/4, 2002, pp. 165–180, https://doi.org/10.1023/a:1015594815016. Accessed 29 Dec. 2023.

[12] "What Is Biochar and How Is It Made? | Golisano Institute for Sustainability | RIT." *Www.rit.edu*, www.rit.edu/sustainabilityinstitute/blog/what-biochar-and-how-it-made. Accessed 3 Jan. 2023.

[13] Dai, Yanhui, et al. "Combined Effects of Biochar Properties and Soil Conditions on Plant Growth: A Meta-Analysis." *Science of the Total Environment*, vol. 713, Apr. 2020, p. 136635, https://doi.org/10.1016/j.scitotenv.2020.136635. Accessed 3 Jan. 2024.

Hypothesis

Exposure to Cadmium will reduce the productivity of the wheatgrass plant[14]. The plant's roots may easily absorb which may result in reduced plant growth[15]. The addition of biochar in contaminated soil may increase productivity and plant growth[16] and therefore, mitigating Cadmium.

Three main hypotheses will be stated for each heavy metal concentration:

1. For concentration with the lowest HM, the Biochar will be most effective
2. For concentration with average HM, the Biochar may be effective
3. For concentrations with the highest HM, the Biochar will be the least effective.

Variables

Table 1: Variables in the experiment

	Named variable	Measure of control	Justification
Independent variable	1. Biochar	1. 25-30 g per pot	1. Each setup should get the same amount of biochar to ensure accuracy
Dependent variable	1. Leaf length 2. Biochar	1. Standard metre stick	1. Accurately measures the length of leaf

[14] Dias, Maria Celeste, et al. "Cadmium Toxicity Affects Photosynthesis and Plant Growth at Different Levels." *Acta Physiologiae Plantarum*, vol. 35, no. 4, 6 Dec. 2012, pp. 1281–1289, https://doi.org/10.1007/s11738-012-1167-8. Accessed 3 Jan 2024.

[15] Ci, Dunwei, et al. "Effects of Cadmium on Plant Growth and Physiological Traits in Contrast Wheat Recombinant Inbred Lines Differing in Cadmium Tolerance." *Chemosphere*, vol. 77, no. 11, Dec. 2009, pp. 1620–1625, https://doi.org/10.1016/j.chemosphere.2009.08.062. Accessed 3 Jan. 2024.

[16] Schulz, Hardy, et al. "Positive Effects of Composted Biochar on Plant Growth and Soil Fertility." *Agronomy for Sustainable Development*, vol. 33, no. 4, 15 May 2013, pp. 817–827, https://doi.org/10.1007/s13593-013-0150-0. Accessed 3 Jan. 2024

	Named variable	How will these variables be controlled?	Why are these variables being controlled
Controlled variable	1. Cadmium concentration 2. Temperature 3. Type of seeds 4. Number of seeds 5. Type of water 6. The volume of water 7. Material of pot 8. Dimension of pot 9. Type of soil 10. Mass of soil	1. Concentration is outlined in the table below 2. 5-18 degree Celsius 3+ 5. Wheatgrass seeds, 50 per pot 5+6. Distilled water 7+8. Plastic pot 9. Loamy soil 10. 250 g per pot	1 Concentration of HM will affect the results 2 Temperature will determine the natural process 3+4 Seeds will ensure stability 5+6 water can affect results 7+8. Material can affect results due to reactions with chemical 9+10 soil needs to be without fertilizers so that accurate readings can be shown

Methodology

My experiment was divided into two parts. For the first part, I prepared the pots with various amounts of Cadmium and biochar, depending on the set-ups listed below. I chose varying concentrations of biochar as I wanted to test the extent to which biochar is successful in mitigating Cadmium. In total, I had 50 setups (8*5) so that I can increase the reliability. Subsequently, I will measure the biomass of all 50 setups as biomass is a good measure of

how productive a plant is as it reflects the amount of sunlight, water, and minerals a plant can use to grow[17]. The process below describes the methodology in detail.

Table 2: Setups of experiment

Set up	**Soil**	**Wheat Grass**	**Cd (6.2 mg)**	**Cd (12.4 mg)**	**Cd (24.9 mg)**	**Biochar**
Set up 1	✓	✓				
Set up 2	✓	✓				✓
Set up 3	✓	✓	✓			
Set up 4	✓	✓	✓			✓
Set up 5	✓	✓		✓		
Set up 6	✓	✓		✓		✓
Set up 7	✓	✓			✓	
Set up 8	✓	✓			✓	✓

Materials

Material	**Quantity**	**Specification**	**Uncertainty**
Pots	50	Plastic 9 cm in height 300 cm3 volume	-

[17] Kirchman, David. "Measuring Bacterial Biomass Production and Growth Rates from Leucine Incorporation in Natural Aquatic Environments." *ScienceDirect*, Academic Press, 1 Jan. 2001, www.sciencedirect.com/science/article/abs/pii/S0580951701300478#:~:text=Biomass%20production%20is%20used%20to. Accessed 13 Jan. 2024.

Material	**Quantity**	**Specification**	**Uncertainty**
Soil	6000g	Loamy texture	-
Wheatgrass seeds (*Triticum aestivum*)	1200	-	-
Cadmium	1.044 g	powder	-
Weighing scale	1	Digital	0.001g
Biochar	600g	-	-
Measuring cylinder	1	200 cm3	+- 5 cm3
Syringe	1	20 cm3	+-0.5 cm3
spoon	1	steel	-
Microwave oven	1	-	-
Towel	1	cotton	-
Bowl	1	Plastic 250 cm3 volume	-
Water	345 cm3	RO	-

Procedure

Preparing pots

1. Soak 1,200 wheatgrass seeds overnight in a bowl of 125 cm^3 of water measuring with a measuring cylinder.
2. Take 8 pots and fill each of them with 250 g of soil measured with a weighing scale. Numbered these pots from 1 to 8 to represent the Set-ups mentioned in Table 2.
3. Measure 6.2 mg, 12.4 mg, and 24.9 mg of Cadmium using a weighing scale and put them in the pots from step 2 according to their respective setup number mentioned in Table 2. Mix the cadmium powder well with the soil with a spoon.

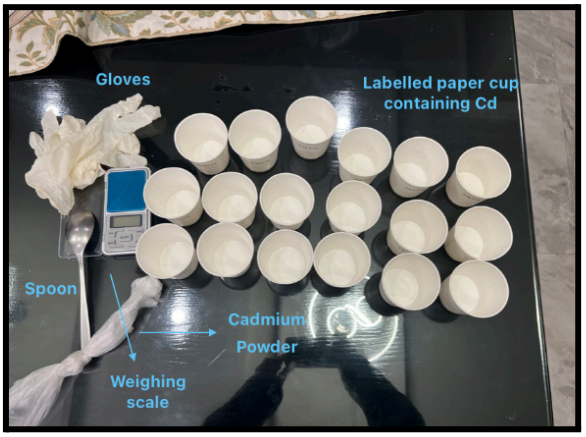


Figure 1: Paper Cups Containing 6.2 mg, 12.4 mg, and 24.9 mg of Cd Powder

4. Measure 25g of Biochar using a weighing scale and put them in the pots from step 2 according to their respective setup number mentioned in Table 2. Mix the biochar well with the soil with a spoon.
5. Take 50 seeds from Step 1 and place them equidistant in the soil of each of the 8 pots prepared in steps 2-4 such that they are 1 cm below the soil.
6. Repeat Steps 2-5 four times to prepare five trials of each Setup mentioned in Table

7. Place all the pots in a warmer area with an average temperature of 21 degrees Celsius.
8. Pour 20 cm^3 RO water on the soil surface of each pot using a 20 cm3 syringe once a day at 8 am till 11 days. Put a piece of tissue paper on the plants for the initial days so that moisture is retained.

Figure 2: Wheatgrass growing in Pots With Different Treatment According to Set-ups Mentioned in Table 2

9. On the 11th day, uproot the wheatgrass from each pot and wash off the soil.
10. Dry the wheatgrass from Step 9 using a cotton towel to remove surface water,
11. Measure the wet mass of wheatgrass from Step 9-10 using a weighing scale and record the value.
12. Measure dry mass of the wheatgrass from Step 11 by dehydrating them in the microwave oven by following the below steps:
    a) Turn the oven on and set the temperature at 50 degrees Celsius for 2 minutes.
    b) After two minutes, note down the mass of the wheatgrass.
    c) Repeat this process, increasing the temperature by 25 degrees Celsius until the mass is the same.

Risk Assessment, Ethical and Environmental Concern

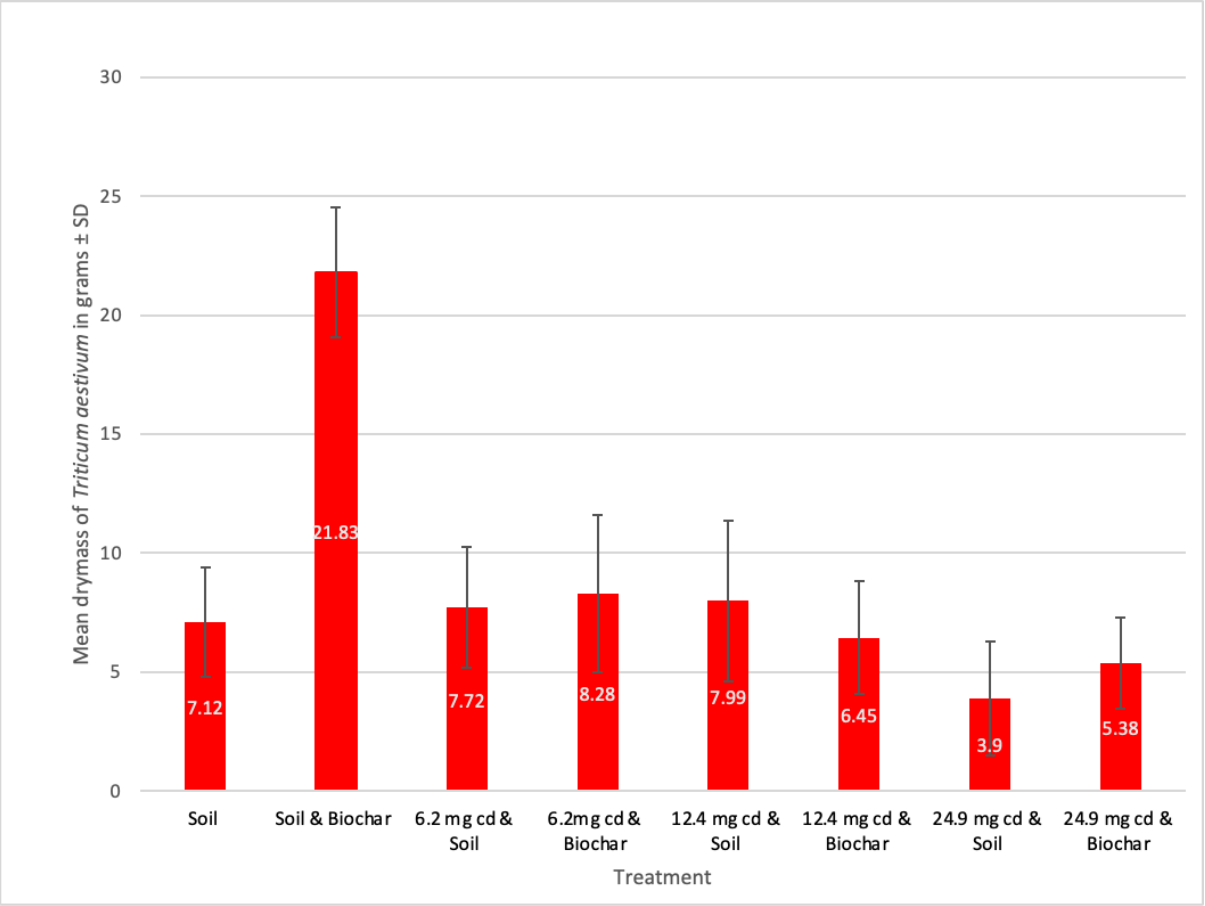
1. **Environmental safety**: Rinsing soil with cadmium present: The society I reside in recycles domestic water and utilizes filters to prevent Cadmium poisoning in water bodies.
2. **Ethical concern**: Plant disposal after biomass experiment: Since it is likely that the plants after the biomass experiment The plants were recycled and used in compost.
3. **Personal Safety from Cadmium**: Throughout the research, protective gear was used to prevent Cadmium poisoning.

Data Collection and Processing:

Table 3: Dry mass with Mean and Standard Deviation (SD) in grams of Triticum aestivum with varying treatments

Treatment	Trial	Dry mass in grams	Mean dry mass in grams	Standard deviation
Normal Soil	1	5.84	7.12	2.3
	2	3.98		
	3	8.92		
	4	9.69		
	5	7.18		
Normal Soil & Biochar	1	25.89	21.83	2.73
	2	18.42		
	3	21.76		
	4	20.63		
	5	22.45		
6.2 Cd of Soil	1	11.45	7.72	2.52
	2	6.65		
	3	8.359		
	4	7.6		
	5	4.57		
6.2 Cd of Soil + Biochar	1	7.73	8.28	3.31
	2	8.8		
	3	5.91		
	4	5.62		
	5	10.38		
12.4 Cd of Soil	1	10.9	7.99	3.37
	2	9.47		
	3	8.38		
	4	9.76		
	5	7.43		
12.4 Cd, Soil & Biochar	1	5.13	6.45	2.38
	2	3.25		
	3	8.98		
	4	5.97		
	5	8.96		
24.9 Cd, Soil	1	4.1	3.9	2.39
	2	2.21		
	3	2.54		
	4	3.31		
	5	3.35		
24.9 Cd, Soil & Biochar	1	6.03	5.38	1.92
	2	3.61		
	3	3.22		
	4	7.8		
	5	6.24		

Graph 1: Mean dry mass of the Triticum aestivum for varying treatments where error bars represent standard deviation



Statistical Test

Since there are more than 2 means to compare and one independent and dependent variable, an one way ANOVA test is used. Welch's ANOVA is used as the standard deviations are different. A p-value of 0.05 rejects the Null hypothesis which states no significant difference between the mean group. ANOVA has a limitation in that even if one pair of the mean is significantly different and other pairs are not, the p-value will be less than 0.05. To overcome this limitation, Post Hoc test is used which compares each pair of means to know which of the pairs are significantly different or not. Here, the Games-Howell Post Hoc test is used as the standard deviations are unequal.

Table 4: P-value (sig.) of Welch's ANOVA test for the dry mass of Triticum aestivum of varying treatments

ANOVA

Drymass

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1121.660	7	160.237	36.202	<.001
Within Groups	141.637	32	4.426		
Total	1263.297	39			

Table 5: P-values of Games-Howell Post-hoc test for the dry mass of Triticum aestivum of varying treatments

Treatment	Soil	Soil + Biochar	6.2 mg of Cd	6.2 mg of Cd + Biochar	12.4 mg of Cd	12.4 mg of Cd + Biochar	24.9 mg of Cd	24.9 mg of Cd + Biochar
Soil	-	<0.001	1.00	1.00	0.674	1.00	0.12	0.877
Soil + Biochar	<0.001	-	<0.001	0.001	<0.001	<0.001	<0.001	<0.001
6.2 mg of Cd	1.00	<0.001	-	1.00	0.922	0.988	0.101	0.713
6.2 mg of Cd + Biochar	1.00	<0.001	1.00	-	0.834	0.982	0.42	0.604
12.4 mg of Cd	0.674	0.001	0.922	0.834	.	0.741	0.001	0.085
12.4 mg of Cd + Biochar	1.00	<0.001	0.988	0.982	0.471	-	0.257	0.991

Treatment	Soil	Soil + Biochar	6.2 mg of Cd	6.2 mg of Cd + Biochar	12.4 mg of Cd	12.4 mg of Cd + Biochar	24.9 mg of Cd	24.9 mg of Cd + Biochar
24.9 mg of Cd	0.12	<0.001	0.101	0.042	0.001	0.257	-	0.364
24.9 mg of Cd + Biochar	0.877	<0.001	0.713	0.604	0.85	0.991	0.364	-

Analysis

Graph 1

From Table 3 and graph 1, it can be derived that when 6.2 mg of Cadmium is added to the soil, there is -8.42% difference in the dry mass of the plant when compared to the regular soil treatment. This may be because Cadmium powder was used instead of solution which is more soluble. However, Cadmium Chloride Salt was used as the solution was unavailable in the school laboratory.

ANOVA and Post Hoc Test:

The result of Welch's ANOVA from Table 4 shows a p-value (sig.) of <0.001 which is less than 0.05, hence Null hypothesis can be rejected meaning that the differences in mean dry mass of *Triticum aestivum* of varying treatments are significantly different from each other[18]. However, the results of the Post Hoc test from Table 5 show that the mean dry mass of 'Soil

[18] Qualtrics. "What Is ANOVA (Analysis of Variance) and What It's Used for | Qualtrics." *Qualtrics AU*, 2023, www.qualtrics.com/au/experience-management/research/anova/. Accessed 21 Dec. 2023.

+ Biochar' treatment is only significantly different from the rest of the treatments as the p-value for it is <0.001, whereas all the other treatments pairs' mean dry mass are not significantly different from each other since the p-value for them are greater than 0.05.

Discussion & Conclusion

The findings suggest that there is not a significant effect of the addition of Cadmium Chloride on *Triticum aestivum*. This may be attributed to the shoots of the plants accumulating toxins[19]. Furthermore, it was also found that when biochar was present in the plant there was high growth but when biochar was present in soil with $CdCl_2$, there was minimal growth. The ineffectiveness may be through some mechanism that is beyond the scope of the investigation. Additionally, when biochar was added to the crops, it was found that the crops were able to retain more water as compared to setups without the water. This is supported by further research papers that suggested that the addition of biochar increased the dry mass of wheat and soil moisture. Therefore, it may be that the addition of biochar can reduce the drought stress on plants and reduce the amount of water irrigated[20].

It can be concluded from the results of this investigation that 6.2 mg, 12.4 mg, and 24.9 mg of Cadmium Chloride ($CdCl_2$) do not significantly affect the growth of wheatgrass in soil because the Post- Hoc test (Table 5) shows a p-value greater than 0.05 for the treatments of soil with and without these masses of CdCl. Hypothesis 1 and 2 will be rejected as the addition of biochar had no significant effect on the mitigation of CdCl in crops. Additionally,

[19] "Toxic Metals Extracted from Contaminated Soils by Wheat and Wheatgrass." *Applied Sciences from Technology Networks*, www.technologynetworks.com/applied-sciences/news/toxic-metals-extracted-from-contaminated-soils-by-wheat-and-wheatgrass-338442. Accessed 18 Feb. 2024.

[20] Li, Hui, and Zhongxin Tan. "Preparation of High Water-Retaining Biochar and Its Mechanism of Alleviating Drought Stress in the Soil and Plant System." *Biochar*, 8 Jan. 2024, https://doi.org/10.1007/s42773-021-00107-0. Accessed 9 Jan. 2024.

Hypothesis 3 is accepted as there is a minimal increase in the mean biomass of 37.94%. This is supported by the overlapping error bars in Graph 1. In Graph 1, since the size of the error bars is very big, it may mean that there is a high human error with controlled variables.

Evaluation

Strengths:

1. **Numerous controlled variables:** Having many control variables helped make comparisons between different trials.
2. **5 number of trials:** The more the number of trials closer the calculated mean to the truth, therefore, increasing reliability.
3. **Appropriate tests are used:** To analyze the results, I used the appropriate statistical tests- Welche's ANOVA and post-hoc test- and accordingly made conclusions.
4. **Biomass to measure growth:** Biomass is a reliable method to measure the plant's productivity.
5. **Plotting error bars:** showed the spread of the data points ensuring the reliability of my data.
6. Accounted for the measure of uncertainty throughout the investigation.

Weaknesses:

Weakness	Impact on investigation	Improvement
Only 5 number of trials used	More number of trials closer is the calculated mean to the truth, therefore, increasing reliability.	Increasing the number of trials in future experiments

Limitations:

Limitation	Impact on investigation	Improvement
No availability of Cadmium solution	Using Cadmium would have ensured more realistic and applicable results	Ensure greater availability of Cadmium
Not an ideal temperature for growth	During the experiment, there was winter season going on which may have led to the results found.	Experiment in a season that ensures growth

Application

Soil degradation is a massive problem in India. Due to increased urbanization and the development of metropolitan cities, there is high exposure to Heavy metals in agriculture, especially Cadmium[21]. To mitigate and alleviate the risk of heavy metal contamination,

[21] Chaudhary, Dr Sudesh. "Heavy Metals in Agricultural Soils of National Capital Region, Delhi: Levels and Ecological Risk." *Current World Environment*, 31 Dec. 2021, www.academia.edu/85024449/Heavy_Metals_in_Agricultural_Soils_of_National_Capital_Region_Delhi_Levels_and_Ecological_Risk?uc-sb-sw=6616163. Accessed 8 Jan. 2024.

microorganisms, and plants have been proven to evolve into mechanisms to reduce the concentration of heavy metal in soil[22]. Furthermore, the use of advanced technologies have been and are being developed to monitor and quantify the levels of heavy metal. It is unsure whether biochar is effective in mitigating heavy metal toxicity, however, it has been proven effective in a few online journals[23].

It is also important to consider the price of biochar as it can be expensive and the average salary for an Indian farmer is under US$36[24]. Burning organic matter will indeed example, for this experiment, I got 90 grams of Biochar for US$3.60. However, it is very easy for farmers to make as this is just burnt organic matter. Burning organic matter will indeed release many air pollutants, however, burning of organic matter is a prominent trend in many Indian farms during winters, and publicizing 'making own Biochar' by the Indian Government may lead to greater ecological benefits from burning organic matter.

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[22] Gaur, Vivek Kumar, et al. "Sustainable Mitigation of Heavy Metals from Effluents: Toxicity and Fate with Recent Technological Advancements." *Bioengineered*, vol. 12, no. 1, 1 Jan. 2021, pp. 7297–7313, https://doi.org/10.1080/21655979.2021.1978616. Accessed 8 Jan. 2024.

[23] Gaur, Vivek Kumar, et al. "Sustainable Mitigation of Heavy Metals from Effluents: Toxicity and Fate with Recent Technological Advancements." *Bioengineered*, vol. 12, no. 1, 1 Jan. 2021, pp. 7297–7313, https://doi.org/10.1080/21655979.2021.1978616. Accessed 8 Jan. 2024.

[24]"New Scheme to Provide Social Security Pension to Farmers." *The Economic Times*, 21 June 2019, economictimes.indiatimes.com/news/economy/agriculture/new-scheme-to-provide-social-security-pension-to-farmers/articleshow/69890993.cms?from=mdr. Accessed 18 Feb. 2024.

Works Cited

"Achieving Aatmanirbharta in Agriculture." *Pib.gov.in*, pib.gov.in/FeaturesDeatils.aspx?NoteId=151185&ModuleId%20=%202. Accessed 10 Dec. 2023

Athar, Rana, and Masood Ahmad. "HEAVY METAL TOXICITY: EFFECT on PLANT GROWTH and METAL UPTAKE by WHEAT, and on FREE LIVING AZOTOBACTER." *Water, Air, and Soil Pollution*, vol. 138, no. 1/4, 2002, pp. 165–180, https://doi.org/10.1023/a:1015594815016. Accessed 29 Dec. 2023.

---. *Water, Air, and Soil Pollution*, vol. 138, no. 1/4, 2002, pp. 165–180, https://doi.org/10.1023/a:1015594815016. Accessed 29 Sept. 2020.

"Bioaccumulation and Biomagnification: Increasingly Concentrated Problems!" *Catalina Island Marine Institute*, 21 Mar. 2021, cimi.org/blog/bioaccumulation-and-biomagnification-increasingly-concentrated-problems/#:~:text=Bioaccumulation%20is%20the%20process%20by. Accessed 10 Dec. 2023.

Chaudhary, Dr Sudesh. "Heavy Metals in Agricultural Soils of National Capital Region, Delhi: Levels and Ecological Risk." *Current World Environment*, 31 Dec. 2021, www.academia.edu/85024449/Heavy_Metals_in_Agricultural_Soils_of_National_Capital_Region_Delhi_Levels_and_Ecological_Risk?uc-sb-sw=6616163. Accessed 8 Jan. 2024.

Ci, Dunwei, et al. “Effects of Cadmium on Plant Growth and Physiological Traits in Contrast Wheat Recombinant Inbred Lines Differing in Cadmium Tolerance.” *Chemosphere*, vol. 77, no. 11, Dec. 2009, pp. 1620–1625, https://doi.org/10.1016/j.chemosphere.2009.08.062. Accessed 3 Jan. 2024.

Dai, Yanhui, et al. “Combined Effects of Biochar Properties and Soil Conditions on Plant Growth: A Meta-Analysis.” *Science of the Total Environment*, vol. 713, Apr. 2020, p. 136635, https://doi.org/10.1016/j.scitotenv.2020.136635. Accessed 3 Jan. 2024.

Dias, Maria Celeste, et al. “Cadmium Toxicity Affects Photosynthesis and Plant Growth at Different Levels.” *Acta Physiologiae Plantarum*, vol. 35, no. 4, 6 Dec. 2012, pp. 1281–1289, https://doi.org/10.1007/s11738-012-1167-8. Accessed 3 Jan. 2024.

Gaur, Vivek Kumar, et al. “Sustainable Mitigation of Heavy Metals from Effluents: Toxicity and Fate with Recent Technological Advancements.” *Bioengineered*, vol. 12, no. 1, 1 Jan. 2021, pp. 7297–7313, https://doi.org/10.1080/21655979.2021.1978616. Accessed 18 Feb. 2024.

Khan, Muhammad Amjad, et al. “Soil Contamination with Cadmium, Consequences and Remediation Using Organic Amendments.” *Science of the Total Environment*, vol. 601-602, Dec. 2017, pp. 1591–1605, www.sciencedirect.com/science/article/pii/S0048969717314341, https://doi.org/10.1016/j.scitotenv.2017.06.030. Accessed 12 Jan. 2024.

Kirchman, David. “Measuring Bacterial Biomass Production and Growth Rates from Leucine Incorporation in Natural Aquatic Environments.” *ScienceDirect*, Academic Press, 1 Jan. 2001, www.sciencedirect.com/science/article/abs/pii/S0580951701300478#:~:text=Biomass%20production%20is%20used%20to. Accessed 13 Feb. 2024.

Li, Hui, and Zhongxin Tan. “Preparation of High Water-Retaining Biochar and Its Mechanism of Alleviating Drought Stress in the Soil and Plant System.” *Biochar*, 8 July 2021, https://doi.org/10.1007/s42773-021-00107-0. Accessed 9 Jan. 2024.

“New Scheme to Provide Social Security Pension to Farmers.” *The Economic Times*, 21 June 2019,economictimes.indiatimes.com/news/economy/agriculture/new-scheme-to-provide-social-security-pension-to-farmers/articleshow/69890993.cms?from=mdr. Accessed 18 Feb. 2024.

Nishijo, Muneko, et al. “Causes of Death in Patients with Itai-Itai Disease Suffering from Severe Chronic Cadmium Poisoning: A Nested Case–Control Analysis of a Follow-up Study in Japan.” *BMJ Open*, vol. 7, no. 7, 1 July 2017, p. e015694, bmjopen.bmj.com/content/7/7/e015694, https://doi.org/10.1136/bmjopen-2016-015694. Accessed 12 Dec. 2024.

Qualtrics. “What Is ANOVA (Analysis of Variance) and What It’s Used for | Qualtrics.” *Qualtrics AU*, 2023, www.qualtrics.com/au/experience-management/research/anova/. Accessed 21 Dec. 2023.

Rutherford, Jill, and Gillian Williams. *Ib Environmental Systems and Societies*. 12 Mar. 2015. Accessed 9 Jan. 2024.

Schulz, Hardy, et al. "Positive Effects of Composted Biochar on Plant Growth and Soil Fertility." *Agronomy for Sustainable Development*, vol. 33, no. 4, 15 May 2013, pp. 817–827, https://doi.org/10.1007/s13593-013-0150-0. Accessed 3 Jan. 2024.

"Soil Degradation | UNDRR." *Www.undrr.org*, 7 June 2023, www.undrr.org/understanding-disaster-risk/terminology/hips/en0005#:~:text=Soil%20degradation%20is%20the%20physical. Accessed 10 Dec. 2023.

"Toxic Metals Extracted from Contaminated Soils by Wheat and Wheatgrass." *Applied Sciences from Technology Networks*, www.technologynetworks.com/applied-sciences/news/toxic-metals-extracted-from-contaminated-soils-by-wheat-and-wheatgrass-338442. Accessed 18 Feb. 2024.

"What Is Biochar and How Is It Made? | Golisano Institute for Sustainability | RIT." *Www.rit.edu*, www.rit.edu/sustainabilityinstitute/blog/what-biochar-and-how-it-made. Accessed 3 Jan. 2024.

World Wildlife Fund. "Soil Erosion and Degradation." *World Wildlife Fund*, 2023, www.worldwildlife.org/threats/soil-erosion-and-degradation. Accessed 10 Dec.2023.